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Constructing land-use maps of the Netherlands in 2030

Ton C.M. de Nijs*, R. de Niet, L. Crommentuijn

National Environmental Assessment Agency—RIVM, P.O. Box 1, 3720 BA Bilthoven, The Netherlands

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Abstract

The National Environmental Assessment Agency of the RIVM in the Netherlands is obliged to report on future trends in the environment and nature every 4 years. The last report, *Nature Outlook 2*, evaluated the effects of four alternative socio-economic and demographic scenarios on nature and the landscape. Spatially detailed land-use maps are needed to assess effects on nature and landscape.

The objective of the study presented here was how to create spatially detailed land-use maps of the Netherlands in 2030 using the Environment Explorer, a Cellular Automata-based land-use model to construct land-use maps from four scenarios. One of these is discussed in great detail to show how the maps were constructed from the various scenario elements, story lines and additional data and assumptions on national, regional and local land-use developments.

It was the first time in the history of our outlooks that consistent, spatially detailed land-use maps of the Netherlands for 2030 were constructed from national economic and demographic scenarios. Each map represents a direct reflection of model input and assumptions. The maps do not show the most probable developments in the Netherlands but describe the possible change in land use if Dutch society were to develop according to one of the four scenarios. The large (societal) uncertainties are reflected in the total set of future land-use maps. The application of a land-use model such as the Environment Explorer ensures that all relevant aspects of a scenario, i.e. economic and demographic developments, zoning policies and urban growth, are integrated systematically into one consistent framework.

Keywords: Land-use modelling; Scenario analysis; Policy analysis; Integrated assessment

1. Introduction

The Netherlands is a small but densely populated country. About 16 million people live in an area of 40,000 km^2. The economic heart of the country is the so-called Randstad. The Randstad comprises the major cities of Amsterdam, Rotterdam, Utrecht and The Hague and incorporates more than 5 million inhabitants. During the last century almost all the land development was for agricultural use, so that forest and nature reserves now cover less than 5000 km^2. To increase the total land for nature areas in the Netherlands, about 2500 km^2 of agricultural land is to be transformed to new forests and nature reserves by 2018 (LNV, 2002; MNP, 2002a). Furthermore, roughly 1500 km^2 land will be needed for the development of residential and industrial areas by 2030 (ABF, 1998). According to current policy plans and trends, 10% of the land use will change in the next 30 years.

The National Environmental Assessment Agency (MNP) is obliged to report on future trends in the environment and nature every 4 years in a so-called outlook. *Nature Outlook 2* evaluated the effects of alternative socio-economic developments on nature and the landscape (MNP, 2002b) within a project consisting of three steps: formulating scenarios, constructing land-use maps and estimating effects on nature and landscape. This article will focus on the second step, constructing land-use maps. This step was aimed at how to create spatially detailed land-use maps of the Netherlands in 2030 from the various scenario elements, story lines, and additional data on national, regional and local land-use developments. These land-use maps should reflect the main assumptions and basic principles of the scenarios for all relevant land uses in order to estimate the potential effects on nature.

In total, four scenarios were translated into spatially detailed land-use maps of the Netherlands in 2030. Only one scenario, Individual World, will be described here to show in detail how the maps were constructed. The following sections will go on to discuss the characteristics of

* Corresponding author. Tel.: +31-30-2743812; fax: +31-30-2744417.
E-mail address: ton.de.nijs@rivm.nl (T.C.M. de Nijs).

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the Individual World scenario, the land-use model, model input and assumptions, and future land-use maps. Scenario implementation is also discussed and conclusions are drawn on how to construct future land-use maps from scenarios.

2. The Individual World scenario

Scenario analysis has evolved into a standard methodology in environmental sciences for analyzing the effects of different driving forces and assessing the associated uncertainties. The scenarios developed for Nature Outlook 2 are related to the IPCC scenarios (IPCC, 2000), which are constructed on two axes. The first axis describes the degree of 'globalization' versus 'regionalization', while the second axis covers the 'individual orientation on material values' versus a more 'cooperative orientation respecting social and ecological values'.

