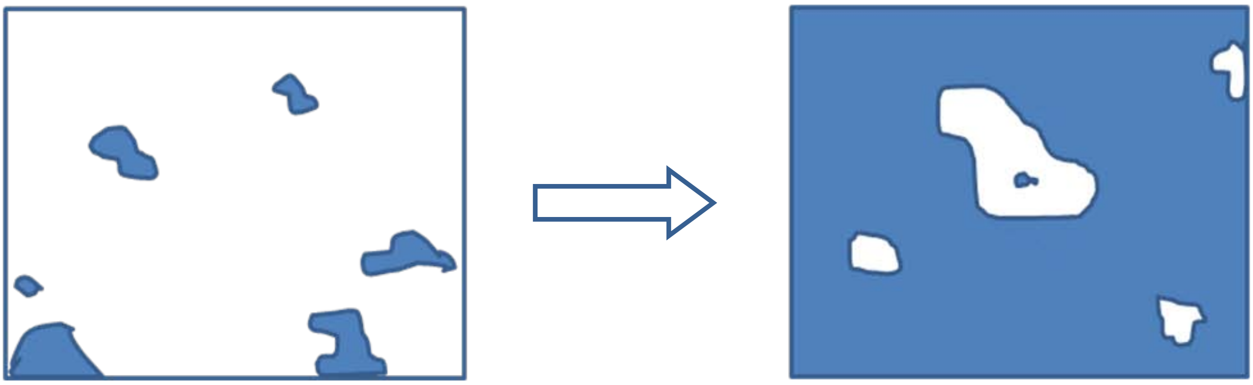
# Evaluating the loss of open space in land use change simulation



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# Colofon

## Title

Evaluating the loss of open space in land use change simulation
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## *Summary*

Although open space preservation has been a major spatial planning issue in many developed, densely populated countries for decades, the amount and quality of open space is diminishing rapidly, affecting both quality of life and viability of ecosystems. For the design of more successful spatial policies we need to anticipate the landscape effects of different future land-use configurations under different social economic and climate change scenarios. This study explores new methods with the help of a group of specifically designed spatial indicators to analyse the landscape impacts on open space that are associated with land use changes in 2040 simulated with the model Land Use Scanner under the chosen W+ land use scenario. The W+ scenario is a global economy scenario combined with a strong increase in temperature.

Apart from the challenging task of developing plausible land-use scenarios this methodology faces the difficulty of determining indirect spatial effects of land-use configurations using spatial data of common land use models of very limited quality in terms of spatial (100 meter grid cells) and attribute resolution (15 land use classes). The latter problem offers a relatively unexplored research area as most landscape related research on openness is only focussed on the spatial effects of current land use.

The main research objective is to explore suitable spatial indicators for measuring negative impacts of land use change in the period 2000 – 2040 on both quantity and quality of open spaces.

In this study open space is roughly defined as all area on land that is not occupied by connected elevated manmade structures and or large infrastructures such as high ways, extended with small surface waters as lakes, rivers and canals and including all types of vegetation. If not indicated otherwise the minimum mapping unit of open space used is 5 hectares. Subsequently, transition processes from open space to fragmented and urban space and the concept of the dominant landscape matrix are described in this study to be able to define appropriate units of open space and place evaluation results in their specific context.

The quality of open space is evaluated from a social, mainly recreational perspective. Indicators are operationalised in a geographic information system using common spatial analysis techniques such as patch and neighbourhood analysis. Two types of indicators were used, i.e. general composition metrics and structural spatial configuration metrics.

The general composition metric indicates an absolute decrease of open space of approximately 5% in 40 years between 2000 and 2040 (W+ scenario), measured in the netto number of gridcells that change from the defined open area land use class to built-up land use classes. This figure gives however, no information about the change in number and sizes of open spaces and the quality loss of open space.

The results in this study show that the first developed structural spatial configuration metric 'size and number of open spaces', is a good indicator for evaluating general national and regional trends in the change of open space.

The second developed structural spatial configuration metric 'degree of openness', is expressed as a ratio between open space and built-up space and appears to be a good indicator for evaluating more qualitative changes in open space and comparing e.g. conversion rates from open to built-up areas between different regions, such as provinces. Alternatively the degree of openness is also analysed using gridcell based moving window neighborhood analysis to prevent spatial effects from non uniform reference areas. This indicator is particularly useful to evaluate spatial changes in openness within defined units of open space.

In the group of developed functional spatial configuration metrics a (national) policy relevant indicator was developed for the evaluation of 'landscape cluttering', based on existing literature on this topic. This indicator can be directly implemented to evaluate the effect of land use changes on landscape cluttering in the Netherlands. The use of neighborhood analysis techniques in this indicator makes comparisons possible from local tot regional scales.

The second functional indicator that was developed, 'attraction and proximity of open space', is an internationally policy relevant indicator. In its current form this indicator measures the social value of open spaces and the resulting maps show in general plausible results. This indicator needs however further eleboration as there are some issues to resolve and further it needs to be adapted to the specific needs of different counties considering the lack of standard procedures to measure the access to green and open space.

In conclusion, this study demonstrates that despite the indicated difficulties for this type of indicator development a number of useful indicators can be developed. However, further research is necessary to resolve some of the issues observed in this study. Finally, it is important to test and calibrate indicators on the basis of historic maps for current land use configurations and compare the results with more sophisticated evaluations of openness for the current situation.

## Contents



*Terminology and abbreviations used*

AGM = ArcGIS Model (built with ArcGIS Model Builder)
AMD = ArcMapDocument (file with mxd extension)

*Basic assumptions*

- If not mentioned otherwise we refer with open space to terrestrial open space, this includes smaller surface waters such as lakes and rivers, but excludes large surface waters, such as sea and related coastal waters (e.g. the large salt and sweet water lakes between the former islands of Zeeland) and large lakes such as the Ijsselmeer and the connected Randmeren
- We assume that the administrative scale level of provinces is a suitable spatial unit to compare spatial differences in openness because of marked bio-physical, cultural-historical and spatial political differences between the different Provinces that influence the land use composition. Further, we expect differences in land use composition between the Provinces because the land use model used allocates land use on the basis of Provincial land use claims.

# 1. Introduction

In the Netherlands, one of the most densely populated countries in the world, urban functions are constantly competing for available space. The increasing urbanisation has led to a growing concern for the preservation of open space and has become therefore a critical issue in spatial planning policy. In the past decades the Dutch government has aimed at minimizing the fragmentation and further loss of open space, especially in the national landscapes.

To study the possible changes in open spaces in the coming decades, a raster GIS oriented, economy based, land use model is used to construct future land use scenario's. The premise here is that the amount and fragmentation of open space is directly linked to the spatial distribution of land use. To effectively evaluate the open space characteristics of different land use scenario's specific indicators are needed, which are missing in the current version of the model. This report explores different methods to assess the impact of land use change on open space through the development and application of specific indicators. The datasets and scenario output of the land use model 'Land Use Scanner' form the basis for the methods applied.

A specific challenge in this research is the difficulty of determining indirect spatial effects of land-use configurations using spatial data of common land use models of very limited quality in terms of spatial and attribute resolution. The latter problem offers a relatively unexplored research area as most landscape related research on openness is focused on the spatial effects of current land use. To overcome the data quality issue special attention must be paid to the design and evaluation of individual and grouped indicators. Further, the use of additional data layers that relate to e.g. landscape typology and cultural heritage can be necessary to detect structural landscape changes.
This report aims to give a more in depth explanation of the methodologies that are addressed in the research paper by Wagtendonk and Koomen (in preparation), including descriptions of analysis functions and spatial datasets used and moreover the report aims to explore alternative methodologies.

The main research objective is to explore suitable spatial indicators for measuring negative impacts of land use change in the period 2000 – 2040 on both quantity and quality of open spaces. The quality of open space is evaluated from a social, mainly recreational perspective.
The report describes the development of indicators for measuring the qualitative and quantitative effects of land use changes on open space in the Netherlands between 2000 and the scenario year 2040. Basis for this development is the land use composition in 2000 as represented by the land use model 'Land Use Scanner' (version DMS 529, Jan. 2, 2008, LANDS_IP) and the model simulations of the land use in 2040 according to the W+ scenario, both in 15 land use classes.

The W+ scenario is a combination of a socio-economic scenario (global economy) and a climate scenario (strong increase in temperature) derived from two independent studies, the Welvaart en Leefomgeving (WLO) study and a study from the Royal Netherlands Meteorological Institute (KNMI), see further Riedijk et al., 2007.

The report is structured as follows:

In section 2 we give definitions for open space and in section 3 we discuss possible spatial transitions from open to built-up space. Section 4 discusses the use of spatial indicators and in section 5 we explore a simple way of visualizing changes in open space. Several general composition indicators are discussed in section 6 and structural spatial configuration metrics in section 7, i.e. number and size distribution of open space patches, size of open space and degree of openness. Next, the development of two functional indicators that measure respectively the degree of cluttering of open space is described in section 8.1 and the social value of open space based on visual and recreational qualities of open space is described in section 8.2.

Finally, in section 9 we draw some preliminary conclusions concerning the developed and evaluated spatial indicators, followed by recommendations for further research.

## 2. Definitions of open space

A relevant problem in measuring changes in open space is the definition of what exactly constitutes open space. As observed by Wagtendonk and Koomen (in preparation) several perspectives on open space exist with more or less specific definitions. In our case we must be able to define open space on the basis of land use composition maps of relatively low resolution, which makes different perspectives that depend upon e.g. photo or field interpretations, obsolete.

Our definition of open space includes all area on land that is not occupied by connected elevated manmade structures and or large infrastructures such as high ways, extended with small surface waters as lakes, rivers and canals and including all types of vegetation. Even though large water bodies (the North sea, sweet and saltwater lakes of Zeeland, the IJsselmeer and the Randmeren) certainly have impact on the open space perception of adjacent open space on land, we decided to consider large water bodies as a separate category of open space that we exclude in this research. The main reason for this choice is that the inclusion of large water bodies in our definition of open space would make comparison of open space characteristics between different units on land less clear as relative changes in open space units including large water bodies will be smaller. Besides, the differences in open space characteristics between units of open space on land or on water are so large that according to us there are no clear arguments for unifying them in combined units. Nevertheless, open water bordering open space, also influences the perception of open space on land. This effect we have incorporated in the sub-indicator land use diversity (alternation water, nature/forest, grass) in section 8.1.