These two basic future trends were adapted for Nature Outlook 2 in terms of five, quite different, entities: living, working, agriculture, nature and government (Luttik et al., 2002), which, in turn, were analyzed for possible developments in the Netherlands, including their spatial implications. The different elements from these thematic analyses were combined into four integrated spatial scenarios (Fig. 1).

The Individual World scenario is characterized by a global orientation. Government withdraws from many areas. Market principles dominate in spatial planning and restrictive zoning policies are being phased out, giving way to urban sprawl and the scattered development of villages in green areas. Only the river forelands of the Rhine, Meuse and IJssel are restricted to urban developments for optimal inland navigation.

Besides large suburbs near the access and exit points of motorways, small 'green villages', consisting of about 100 houses with an average area per house of 2500 m^2, develop in regions with low noise levels and located near nature, forest or extensive agricultural areas. The 'Waterman' Plan, consisting of the offshore development of a residential island near The Hague has been carried out.

The greatest demand for industrial and commercial areas is near the urban areas close to access roads to motorways. Accessibility by public transport is less important. Huge industrial and commercial complexes develop at the cost of smaller or more poorly located sites. Furthermore, the harbour area of Rotterdam has been extended into the sea with the development of the so-called Second (12 km^2) and Third (25 km^2) 'Maasvlakte'. Project developers have created three new lakes in the Randstad, offering all kinds of water recreation. A border lake around the empoldered Noord-Oost Polder has been created as stated in the Fifth Spatial Policy Plan (VROM, 2001).

Agricultural subsidies are diminished, leading to a sharp decrease in agricultural area. Less profitable agricultural land will be left fallow. Large pieces of agricultural land will be bought up by nature conservation organizations for the development of nature reserves and by private individuals for building their own rural estates.

3. The Environment Explorer

The Environment Explorer, used in this study to construct the future land-use maps (Engelen et al., 2003), is a so-called Cellular Automata (CA)-based land-use model of the Netherlands distinguishing 17 land-use types. The model simulates the development of 10 'active' functions: high and low-density residential areas, industrial areas, commercial services, public services, recreation, greenhouses and three types of forest and nature. The model also distinguishes three 'passive' functions: grassland, arable

Globalisation

Individualisation | Co-operation

Individual World	**Cooperative World**
▪ Liberalization of agricultural markets and restrictive zoning policies ▪ Spatial residential areas and scattered green villages ▪ Large-scale industrial areas ▪ Major increase in natural areas and rural estates	▪ Continuation of current agricultural system, with subsidies for farmers and restrictive zoning policies ▪ Increase in scale in agricultural sector ▪ Dense residential areas ▪ Development of water retention areas
Individual Region	**Cooperative Region**
▪ Liberalization of agricultural markets and restrictive zoning policies ▪ Development of organic agricultural practices ▪ Spatial residential areas and scattered green villages ▪ Dispersed increase in natural areas	▪ Continuation of current agricultural system with subsidies for farmers and restrictive zoning policies ▪ Development of local organic agricultural practices. ▪ Dense but scattered residential areas ▪ Dispersed increase of natural areas

Regionalization

Fig. 1. The four scenarios in Nature Outlook 2 and their major characteristics.

land and other agriculture, and four 'static' features: airports, fresh water, salt water and foreign land. The passive functions are not simulated but can switch to one of the active functions, while the static features cannot change in land-use type but will influence the allocation of the active functions.

The national or regional developments of the active land uses are allocated on a 500-m grid-based land-use map of the Netherlands (Fig. 2). The model calculates the transition potential for each grid cell for each active land use. The land-use developments in each region are allocated to the grid cell with the highest transition potential. This transition potential is the weighted sum of the neighbourhood potential (NP), the policy or zoning map (ZM) and the suitability map (SM):

$$\mathrm{TP}_{k,i} = \mathrm{NP}_{k,i}(c_1\mathrm{ZM}_{k,i} + c_2\mathrm{SM}_{k,i})$$

in which c_1 and c_2 are two weighting factors, k the land use and i the cell indices. The neighbourhood potential is calculated with a CA model. The behaviour of the CA model is defined by a set of rules describing the relative influence of all 17 land uses on the 10 active land uses within a radius of eight cells (Fig. 3). In this way, the relative attraction or repulsion of the active land uses by all other land uses is described. The zoning map indicates where land use may and may not be developed according to policy plans. A suitability map is defined for each land use, indicating the relative suitability of a grid cell. For a more detailed discussion, including the mathematical description, the reader is referred to the Technical Documentation (De Nijs et al., 2001).