Note that in the current version of Land Use Scanner the above mentioned large water bodies are included in the definition of the open space map units (see
Figure *1*[1]). The model documentation does not give an explanation for this choice. Possible a purely visual definition of open space units is followed.

Smaller water bodies such as lakes, rivers and canals we included however in the definition of the open space units as they only form a relative small portion of the total amount of open space within an unit and they are more an integrated part of the landscape instead of an transition between water and land landscapes. It is true however that each type of water body forms a physical access border to other parts of the open space and contribute in some specific cases, such as large artificial canals, to the fragmentation of open space.

Obviously, what is considered open space and what not, is strongly scale dependent. In our case issues as whether to add small public green areas within the city borders to the total area of open space, are however not relevant. The resolution of our source data determines the delineation of our land use classes, which on their turn determine what can be considered open space and what not (see Wagtendonk and Koomen, in preparation).

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[1] Figure 1 also shows the problems associated to such a definition, the islands of Zeeland, parts of the coastal area of Noord- and Zuid-Holland and the northern part of Friesland and Zeeland all fall in the same class of nearly 3 million hectares of open space, while there are distinct differences between the three regions in the open space sizes on land.

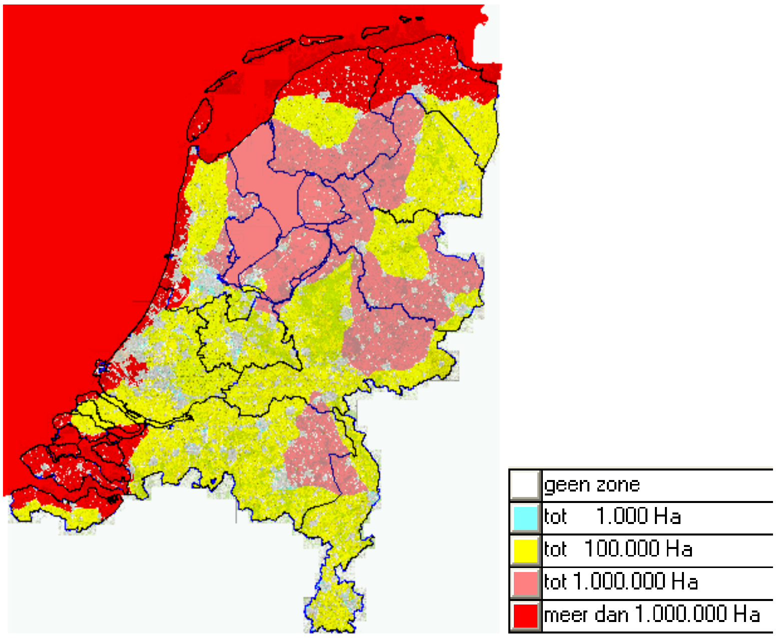


*Figure 1* Open space size units in the Land Use Scanner model

Finally, we did not consider natural borders of open space formed by e.g. relief (hills, mountains, cliffs, valleys), in the first place because of the near absence of big relief differences in the Netherlands. But also because in the cases where relief obstructs the view on open space, such as the dunes along the coast obstruct the view on the North Sea, we consider relief being part of open (natural) space in the same way we consider forests and other forms of high vegetation part of open (green) space.

In *Table 2* in section 6 the used land use classification to separate open space from built-up / urban space is shown.

# 3. Transitions of open space

For the measurement of changes in open space it is important to understand how the transition from open space to built-up or urbanized space takes place, what stages and which spatial patterns can be distinguished, e.g. is open space occupied by built-up elements concentrated in different clusters or are these elements totally dispersed. And what is the result of this occupation, is open space fragmented in different units of open space or does it merely mean a reduction in total area size.

Initially, open space constitutes the matrix in which built-up elements develop, but beyond a certain threshold level the open space is dissected and filled up to such degree that a reversed situation will be reached. The remaining open space forms now the perforation in a matrix of built-up space. Although urbanisation processes show cyclic stages from urbanisation, suburbanisation, counter urbanisation and re-urbanisation in terms of population change, the resulting built-up space occupation does not visually reflect this process. Instead, the urbanisation process shows a continuous trend of extending built-up area, but with variable speeds over time. Another process that the spatial pattern does not show is that many remaining open areas are visually open but functionally urbanized (Antrop, 2004, pp. 17).

In *Figure 2* the different stages from open to built-up space are illustrated. In the left image open space is the matrix in which a number of built-up elements are located. In the middle image open space is in a process of fragmentation (dissection by infrastructure and shrinkage/fragmentation by urban extension) and it is not exactly clear if the matrix is formed by the open space or the built-up space. In the right image the matrix is formed by the built-up space with some remaining open spaces. It is important to understand which elements in a certain space form the matrix and which elements occupy this matrix, because the matrix is both the largest and the most connected spatial element and has consequently a dominant influence on the functioning of a landscape (Forman and Godron, 1986).

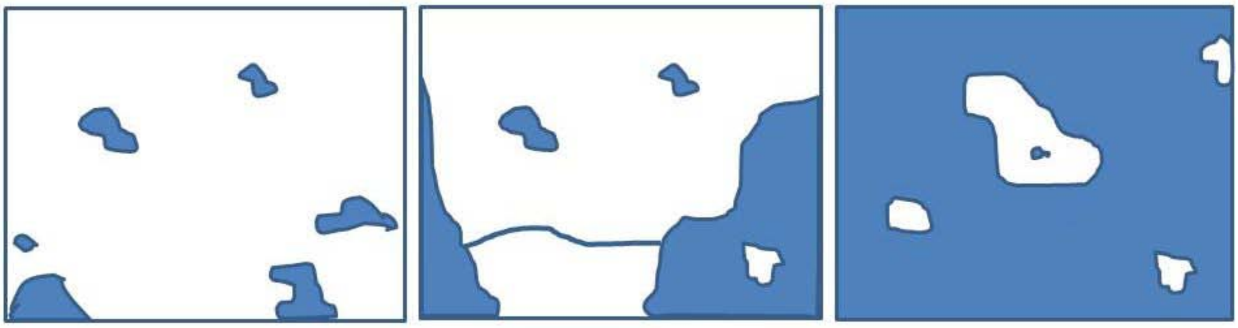

*Figure 2* Degrees of openness. Left: matrix of open space with 5 built-up elements. Middle: balance between 3 built-up and 3 open spaces. Right: matrix of built-up space perforated with 4 open spaces.

An interesting perspective on open spaces can be acquired by applying the landscape analysis concepts of Forman and Godron (1986) on open spaces. Forman and Godron use a concept of matrix and network to describe elementary characteristics of landscapes and to describe transitions between different states of landscapes. In their view the matrix is the most extensive and most connected landscape type and has the largest influence on the way the landscape functions. Criteria used for the classification of landscape elements as the matrix are the relative area, the connectivity and the control over landscape dynamics of a landscape element. If we look at the artificial and semi-natural landscape of the Netherlands it would make sense, from a functional and ecological point of view, to consider the urban built-up area connected by an extensive network of infrastructure corridors , the main landscape matrix even though open spaces are still the dominant landscape element in terms of area. Unless its small relative area, the transport and urban network form, just like the hedgerows in a bocage landscape, the main landscape element constituting the matrix. In this matrix the main transport lines, such as highways and elevated or multiple track train connections form the main branches of the matrix while lower order transport connections form the smaller matrix branches. While connecting urban concentrations, the roads form physical and visual barriers between the other elements and encircle them into isolated islands of open space. At the same time roads favour migration, exchange of genes and necessary resources for the most dominant species in this environment: man, while putting at disadvantage all other species. Also the third matrix criterion the control over landscape dynamics links without doubt to the urban built-up and road network as these control and shape current and future landscape dynamics.

However, the main perspective taken in this research is not an ecological and functional perspective, but a social/cultural and visual perspective on open spaces. From this perspective, in which the main landscape function is to support the wellbeing of its users and pleasing the eye of the beholder, the open spaces itself which occupy the largest areas matrix of the Dutch landscape, could be considered the matrix. In which roads and other not built-up sealed land cover can form part of these visually connected open spaces. This is however dependent on the scale of observation.

E.g. on a national scale all these open spaces are confined and visually separated by more intrusive transport routes, e.g. because they are built elevated and/or because they are intensively used (visual, audio and smell intrusion by large motorized moving objects), and built-up types of land uses (including road furniture such as sound barriers, elevated road signs including variable-message/matrix signs, guard rails, light and utility poles, billboards, etc.).

As we use a quite rough, national and regional obeservation scale, with a minimal mapping unit of 100x100 meter, we consider the major road network in combination with the built-up area as the most extensive and most connected landscape elements that break up the matrix in different spatial units.

A separate category in this social/cultural and visual perspective on open space is formed by (high) vegetation. Where open space is defined as green open space, high vegetation is included in the definition, but where open space is explicitly defined as a visually open space, high vegetation clearly falls outside this definition. In this study we adopt a definition of open space that includes all green areas for the simple reason that we cannot distinguish high from low vegetation in the nature areas.

How fast and in which spatial constitutions the transition from predominantly open space to predominantly built-up space takes place depends among others from the urbanization rate, the dimensions of the initial space (e.g. confined between geographic features such as major lakes and ocean) and the spatial composition of the existing built-up area. To evaluate the open space characteristics of possible future landscapes such information is very important and should be incorporated as much as possible in the land use modelling process. In the land use model used in this study this kind of information is already incorporated because the speed of urbanisation and the distribution of the built-up area will depend strongly of the implemented land use scenario, while the current land use distribution is an important starting point for the model.

Because we consider an understanding of transition processes from open to built-up space very important for the evaluation of the state and characteristics of open spaces, we borrow and adapt some practical concepts and terms to describe the spatial transitions above from the related field landscape ecology and studies on urban sprawl.

A useful classification of spatial changes in the shape and extent of natural areas was made by Forman (1995), who distinguished 5 different categories of spatial change, see Figure 3.