In a previous study, the Environment Explorer, including the set of rules for the CA model, was calibrated for the development of the land use over the 1989–1993 period. The final model result was compared with observed land use data (CBS, 1993, 1997). The Kappa statistic, K-histo and K-locations, defined according to Pontius (2002), and the Fuzzy Kappa statistic according to Hagen (2003) are all shown in Table 1. Here, simulated land use in 1993 and observed land use in 1989 are compared with observed land use in 1993. The results of the calibration are discussed in Section 6.

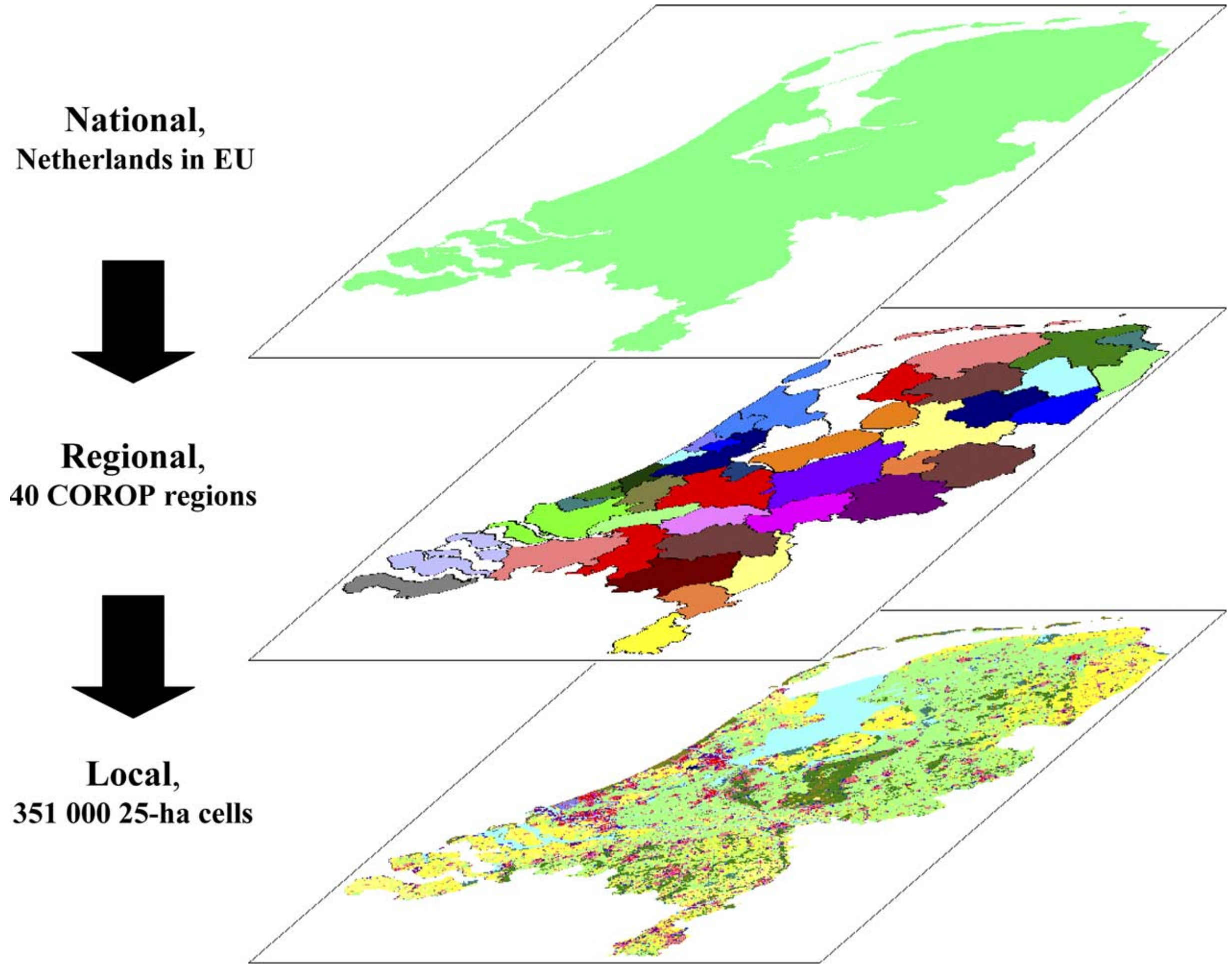

Fig. 2. The three spatial levels, national, regional and local, represented in the Environment Explorer.

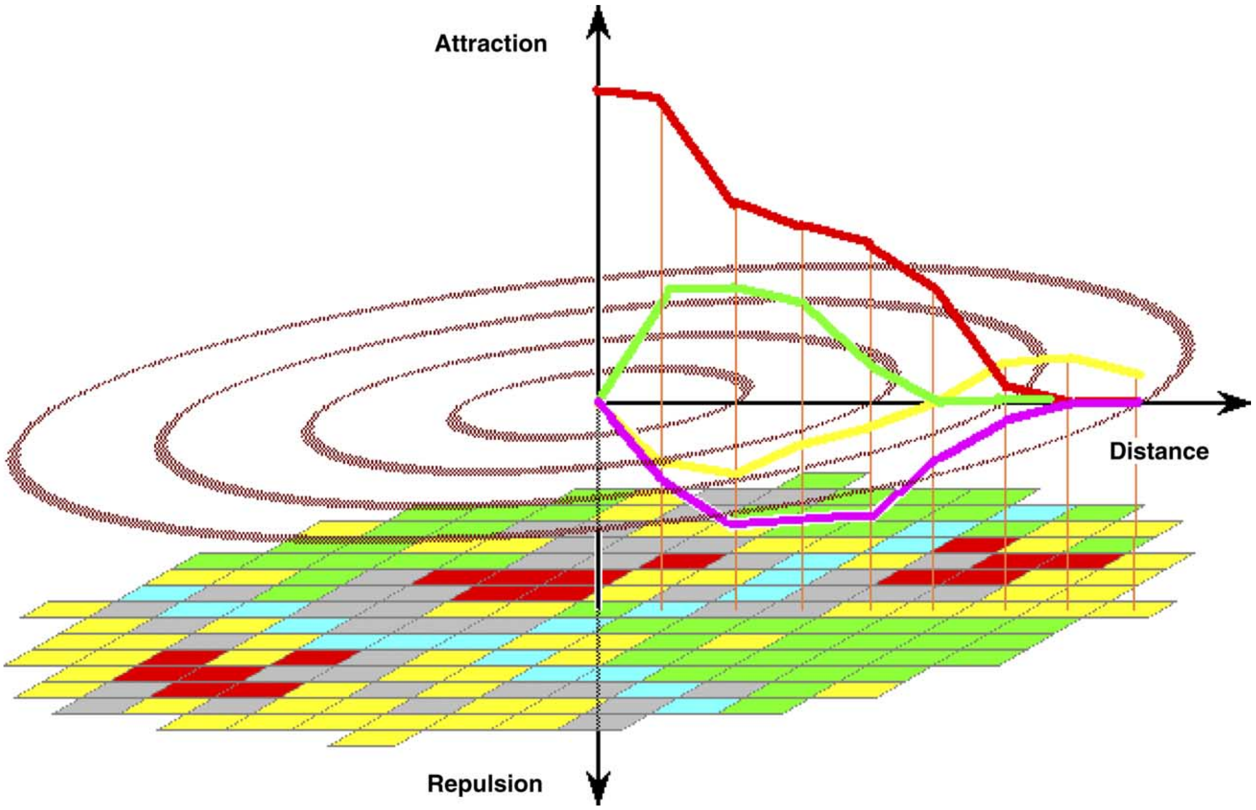

Fig. 3. Schematic representation of the 196-cell neighbourhood in the Environment Explorer. One set of the CA rules is shown superimposed on the neighbourhood map.

4. Model input and assumptions

The Environment Explorer was used to situate the growing demands on land according to the various trends in the scenarios (De Nijs et al., 2002).

The original set of land uses in the model was adjusted for Nature Outlook 2 to reflect the main scenario assumptions. The total number of land uses in the model is limited to 17. In order to accommodate two new land uses, industrial area and commercial and public services were aggregated into one land-use 'industrial/commercial' area. The two vacant land uses were defined as green villages and as an extra natural land-use. In total, four natural land uses were defined given the type of nature management and use: almost natural, half-natural, recreational and extensive-agricultural.

Once the set of the land uses had been defined, an initial land-use map was constructed on the basis of the 1996 Soil Statistic map of the Netherlands (CBS, 2000). Agricultural land use in this map was reclassified with the Land-use map of the Netherlands (SC-DLO, 1999), and residential area was reclassified according the Residential Typology (ABF, 1998).

The development of each land use in the Environment Explorer is defined by four inputs: a policy map, a suitability map, CA rules and regional development. The specific scenario elements are used in the definition of these four elements. Table 2 gives a detailed overview of the model specification.

For each land-use, zoning and suitability maps were defined according the characteristics of the scenario. The zoning maps include the planned developments for all land uses (VROM, 1999), while the forelands of the Rhine, Meuse and IJssel are restricted to urban land-use development. The suitability maps for the urban land uses include the access roads to motorways. Suitability of green villages was determined from the combination of a noise map (Dolmans et al., 2000) and a soil map. The noise map is used to identify the relatively quiet areas in the Netherlands, while the soil map identifies the less profitable soils, which are assumed to lay fallow.

Table 1
Results of the calibration of the Environment Explorer for 1989–1993, where simulated land use in 1993 and observed land use in 1989 are compared with observed land use in 1993 for Kappa, K-location, K-histo and Fuzzy Kappa

Land-use map 1 Land-use map 2	Simulated 1993 Observed 1993	Observed 1989 Observed 1993
Kappa	0.933	0.948
K-location	0.949	0.958
K-histo	0.983	0.989
Fuzzy Kappa	0.925	0.942

Table 2
Detailed specification of the Individual World scenario in the Environment Explorer

Scenario elements		Implementation
Residential areas		
High density	122 km^2	Regional trends
Low density	489 km^2	Regional trends
Green villages	486 km^2	Regional trends
Regional distribution of residential developments conforming to previously developed Trend scenario (MNP, 2001)		Regional trends
Restriction of residential developments in the riverbed of the Rhine, Meuse and Ijssel		Zoning map
Location of low and high-density residential areas near access roads to motorways		Suitability map
Location of green villages in nature reserves, forests and extensive grassland		Suitability map and CA rules
Location of green villages in regions with low noise levels (<50 dB(A), MNP, 2001)		Suitability map
Development of small green villages (<1 km^2)		CA rules
Offshore development of the so-called Waterman Plan near The Hague		ArcGIS
Industrial/commercial areas		
Industr./Comm. Areas	683 km^2	Regional trends
Regional distribution of developments conforming to previously developed Trend scenario (MNP, 2001)		Regional trends
Restriction of developments in the riverbed of the Rhine, Meuse and Ijssel		Zoning map
Location of industrial/commercial areas near motorways and access roads		Suitability map
Development of large-scale industrial/commercial areas, industrial complexes		CA rules
Extension of the Rotterdam harbour into the sea, with the so-called		
Second Maasvlakte (12 km^2) and third Maasvlakte (25 km^2)		Zoning map and Suitability map
Recreation		
Recreation	300 km^2	Regional trends
Regionally distributed according to the relative number of inhabitants per region in 2030		Regional trends
Nature reserves		
Almost natural	4550 km^2	Regional trends
Half-natural	1625 km^2	Regional trends
Recreational	325 km^2	Regional trends
Ext. grasslands	0 km^2	Regional trends
Regionally distributed according to relative share of sandy and peat soils		Regional trends
Location of nature reserves on less profitable agricultural soils		Suitability map
Extension near existing nature reserves		CA rules
Water		
Fresh water	100 km^2	
Development of new recreational lakes in the Krimpenerwaard and the Alblasserwaard		ArcGIS
Development of a border lake around the empoldered Noord-Oost Polder as suggested in the Fifth Spatial Policy Plan (VROM, 2001)		ArcGIS