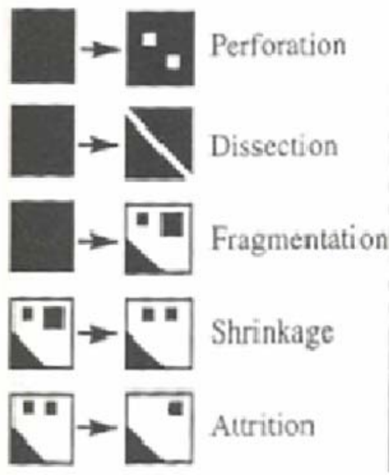


*Figure 3* categories of fragmentation according to Forman (1995)

Obviously the processes described by Forman (1995) in which natural areas with high vegetation are perforated and fragmented are the reverse of the processes in which empty, open areas are dissected and filled up by built-up elements. However, most of the terminology used can also be used to describe changes in open space (which in our case also includes vegetated natural space), as illustrated in Table 1. However, our definition of open space expressly includes stretches of land without any visual obstructions. Therefore the term 'perforation' is for example less suitable to describe the process in which an open space is occupied by isolated elements. We prefer therefore the term intrusion which describes the physical process more correctly and has a similar connotation.

All other process terms used by Forman are also applicable for the fragmentation of open spaces and are therefore adopted. The pictograms used by Forman we adapted by replacing the dark (built-up) area by light (open) area and vice versa. We also changed the order of the different change processes. Although there is not a strict order in which the transition process takes place, we followed the order of the more common succession stages, in which intrusion and dissection are among the first stages and shrinkage and attrition (disappearance of the last relicts of open space) are usually the last stages. The term fragmentation was shifted to the lowest position in the table as fragmentation is the only process in which more change processes can be combined. Further we indicated if the changes lead to changes in area and total number of open space units within a given area (see also section 7).

*Table 1* Categories of open space fragmentation (adapted from Forman, 1995)

| | | Change in number of open space units | Change in total area of open space |
|---|---|---|---|
|  | Intrusion | - | ↓ |
|  | Dissection | ↑ | - |
|  | Shrinkage | - | ↓ |
|  | Attrition | ↓ | ↓ |
|  | Fragmentation | - / ↑ | ↓↓ |

Other, but less systematic, concepts and terminology to describe the transition processes of open space are put forward by e.g. Antrop et al. (1994) and Gulinck et al. (2007) who distinguish different fragmentation processes of open space caused by transport infrastructure, building and agricultural activities:

- Dissection (by infrastructure and other linear barriers)
- Densification (more houses, infrastructure and other built-up elements per km2)
- Congestion (progressed densification typical for peri-urban network with remaining fragments of open space)

From these processes dissection can be considered similar to the intrusion and dissection processes illustrated by Forman (1995), while the densification and congestion processes can be considered similar to respectively the shrinkage and attrition processes in table 1.

# 4. The use of spatial indicators

Indicators applied should have a clear theoretical basis to make them transparent and easily understandable. Further they should clarify the significance of simulation results for specific policy themes, and discriminate sufficiently between different simulation results (Ritsema van Eck and Koomen, 2007). And only by combining different indicators more comprehensive assessments can be made (Fry et al., 2009). This is especially true for the many values that open space can represent.

Spatial indicators based on spatial data are usually referred to as spatial or landscape metrics or indices when exclusively developed for categorical maps, and can be divided in general composition metrics and spatial configuration metrics (McGarigal, 2002). General composition metrics summarize the amount and variation in land use types for a specified area. These types of indicators are already available in the land use model applied and are therefore addressed only very shortly in this report (section 6). Spatial configuration metrics can be subdivided in structural and functional spatial configuration metrics. Structural spatial configuration metrics quantify the spatial configuration of units on a map without explicit reference to the appreciation of different types of open space. The second subclass of functional spatial configuration metrics is directed towards evaluating the functional meaning or value of open space. Both type of spatial configuration metrics are used in this research.

Another way of classifying spatial indicators is to distinguish indicators that quantify characteristics of open space in absolute sense or only as relative changes. For the latter type of indicators, here referred to as 'change indicators', additional reference maps are needed that represent an initial situation that can be affected by specific land use changes. This is especially relevant for land use transitions that negatively affect (irreversible) values of a steady state situation that are expressed in existing value or alert maps, such as the geomorphologic value map ('signaleringskaart', see Koomen et al, 1999), or in landscape / cultural-historical value maps.

Change indicators are also relevant for the qualitative evaluation of spatial effects that result from projected land use changes and are difficult to assess in absolute and/or quantitative terms because of the discussed data limitations.

# 5. Visualizing changes in open space

In this study we aim for the development of spatial indicators that can measure qualitative and quantitative effects of land use changes on open space in the Netherlands between 2000 and the scenario year 2040. The first group of spatial indicators we explored are visual indicators that enable us to facilitate the visual, qualitative, comparison of changes in open space between different time periods. This is done by producing a more generalized, less irregular and fragmented pattern of the built-up land uses that occupy the open space. We tested the standard functions 'boundary clean' and 'majority filter' that are available in the ESRI GIS software ArcGIS version 9.3.

The Boundary Clean function smoothes the boundary between zones by expanding and shrinking it. As sorting technique best results were acquired with the option ASCEND which takes care that zones with smaller total areas (in most cases the urban areas) have priority to expand into zones with larger total areas (in most cases the open spaces). This implies that small urban areas surrounded by open space become more evident (in this way simulating the impact built-up structures have on the perception of surrounding open space) and at the same time small open spaces surrounded by urban fabric become smaller or even eliminated (which addresses the effect that the smaller open space becomes the more irrelevant it becomes). The effect of this function is especially visible on larger map scales (see Figure 4).

*Figure 4* Built-up land use types (in dark-grey) in the year 2000 in the region around Amsterdam directly derived from the land use model (left) and after applying the Boundary Clean function (right).

Figure 5 displays two maps of the current land use configuration (2000) and the simulated land use pattern in 2000 (W-scenario) after applying the Boundary Clean function for both maps. On this smaller scale the improvement for visual comparison is clearly less obvious than on the larger map scale (as was displayed on the right map in Figure 4).

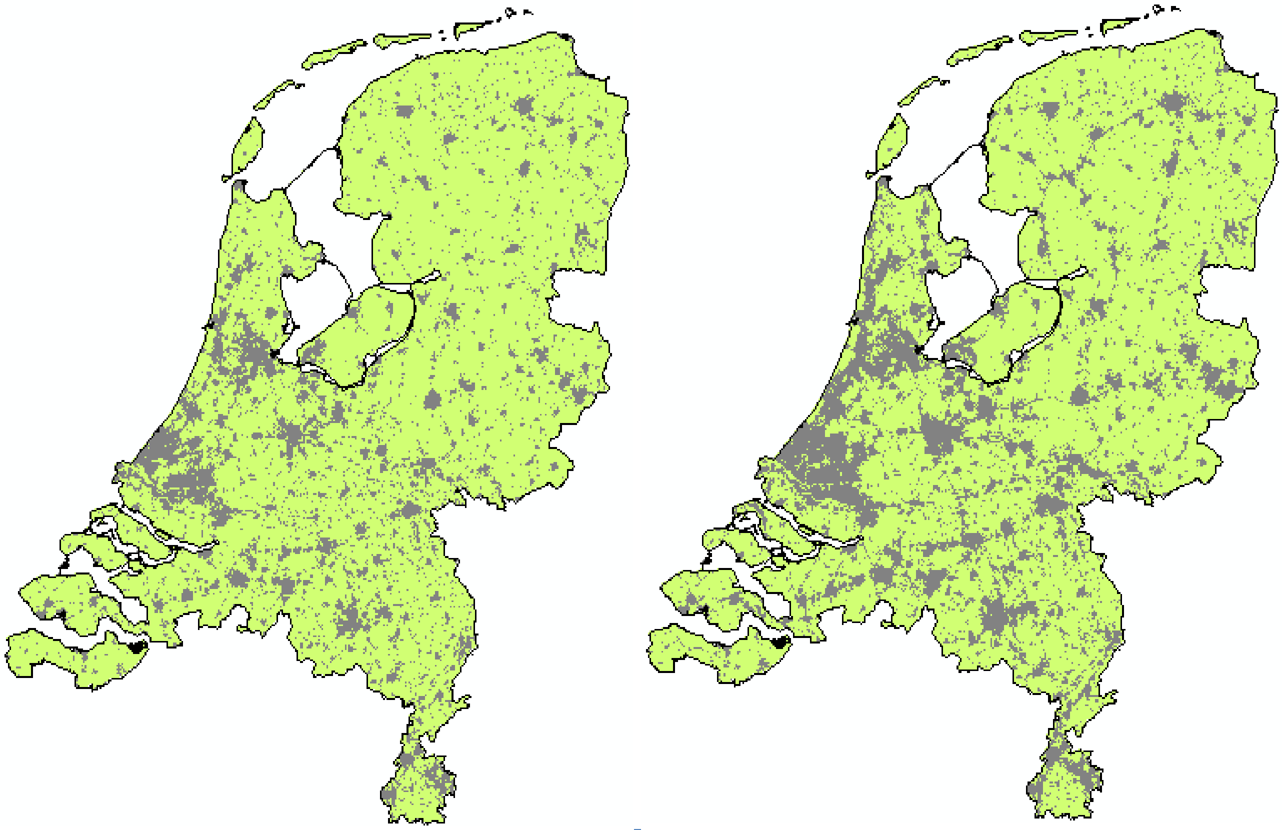

*Figure 5* Maps of open (green) and built-up (dark grey) land use after applying the Boundary Clean functions for the year 2000 (left) and the scenario year 2040 (right)

A second function tested is the Majority Filter which replaces cells in a raster based on the majority of their contiguous (four) neighbouring cells. The result is displayed in
Figure *6* (right) again for the region around Amsterdam together with the original not generalized map (left).

*Figure 6* Built-up land use types (in dark-grey) in the year 2000 in the region around Amsterdam directly derived from the land use model (left) and after applying the Majority Filter function (right).

In comparison to the Boundary Clean function this function retains better the original land shapes in the land use pattern (which is not a plus, because we strive for more generalization) but at the same time it removes better the small isolated built-up land use patches in the open area. The latter is an undesired effect because it makes appear the open area more open than it actually is. From the both tested functions we think therefore that the Boundary Clean function is the more useful.

# 6. General composition metrics

As we explained in section 4 we explore shortly the use of one indicator that can be classified as a general composition metric (McGarigal, 2002). Such a metric summarizes the amount and variation in land use type for a certain area. One of the simplest general composition metrics regarding open space measures the total amount of open space in the Netherlands. In our case this regards the variation between open and non open land use classes for the Netherlands as a whole, or for specific spatial units (e.g. Provinces).