The influence of the neighbourhood on the spatial dynamics is defined by the CA-rules set. The calibrated set of CA rules of the Environment Explorer was applied for all original land uses that did not change. Rules that correspond the best to the new land-use definitions were chosen from the calibrated set of CA rules for the new land uses. In this way, the new land use, i.e. industrial/commercial areas, is based on the original rules for industrial areas. The majority of the original aggregated land uses consists of industrial area. The positive attraction of industrial cells to other industrial cells was increased at larger the distances within the neighbourhood to realize larger industrial areas. The rules for green villages are based on the low-density residential areas. However, to create small green villages occupying only one cell of 25 ha, the rules were modified. The original attraction of this land use to cells with the same land use has been changed to repulsion so as to create small villages occupying only one cell.

Land-use developments on a national scale comprise 12,200 ha high-density residential area, 48,900 ha low-density residential area, 48,600 ha green villages, 30,000 ha recreational areas, including parks, sports and camping grounds, and 68,300 ha industrial and office area. The regional development of residential and industrial/commercial areas are based on the 'Trend' scenario, developed in the previous assessments of the Fifth Spatial Policy Plan (VROM, 2001; MNP, 2001). The national development of recreational area is distributed over the regions according to the number of inhabitants per region in 2030 given in the Trend scenario.

Total development of natural areas in the Individual World scenario is assumed to be 650,000 ha. A major part of these developed areas (400,000 ha) consists of rural estates. The national development is allocated to the region given its relative share of the national amount of land with agriculturally less profitable soils. The less profitable soils are the sandy soils with a clay content of less than 10% and subsiding lands due to the oxidation of the peat substrate. Finally, agricultural land use diminishes by 860,000 ha in this scenario, almost 20% of the total area of the Netherlands.

Because of practical reasons, the new fresh water lakes, the border lake around the empoldered Noord-Oost Polder and the 'Waterman' Plan have been added to the simulated land use map in ArcGIS.

5. Future land use in an individual world

The future land use in 2030 is shown in Fig. 4. This map directly reflects the assumptions concerning urban and rural developments.

The Randstad region urbanizes to a high degree, especially around Utrecht in the centre of the Netherlands. One of the new high-density residential areas is located more to the east, in the Gelderse Vallei between Veenendaal