For a clear comparison between the spatial effects of 'current' land use in the year 2000 and simulated land use in 2040 we work for both periods with the same country boundaries, excluding the North sea, the big salt and fresh water lakes of Zeeland, the IJsselmeer and the 'randmeren'. All other water bodies are included in the considered land surface, in total an area of 3.507.290 hectares. We do not consider changes in total surface caused by reclamation of land outside the indicated borders.

Table 2 shows the used classification scheme for classification in open and built-up land use types for both time periods.

*Table 2* Division land use classes in open and built-up space

| **Open space** | **Built-up space** |
|---|---|
| Recreation<br>Nature/forest<br>Arable land<br>Grassland<br>Water (excluding the large water bodies) | Residential – high density<br>Residential – low density<br>Residential – rural<br>Commercial<br>Seaport<br>Greenhouses<br>Intensive livestock farming<br>Infrastructure<br>Building lot |

Table 3 lists the total area and percentage of open space in the Netherlands for the year 2000[2] and the scenario year 2040[3], showing an absolute decrease of open space of approximately 5% in 40 years.

*Table 3* Amount of open space for current and simulated land use

| | **LU 2000** | **LU 2040 W-scenario** | **Total area** |
|---|---|---|---|
| **Open space Netherlands** | 2.993.983 ha (85,4 %) | 2.794.189 ha (79,7 %) | 3.507.290 ha |

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[2] Based on land use 2000 in Ruimtescanner, as received 9 September 2009 from Eric Koomen. Filename: gg_2000, reclassified to os_gg2000 and masked with nl_grens_mask to osgg2000.

[3] Filename 'osggw2040'. Based on simulated land use 2040 according to W scenario (dom_ggw2040 / Dominant_ggModel_W_scenario2040_prov.asc). The 22 land use classes in this scenario are reclassified to the 15 classes from the current land use map 2000 (the class 'meerjarige teelt' is reclassified to 'grondgebonden teelt') and subsequently to the 2 classes confined and open.

# 7. Structural spatial configuration metrics

## *7.1 Size and number of open spaces*

With size of open space we do not refer to the total area of open space but to the size of units of open space, according to the definition given in section 2 with contiguous gridcells of open space. Size of open space is particularly relevant for ecological and environmental values, but is also important for e.g. recreational values where there is a relation between the size of an open space and the distance people are prepared to travel to reach this space. Therefore small open spaces in a densely populated area can still be valuable, because of its greater accessibility for large amounts of people.

In our GIS analyses the border of open space is automatically positioned at those locations where gridcells classified as open space, are unconnected. Subsequently, we can determine the map unit size of open space by counting the number of connected grid cells of the 'open' land use types using the 4 sides connection rule (so diagonal open space cells are not considered connected). In GIS this is done by converting groups of contiguous raster cells that are classified as open space into individual polygons[4] in the land use maps of 2000 and 2040.

Important continuous borders of open space are formed by the dense urban fabric of cities and by large linear obstructions such as highway infrastructure or elevated railway connections. These different land use types are expressed in land use model maps, but the linear infrastructure is in general less well presented in most raster based land use models , e.g. a large road or high way is represented by a more or less interrupted linear sequence of grid cells of one or two cells wide. Applying such incomplete map representations would mean that open spaces that are in reality interrupted by infrastructure are considered connected according to the map.

In the applied model Land Use Scanner this problem is recognized in simulations of future land use by imposing the map representation of important existing or simulated infrastructure using a row of gridcells in either direction of minimal one gridcell wide. However, in the available land use maps used in the model for the year 2000, infrastructure is not imposed and therefore much more weakly expressed as can be seen in Figure 7 and Figure *10*.

[4] Raster to vector (no simplify) from osgg00_2 and osggw40_1 followed by selection and export of cells with gridcode 1, to respectively 'os_gg2000_polys_open2.shp' and 'os_ggw2040_polys_open1.shp'

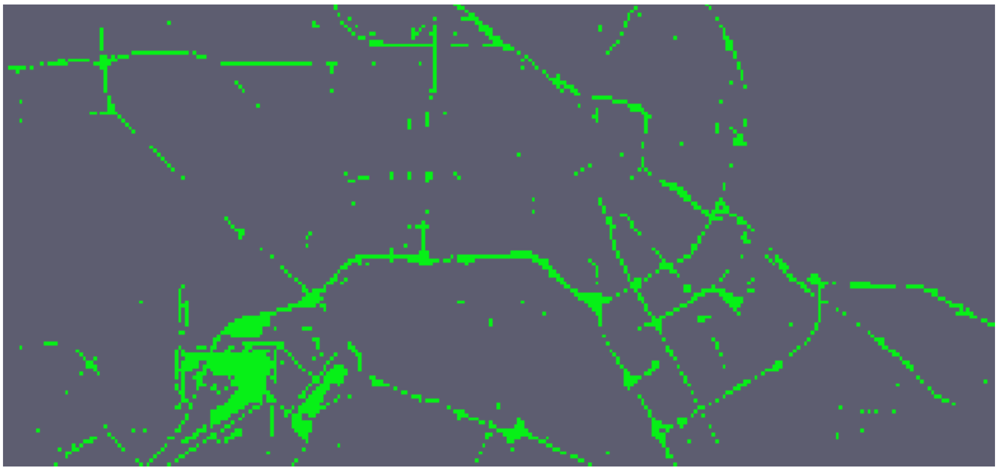

Figure *7* Infrastructure in land use map 2000 as used in the Land Use Scanner model

For the year 2000 this consequently leads to the formation of fewer units of open spaces compared to the year 2040 and in particular a supersized rest unit of 2.813.099 ha (in the rest class > 100.000 ha), as can be seen in the size distribution of open space units shown in Figure *8*.


*Figure 8* Size-distribution of open space units in 2000 and 2040 (the rest class > 100.000 ha. contains one connected unit of open space with an area of 2.813.099 ha.)

To prevent the formation of too little and unrealistic large map units of open space we employ therefore an additional data layer of existing major roads[5] (see Figure 9) and existing railways (as far as present in the model simulation of 2040) that replaces other land uses with infrastructure in both the land use 2000 map and the 2040 map, and limits the maximum size that map units of open space can have.

[5] Existing roads listed in the Nota Ruimte as present in BeleidsOndersteunend Ruimtelijk Informatie Systeem, Boris 4.2 were updated with some missing roads that were present in the Land Use Scanner maps. The update process is documented in the ArcGIS Model 'Size of open space (new 2 May 2011)', resulting in the updated land use gridlayers osgg00_2 and osgg40_1.

Obviously, there are good reasons to argue a different or further subdivision of open space units. For example regional, provincial and other type of lower class connection roads can be very intensively used and have a large impact on the perception of open spaces (see e.g. example given by Veeneklaas et al. 2006, p. 58, of national road N217 in ʻs Gravendeel). We have chosen however to divide open space units on the relatively small scale level based of the national highway network (supplemented with some important major connection roads and the existing railways present in the model simulations of 2040), because this is the only type of infrastructure that is sufficiently represented and/or modelled in land use models. Furthermore, other type of linear infrastructure is in any case less intrusive (and therefore less dividing) on open space, because of lower traffic intensities. An exception could which could be considered are specific infrastructures such as major dikes and elevated high speed railway lines. In the same vein it could be decided to include or exclude other land use types that are not well represented in the model maps. However, we consider highways and major roads more important for the determination of open space size than any other infrastructures or natural barriers of open space[6].

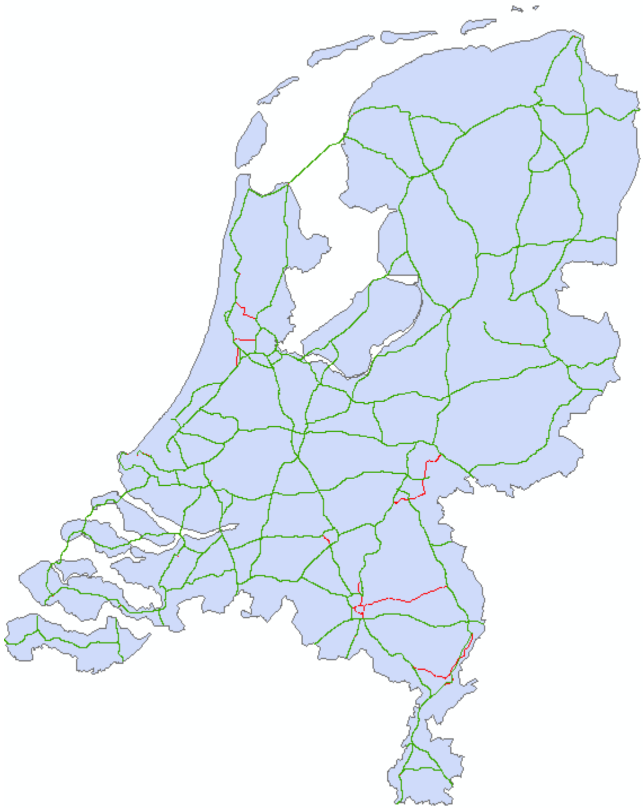

*Figure 9* Applied additional map layer with major roads. In green the roads from the Nota Ruimte available in Boris 3.2, in red the added or replaced roads.

[6] The rationale behind this is that open spaces are both from a human visual and perceptional perspective and a landscape ecological perspective confined and separated by large and busy roads which are specifically designed to connect different built-up areas with each other.