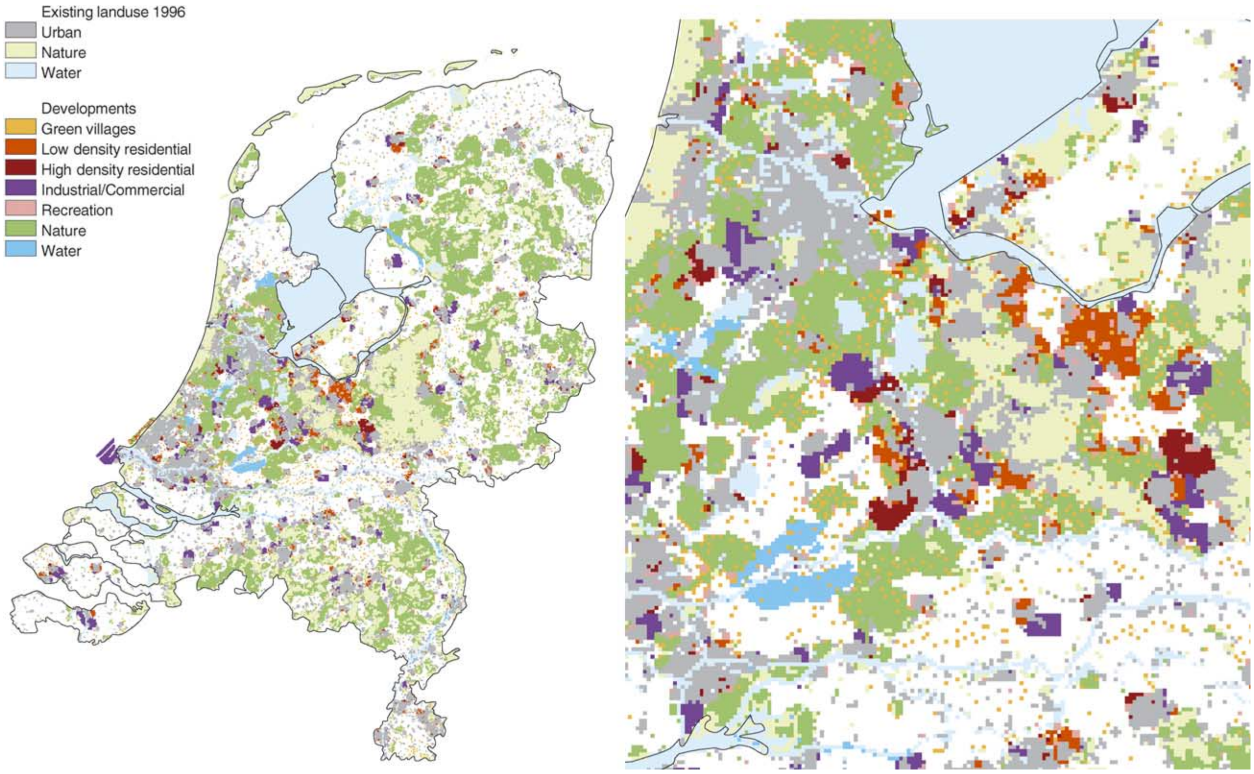

Fig. 4. Land use in 2030 for the Individual World scenario on national and regional scales.

and Ede. Large residential suburbs develop in green rural areas, where former spatial policy restrictions to protect the cultural or ecological value of the area were lifted. Green villages develop scattered throughout the open space between the Rhine and Meuse, and in nature reserves, forests and extensive grasslands. The large increase in residential areas and rural estates causes a reduction in the available land for new developments, resulting in relocation of development to the surrounding regions. Huge, well-accessible industrial/commercial complexes develop near the access roads to motorways.

Agriculture disappears from the less profitable sandy and subsiding peat soils, introducing opportunities for development of nature reserves and rural estates. The agricultural area decreases the most in this scenario, by 36% relative to the situation in 1996.

6. Discussion

In this study future land-use maps were constructed from different scenarios. National development of urban and natural areas was translated into detailed spatial maps of the land use in 2030. One should be very careful in further application of these results. In the case projected here they have been used to show the potential effects on nature and the landscape, and to see whether policy objectives can be realized in the context of various societal developments.

Application of a land-use model such as the Environment Explorer will ensure that future land-use maps are linked to current spatial developments and also to the way the spatial socio-economic system functions (Helling, 1998).

This analysis adheres to historical trends as far as possible. For this reason the model was calibrated over the period, 1989–1993. The results of the calibration in Table 1 showed the observed land use in 1989 to be a better predictor of the situation in 1993 than the simulated map of 1993. This seems to be the case for many spatial allocation models (Pontius et al., 2003). In itself, this may not be so peculiar. It is difficult to get a historically consistent set of land-use maps to calibrate the land-use model. Observed land-use maps for 1989 and 1996 in the Netherlands are not consistent in time and differ to a large extent because of small changes in the definitions of the land-use categories. These small changes have a large effect on the dominant land use at a 500-m resolution. For instance, 15% of the recreational area in the observed land-use map of 1989 is not present at the same location in the observed land-use map of 1993. The inconsistency will most probably decrease with smaller grid sizes. The inconsistency in land-use maps does not directly influence the Kappa statistics, but indirectly influences the behaviour of the model as defined in the CA rules. Furthermore, the spatial allocation of developments is, to some degree, random (White and Engelen, 1993), which makes it hard to simulate the exact location of land-use developments. The initial land-use map will be a better predictor for relative short simulation periods when spatial developments are relatively small. Over a longer period, spatial developments will increase and the simulated map will, most likely, perform better, compared to the initial map because the total amount of changed land use increases.

The development of low and high residential areas adheres more strictly to the calibrated model than new defined functions such as green villages. Low and high residential developments represent an extrapolation of current trends, while development of green villages, as assumed in the scenario, should be viewed as a transition in the spatial behaviour of the residential actors (Aspinall, 2003; Black et al., 1998). The addition of a new form of land use such as green villages is a way to incorporate these assumed transitions. The behaviour of such a new land use to explore the effect of a transition can, by definition, not be calibrated on trends in historical data. In the long term, these transitions in society form major uncertainties. Scenario analysis is a way to cope with these uncertainties. Four spatially detailed land-use maps were constructed for evaluating the effects of scenarios on environment and nature in the Nature Outlook 2. Each of these maps reflects model input and assumptions. The maps do not show the most probable developments in the Netherlands but describe the possible change in land use if Dutch society were to develop according to one of the four scenarios. The total set of future land-use maps reflects the large (societal) uncertainties that are characteristic for such long-term analyses on a spatially detailed scale.

The construction of future land-use maps can be improved by:

- making causal, consistent and plausible scenarios relating past and present developments to future ones, including potential and probable transitions (CPB, 1996; Myers and Kitsuse, 2000);
- utilizing the five driving forces in the development of the scenarios: international political developments, economy, demography, technology and socio-cultural;
- including the most sensitive and uncertain variables of the spatial allocation model in the definition of the scenarios.

The reliability of the spatial allocation models should be improved by means of calibration and validation of the land-use patterns they describe (Straatman et al., 2004). The advances in satellite-based land-use maps and new methodologies to compare observed and simulated maps offer good possibilities to calibrate and validate the models on an independent data set and to perform uncertainty and sensitivity analyses.

Additional analysis of observed spatial developments are needed to support the models (Verburg et al., 2004). Only a relatively small number of analyses for intercomparison have been reported, especially for urban developments. Results of these studies are important to set model parameters within realistic ranges. More comparable studies for regions with different spatial developments may shed some light on the variability of location processes in the different land uses.

In the case of CA-based land-use models, a methodology should be developed to distil the essential set of rules from observed changes in land-use maps. The set of rules driving multi-state CA models yields a huge set of parameters and this hampers model calibration. Analyses of models for different areas—water and soil quality, ecological effects, and traffic and transport—show that in most cases only a limited number of variables, 10–15, actually determine the results of the model.

7. Conclusions

For the first time in the history of our outlooks, consistent, spatially detailed land-use maps of the Netherlands in 2030 have been constructed from national economic and demographic scenarios. Construction of these maps does require extra information on spatial distribution at regional and local level. National economic and demographic scenarios have been extended with assumptions on the spatial behaviour of the different actors, activities and land-use functions.

The application of a land-use model such as the Environment Explorer ensures that all relevant aspects of a scenario, i.e. economic and demographic developments, zoning policies and urban growth, will be integrated systematically into one consistent framework. Each of these elements can be defined by the user on the basis of historical trends, scenario assumptions or urban designs, in which prescriptive design methods and descriptive long-term projection methods are linked.

The assumptions in the scenarios and their implementation in the allocation model define the resulting land-use maps for 2030. The maps do not show the most probable developments in the Netherlands but describe the possible change in land use if Dutch society is to develop according to one of the four scenarios. The large (societal) uncertainties are reflected in the total set of future land-use maps. The set of land-use maps is important for evaluating potential effects on nature and landscape according to the trends in society. And the final issue is what the effect will be if the Netherlands does indeed develop according to one of these scenarios?

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