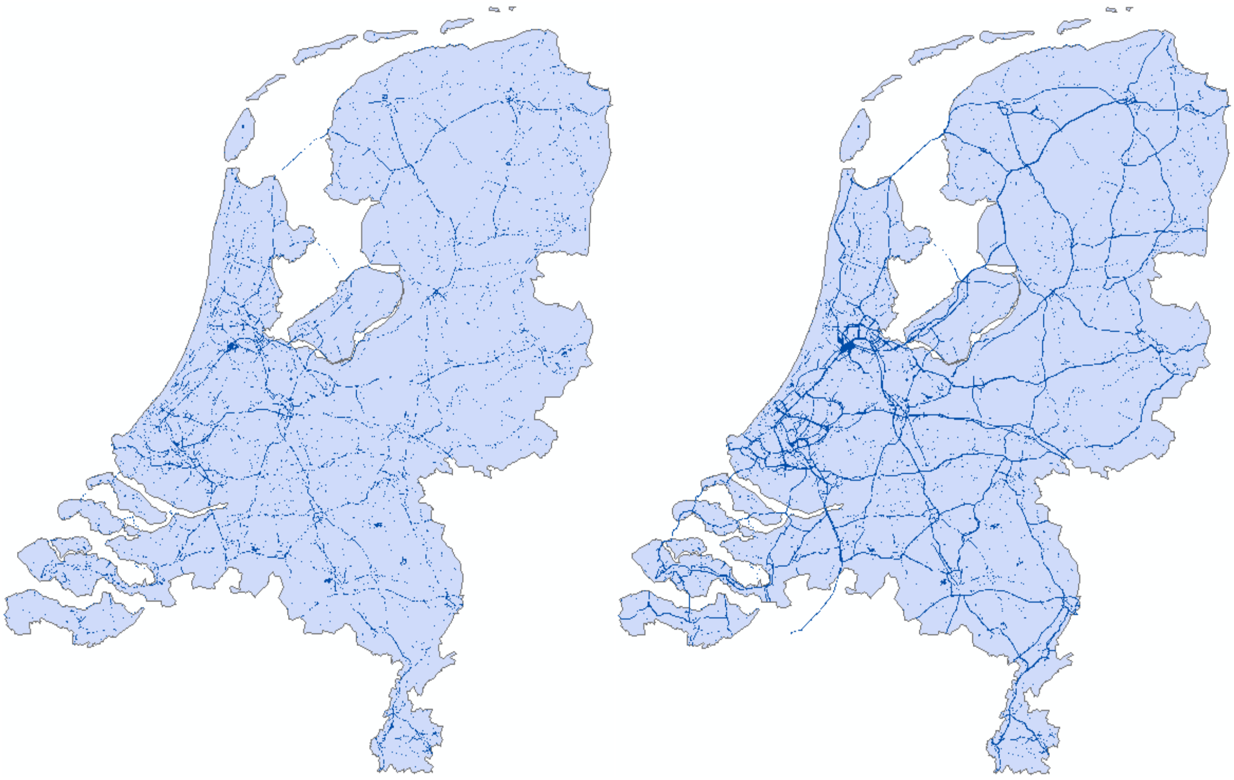

*Figure 10* Infrastructure (roads and rails) in used Land Use Scanner maps 2000 (left) and 2040 (right)

By updating the areas of urban fabric and conurbations with the infrastructure network, a connected urban framework, see Figure 11, is formed that forms the blueprint for the remaining units of open space, that are presented in Figure 12.

The largest units of open space are located in the northeast part of the country (up to 171.089 hectares). Obviously, open space is not only determined by the infrastructure network but can also be confined by continuous, connected built-up areas. In *Figure 13* three different types of open space (in terms of confinement) are illustrated for an open space east of the city of Utrecht confined by 5 high ways (A27, A28, A1, A30 and A12) and one city (Zeist) .

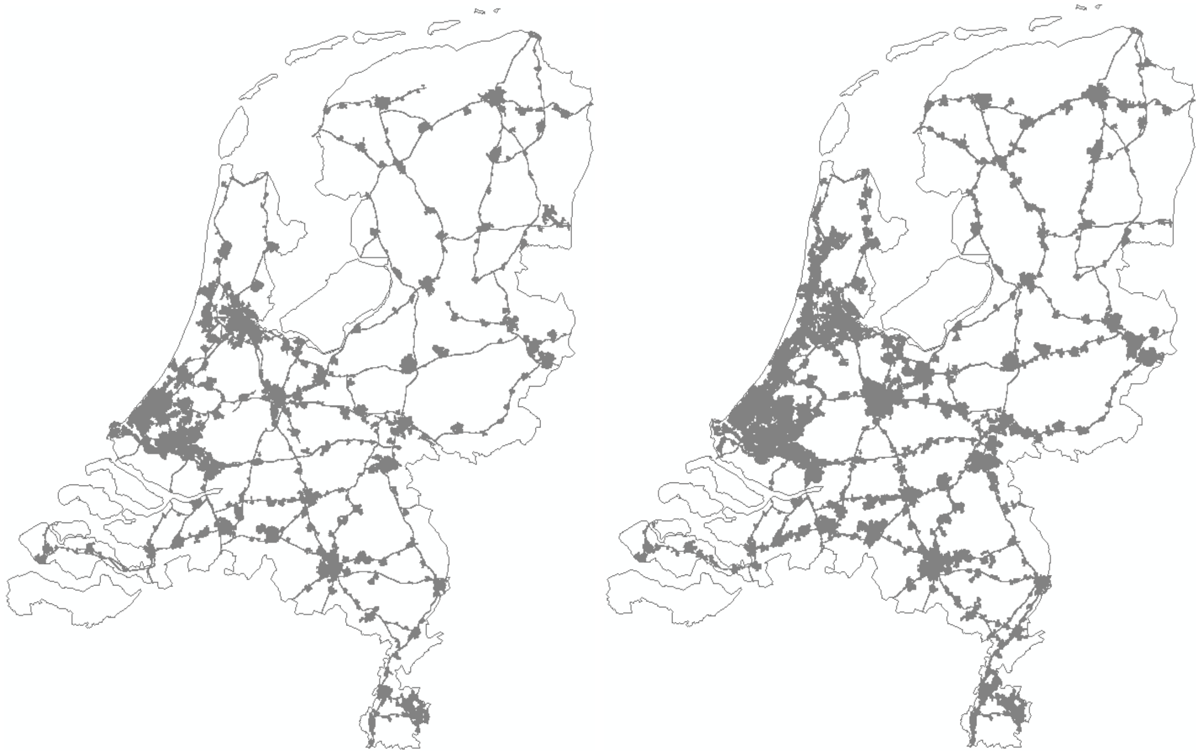

*Figure 11* The 'urban-infra' frame work in 2000 and 2040

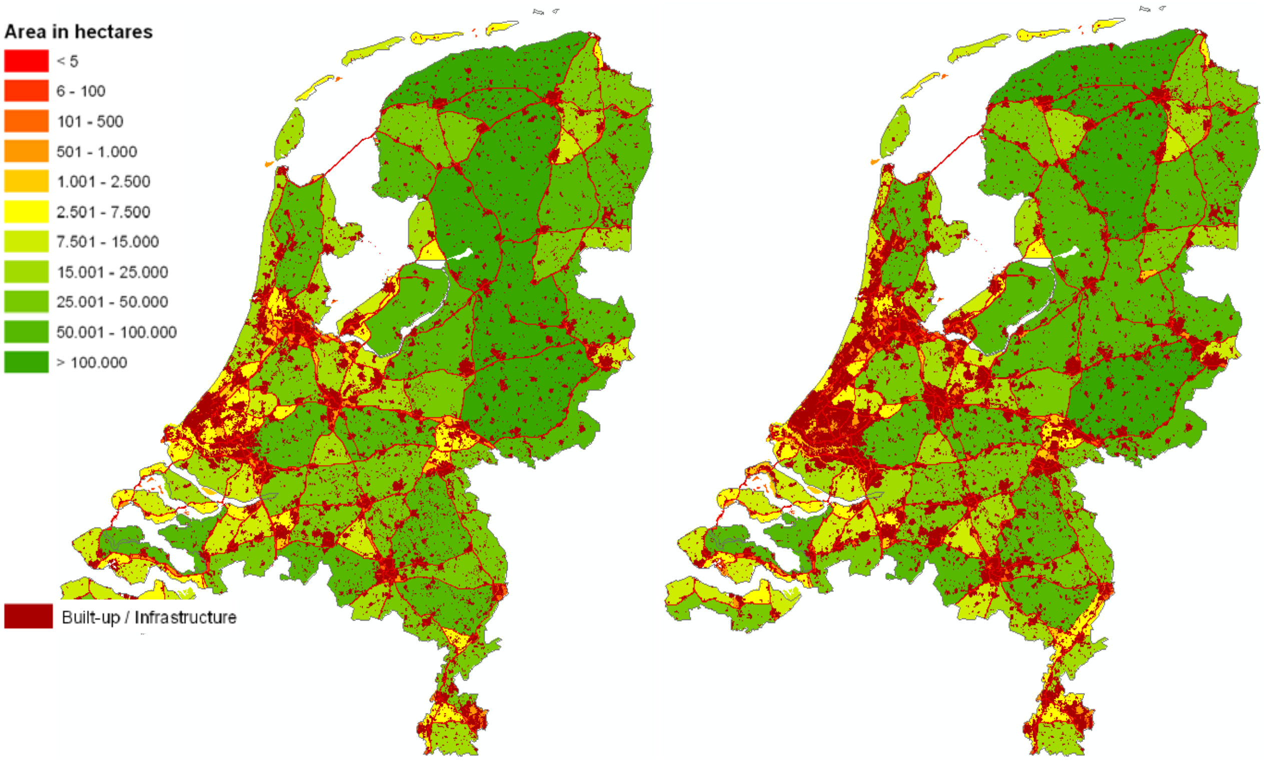


*Figure 12* Open spaces in 2000 (left) and 2040 (right) classified in 11 classes according to a manual adjustment of the natural breaks classification

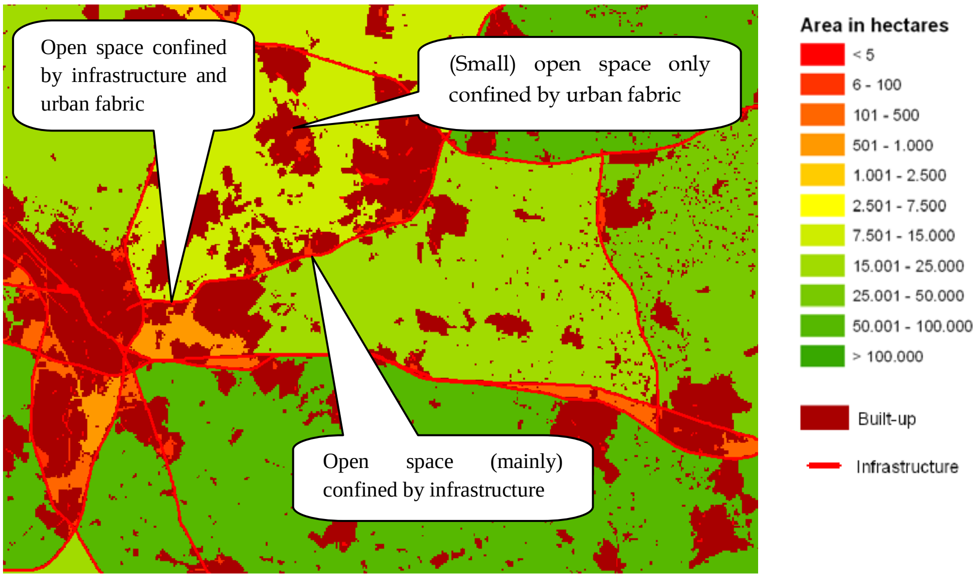


*Figure 13* Different size classes of open space confined by infrastructure and urban fabric

In Table 4 and Figure 14 open spaces are classified according to their size class. The distribution shows that the majority of spatial units are between one and five hectares cells large. These are typical the open spaces that are enclosed in the urban fabric or between urban fabric and road infrastructure. The larger open spaces are almost completely determined by the areas confined by the highways and partly by extensive built-up areas.

Changes in open space

The figures in Table 4 show an increase between the years 2000 and 2040 in the number of open spaces for most size classes, and a decrease of the average size of open spaces, indicating the fragmentation of larger open space units into smaller ones. In some size classes the average size increases, depending upon the balance between the spillover from larger fragmenting open spaces and loss of open spaces through fragmentation to smaller size classes.

*Table 4* Number of open space units per area class

| Size class | Unit size in hectares | Number open spaces 2000 | Average size / sum area 2000 | Number open spaces 2040 | Average size / sum area 2040 |
|---|---|---|---|---|---|
| 1 | <= 5 | 5.521 | 1,59 / 8.763 | 7.932 | 1,55 / 12.279 |
| 2 | 6-100 | 777 | 19,2 / 14.895 | 1.112 | 18,9 / 21.004 |
| 3 | 101-500 | 87 | 211 / 18.323 | 132 | 220 / 29.065 |
| 4 | 501-1.000 | 22 | 742 / 16.323 | 27 | 768 / 20.737 |
| 5 | 1.001-2.500 | 16 | 1.476 / 23.619 | 19 | 1.419 / 26.953 |
| 6 | 2.501-7.500 | 32 | 4.729 / 151.338 | 30 | 4.136 / 124.085 |
| 7 | 7.501-15.000 | 17 | 11.133 / 189.265 | 21 | 10.605 / 222.716 |
| 8 | 15.001-25.000 | 16 | 19.180 / 306.894 | 17 | 19.356 / 329.046 |
| 9 | 25.001-50.000 | 19 | 32.857 / 624.292 | 14 | 33.117 / 463.634 |
| 10 | 50.001-100.000 | 14 | 64.108 / 897.516 | 17 | 63.848 / 1.085.417 |
| 11 | > 100.000 | 5 | 143.22 / 716.121 | 3 | 152.757 / 458.271 |
| | **Total** | 6.525 | 455 / 2.967.349[7] | 9.323 | 300 / 2.793.207[7] |

[7] Note that this summed area is different (smaller) from the total open space in the Netherlands in 2000 and 2040 calculated in

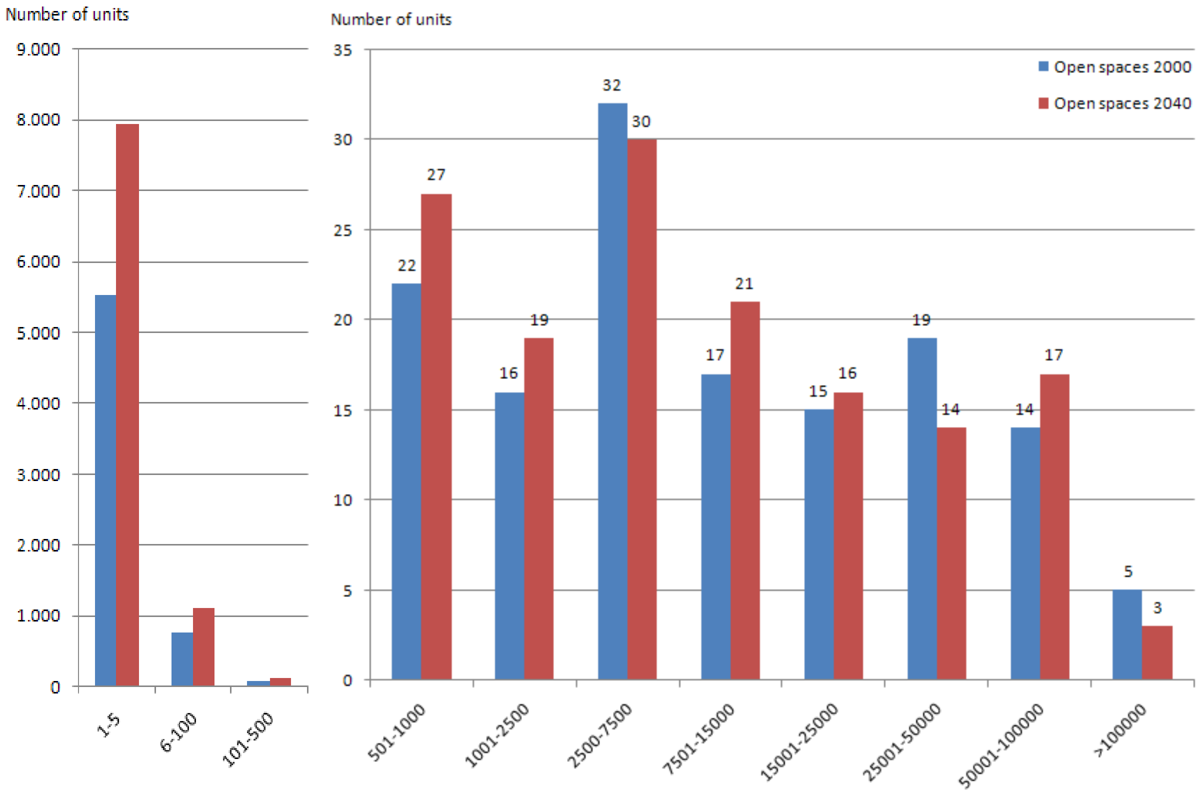


*Figure 14* Number of open space units per sizeclass in 2000 and 2040

The number of open spaces between 50.000 and 100.000 hectares shows an increasing trend, which is clearly the result of the breaking up of two of the largest open space units (size classes > 100.000 hectares) into more smaller ones. In the same way the breaking up of the large open spaces between 25.000 and 50.000 hectares results in an increase in the number of open spaces in all underlying smaller size classes (apart size class 2.500-7.500 hectares).

Changes in built-up space

In the same manner we can also evaluate if we find comparable size changes for small isolated patches of built-up land use, which can be considered an indication of more dispersed c.q. less compact urban development. We applied the 4 gridcells neighborhood rule to define separate units of built-up space, implying that the gridcells in diagonal lines of 1 gridcell wide are considered to be separate units of built-up space.

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Table 3 of chapter 6 (based on the land use grids osgg2000 and osggw2040), because this calculation is based on the adapted land use grids osgg00_1 and osgg40_1, which are both a combination of a grid representation of the selected major roads in the Netherlands (mjr_rds_1_0) and respectively osgg2000 and osggw2040.

To prevent the formation of very large connected areas of built-up land use, we decided to exclude infrastructure[8] from the definition of built-up area in both 2000 and 2040. The consequense of this choice is that large cities and urban regions are split up in different sections dissected by the major infrastructure.

The figures in Table 5 show an increase of the number and area of both the smallest 1 hectare units and the larger built-up units between 100 and 7.500 hectares. In general, the total change in the number of built-up area units is small (+ 3%) , but the area growth is rather large (+ 32%), while he average unit size increases from 25,3 to 32,4 hectares. If we look at the change map of built-up area 2000-2040 in Figure 15 we see indeed that most new built-up area is added as an extension of already existing built-up area. In fact, a 'select by location' query in GIS shows that there are no built-up spaces in 2040 that do not have spatial intersection with built-up spaces that already existed in 2000. In other words, the land use model did not allocate any new isolated built-up space. Most striking is the formation of two very large built-up units between 15000 and 25000 hectares in the coastal area between Rotterdam and Haarlem by the connection of already existing units of built-up area.

*Table 5* Number and area of small isolated patches of built-up space

| Unit size in hectares | Number 2000 | Average size / sum area 2000 | Number 2040 | Average size / sum area 2040 | % change number | % change area |
|---|---|---|---|---|---|---|
| 1 | 7437 | 1,0 / 7437 | 9577 | 1,0 / 9577 | 28,8 | 28,8 |
| 2 | 3220 | 2,0 / 6440 | 2504 | 2,0 / 5008 | -22,2 | -22,2 |
| 3 | 1706 | 3,0 / 5118 | 1155 | 3,0 / 3465 | -32,3 | -32,3 |
| 4 | 1079 | 4,0 / 4316 | 795 | 4,0 / 3180 | -26,3 | -26,3 |
| 5 | 672 | 5,0 / 3360 | 500 | 5,0 / 2500 | -25,6 | -25,6 |
| 1-5 | 14114 | 1,9 / 26671 | 14531 | 1,6 / 23730 | 3,0 | -11,0 |
| 6-100 | 3784 | 23,0 / 87108 | 3759 | 24,3 / 91481 | -0,7 | 5,0 |
| 101-500 | 562 | 218 / 22515 | 668 | 216 / 144534 | 18,9 | 18,0 |
| 501-1000 | 109 | 712 / 77559 | 130 | 699 / 90833 | 19,3 | 17,1 |
| 1001-2500 | 73 | 1547 / 112958 | 92 | 1515 / 139379 | 26,0 | 23,4 |
| 2500-7500 | 8 | 3945 / 31560 | 25 | 3769 / 94218 | 212,5 | 198,5 |
| 7501-15000 | 1 | 13590 / 13590 | 0 | 0 | -100,0 | -100,0 |
| 15000-25000 | 0 | 0 | 2 | 19098 / 38196 | - | - |
| > 25000 | 0 | 0 | 0 | 0 | - | - |
| **Total** | 18651 | 25,3 / 471961 | 19207 | 32,4 / 622371 | 3,0 | 31,9 |

[8] On the basis of raster majorinfra2_0, see further the ArcGIS model 'Size-of-open-space-new2mei2011'

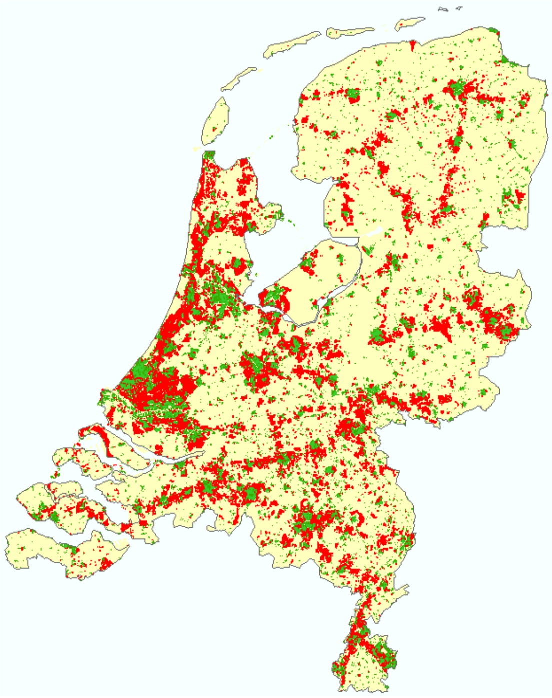


*Figure 15* In red the added built-up area between 2000 and 2040

Discussion

Although the general trend in the extension of built-up area and the fragmentation of open spaces makes sense, a part of the results might be explained by methodological differences between the derivation of the land use of 2000 and the simulated land use of 2040, especially for the smaller units. We expect however that infrastructure has the biggest influence on the formation of the larger open space units. By using the additional infrastructure layer the most important differences caused by the unequal representation of infrastructure on the Land Use Scanner maps of 2000 and 2040 should have been avoided.

Because roads and highways are difficult to model in land use models the open space size indicator is of limited use for evaluating the effects of longitudinal land use changes on open spaces in the future. However, because the highway network is in general not subject to fast changes, the indicator is useful as a base indicator for other indicators, such as the degree of openness which depend on the size of openness (see next section). Further, it is a useful indicator to make comparisons between different areas, e.g. provinces.

Other issues with this indicator are its lack of sensitivity for the visual impact of built-up land use classes on open space. As long as two open spaces connect through a single grid cell of 100 by 100 meters the open spaces are considered as one space while from a visual perspective the narrow connection will divide the space in two parts. The practical value of this indicator is its indication for the total amount of open space available for spatial developments within practical units of space.

## 7.2 *Degree of openness*

The degree of openness depends on the presence of built-up elements in open space. As was described in section 2, these elements can fill the open space until different levels, be distributed in different ways and be concentrated in different clusters or be totally dispersed.

Because we have to deal with different gradations of open space or degrees of openness we need a method that is flexible enough to evaluate different degrees of openness. In studies targeted at urban sprawl, levels of urbanization are usually measured in terms of spatial concentration. A relative straightforward and simple way of evaluating dimensions and changes in open space would be to treat open space simply as the inverse of built-up space. In that way we can evaluate the degree of openness by measuring the spatial concentration of urban built-up space. We should however keep an eye on the relation between built-up and open space, as the specific concentration patterns of built-up space have specific consequences for the dimensions and specific qualities of open spaces. Ritsema van Eck and Koomen (2007) reviewed a number of indicator based methods based on the distinction of measurements of spatial concentration by Johnston et al. (2003): (1) concentration within an area using density gradients, (2) concentrations formed by sets of contiguous areas in which the size and shape of individual urban constellations are important and (3) concentrations formed by the proximity between a set of areas, in which the spatial dispersion of groups of urban areas is studied. The second approach that resembles most patch based landscape ecological approaches (Ritsema van Eck and Koomen, 2007) is most useful for our purposes to measure different degrees of openness and alternations with more built-up areas.

A more simple way of determining the degree of openness of an area, resembling the 1st mentioned indicator based method by Ritsema van Eck and Koomen (2007), is by calculating the ratio between built-up and open land use types. This ratio can apply for the whole of the Netherlands, or within some spatial division on lower scale levels, e.g. provinces or the road units introduced in the previous paragraph. It can however also be the ratio between open and not open land use types within a zone of fixed shape and area (e.g. a circle with certain radius) around a central point that can be calculated for every single gridcell using a moving window analysis. Further, the ratio between units of open and built-up space (resembling the 2nd mentioned indicator based method by Ritsema van Eck and Koomen (2007) can be based on their areas but also on their numbers. Finally, patch size distribution of both open and built-up spaces can further characterize different forms of openness and urbanization and show differences between regions and land use scenarios. We will explore different options for this indicator here.

An initial idea of the degree of openness of an area we get by comparing the number and sizes of open spaces (as has been done in the previous section) with numbers and sizes of built-up elements on a national and a provincial level.

Open space and built-up units are constructed on the basis of a land use map that was reclassified in gridcells of open and built-up land use, updated with the major roads map (and the part of the railway map coinciding with the railway infrastructure in the 2040 maps), that means that major roads are represented by continuous linear sequences of gridcells. Using the region group function in ArcGIS with the four-neighbour rule all individual groups of adjacent open or built-up cells are distinguished[9]. In Table 6 numbers and average sizes of open and built-up spaces are listed for the year 2000 and the 2040 scenario.

*Table 6* Number and average size of open and built-up units for the Netherlands and by province in 2000 and 2040 (Based on output by AGM 'Size of open space')

| **Degree of openness** | **LU 2000** | | | | **LU 2040 W-scenario** | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of open units | Average unit size (ha) | Number of built-up units | Average unit size (ha) | Number of open units | Average unit size (ha) | Number of built-up units | Average unit size (ha) |
| **Netherlands** | 6.534 | 451 | 20.942 | 25,6 | 9.436 | 281 | 19.767 | 35,8 |
| **Provinces** | | | | | | | | |
| Groningen | 351 | 605 | 1128 | 22 | 481 | 431 | 1152 | 26 |
| Friesland | 335 | 968 | 1416 | 18 | 420 | 754 | 1486 | 23 |
| Drenthe | 200 | 1231 | 1151 | 20 | 284 | 842 | 1719 | 17 |
| Overijssel | 368 | 826 | 1889 | 20 | 568 | 514 | 1901 | 26 |
| Flevoland | 261 | 507 | 494 | 29 | 531 | 234 | 667 | 34 |
| Gelderland | 567 | 786 | 3661 | 18 | 914 | 463 | 2415 | 37 |
| Utrecht | 396 | 286 | 790 | 40 | 636 | 155 | 655 | 70 |
| N-Holland | 1069 | 202 | 1645 | 42 | 1516 | 125 | 2181 | 45 |
| Z-Holland | 1348 | 157 | 1630 | 56 | 1486 | 118 | 1012 | 125 |
| Zeeland | 409 | 387 | 1107 | 17 | 469 | 335 | 1268 | 18 |
| N-Brabant | 771 | 533 | 4125 | 22 | 1434 | 270 | 3620 | 31 |
| Limburg | 471 | 376 | 1906 | 23 | 697 | 243 | 1691 | 31 |

On a national level we see between 2000 and 2040 a strong increase in the number of open space units accompanied by a decrease in average are size, while the number of built-up elements is more or less stable, but with a considerable growth in  average unit area. These figures indicate that in general the filling up of open space takes predominantly place by the growth and mutual connection of already existing built-up elements, i.e. a relative compact form of urban growth and not by a dispersed, urban sprawl type of, urban expansion.

On the provincial level the figures in the table show among others that, as expected, the most urbanized provinces North and South Holland also contain the largest numbers of open space units with relative small average areas, which is an indication for a more progressed state of the transformations of open space by fragmentation, attrition and shrinking. The scenario year 2040 shows a similar division with again the highest, further increased numbers of open space units for (particularly) North and South Holland, but also strong increases for Flevoland (over 100 %), Noord-Brabant, Gelderland, Utrecht and Overijssel, all accompanied with strong decreases of average unit sizes. Remarkable though, is that the lowest increase in numbers of open space units is found in South Holland which is attended by a strong decrease in the number of built-up units. This seems to indicate that urban growth takes especially place at the borders of existing urban land use and that isolated urban patches connect to each other to form larger patches while

[9] A flaw in this operation might be that this way also groups of built-up cells are distinguished using the four-neighborhood rule, creating to many groups of built-up cells for for example infrastructure running in diagonal directions over the map. Checking this problem I find that this problem is only true for smaller infrastructure, most highways are represented by contiguous polygons of two gridcells wide. Furthermore, the smaller infrastructure for which this problem applies, is often present in both the 2000 and the 2040 maps, so have minimal effects on the relative changes.

already built-up open spaces diminish further in size. A short look at the land use maps of 2000 and 2040 indeed confirms this spatial process, the coastal cities Rotterdam, The Hague, Leiden and Zoetermeer grow towards each other (for important parts connected through extensive zones of greenhouses) to become one large coalesced urban area.

Also noticeable is that the highest numbers of built-up space units in the table with relative small average area sizes can be found in the provinces of Noord-Brabant, Gelderland and the Northern part of Limburg. If we look at the land use map of 2000 we can see that these figures can be best explained by the high concentrations of intensive livestock farming in these provinces, that consist of small built-up elements (barns) dispersed over the country side.

In Figure 16 and Figure 17 we plotted for respectively the land use in 2000 and the scenario year 2040 the ratio of the number of open and built-up patches against the (normalized) average patch size of open and built-up units.

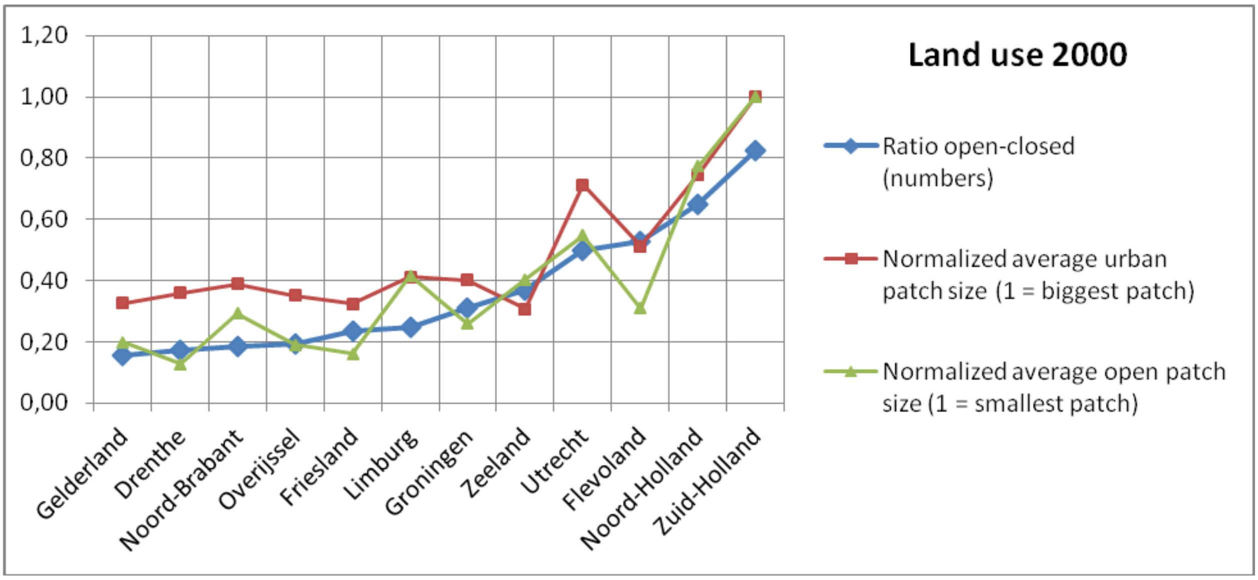



*Figure 16* Ratio of numbers of open and built-up units and normalized average unit sizes in 2000

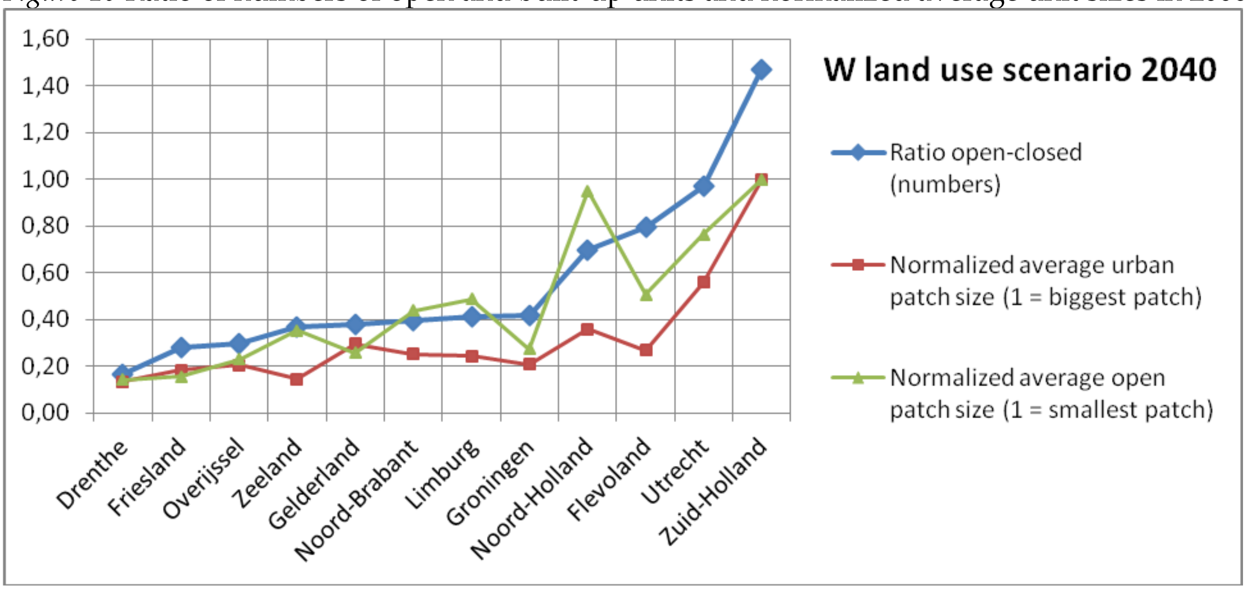



*Figure 17* Ratio of numbers of open and built-up units and normalized average unit sizes in 2040

The figures show that in general that with an increasing ratio between numbers of open and built-up units the open space unit size tends to decrease, while the average area sizes of the built-up elements tend to increase. The figures show also some changes in the rank positions of some provinces in the ratio of numbers of open and built-up units. Zuid-Holland keeps the highest ratio, but North Holland is overtaken by Flevoland and Utrecht. Also Gelderland and Noord-Brabant move to higher places in this ratio ranking. Biggest deviations in the visible trends can be seen for the provinces of Utrecht and Flevoland in 2000. Utrecht shows bigger built-up units and smaller open units than can be expected for its ratio ranking, while Flevoland has clearly larger patches of open space for its ratio ranking in 2000. In 2040 the biggest deviation is found for the province of North Holland that shows particularly small average open unit sizes for its position in the ratio-ranking.

Table 7 gives the ratio between open and built-up spaces based on their areas for the whole of the Netherlands and for the separate provinces in the year 2000 and in the 2040 scenario. The table shows that there are distinct differences between the provinces with the lowest ratios for the provinces of Noord-Holland, Zuid-Holland and Utrecht and the highest ratios for the provinces Friesland and Drenthe in both time periods. The last column in the table gives the percentage of area change, i.e. open space converted into built-up space, between 2000 and 2040 and shows that the least open provinces show also the fasted conversion rates and the most open provinces the slowest rates, with the province of Groningen as an exception with the slowest conversion rate of all. Figure 18 shows the spatial distribution of the ratios of table 5 in two maps for 2000 and 2040.

*Table 7* Degree of openness and area conversion rates for the Netherlands and by province in 2000 and 2040 (Based on output by AGM 'Degree of open space')

| **Degree of openness** (ratio open/built-up) | **LU 2000** | | | **LU 2040 W-scenario** | | | **Conversion rate** |
|---|---|---|---|---|---|---|---|
| | Open (ha) | Built-up (ha) | **Ratio** | Open (ha) | Built-up (ha) | **Ratio** | % area change open→built-up |
| **Netherlands** | 2.993.983 | 513.307 | 5,8 | 2.794.189 | 713.101 | 3,9 | -6,7 % ↓ |
| **Provinces** | | | | | | | |
| Groningen | 213228 | 24015 | 8,9 | 207215 | 29970 | 6,9 | -2,8 ↓ |
| Friesland | 324941 | 24207 | 13,4 | 314956 | 34254 | 9,2 | -3,1 ↓ |
| Drenthe | 246921 | 21080 | 11,7 | 238917 | 29071 | 8,2 | -3,2 ↓ |
| Overijssel | 305343 | 34677 | 8,8 | 291277 | 48730 | 6,0 | -4,6 ↓ |
| Flevoland | 132676 | 13311 | 10,0 | 123556 | 22458 | 5,5 | -6,9 ↓ |
| Gelderland | 448792 | 63223 | 7,1 | 422310 | 89665 | 4,7 | -5,9 ↓ |
| Utrecht | 113648 | 30558 | 3,7 | 98410 | 45787 | 2,2 | -13,4 ↓ |
| Noord-Holland | 218019 | 66653 | 3,3 | 186852 | 97828 | 1,9 | -14,3 ↓ |
| Zuid-Holland | 212842 | 89062 | 2,4 | 175133 | 126808 | 1,4 | -17,7 ↓ |
| Zeeland | 159857 | 17307 | 9,2 | 154301 | 22893 | 6,7 | -3,5 ↓ |
| Noord-Brabant | 414475 | 85540 | 4,9 | 386179 | 113816 | 3,4 | -6,8 ↓ |
| Limburg | 178462 | 42156 | 4,2 | 169281 | 51274 | 3,3 | -5,1 ↓ |

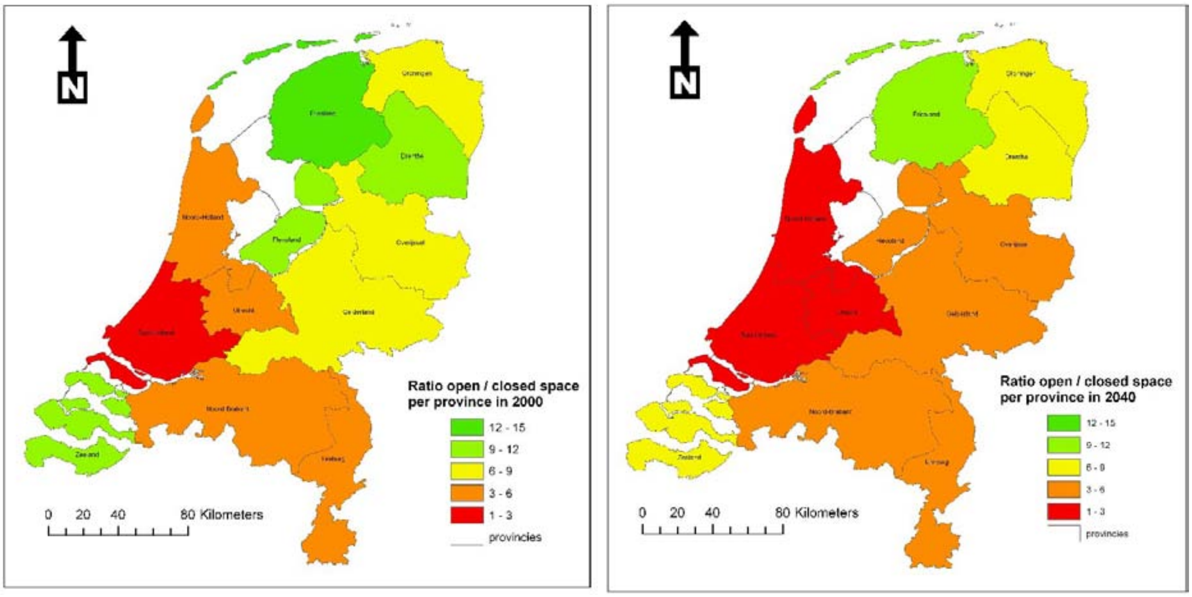



*Figure 18* Spatial distribution of ratios open / built-up space per province in 2000 and 2040 Source: AMD: Degree_of_open_space.mxd, Layernames: 2000 Provinces/Ra_OSURprov and 2040 Provinces/RaOSURprv40.

Although both table and maps demonstrate distinct differences between openness for the different provinces they give little spatial information about patterns and changes on larger map scale levels. Therefore we mapped the ratios between open and built-up space also on the larger scale level of the major road units that were introduced in section 7.1. The resulting maps displayed in Figure 19 show a pattern in which the area with the lowest degree of openness seems to run in a broad northwest to southeast orientated belt over the Netherlands.

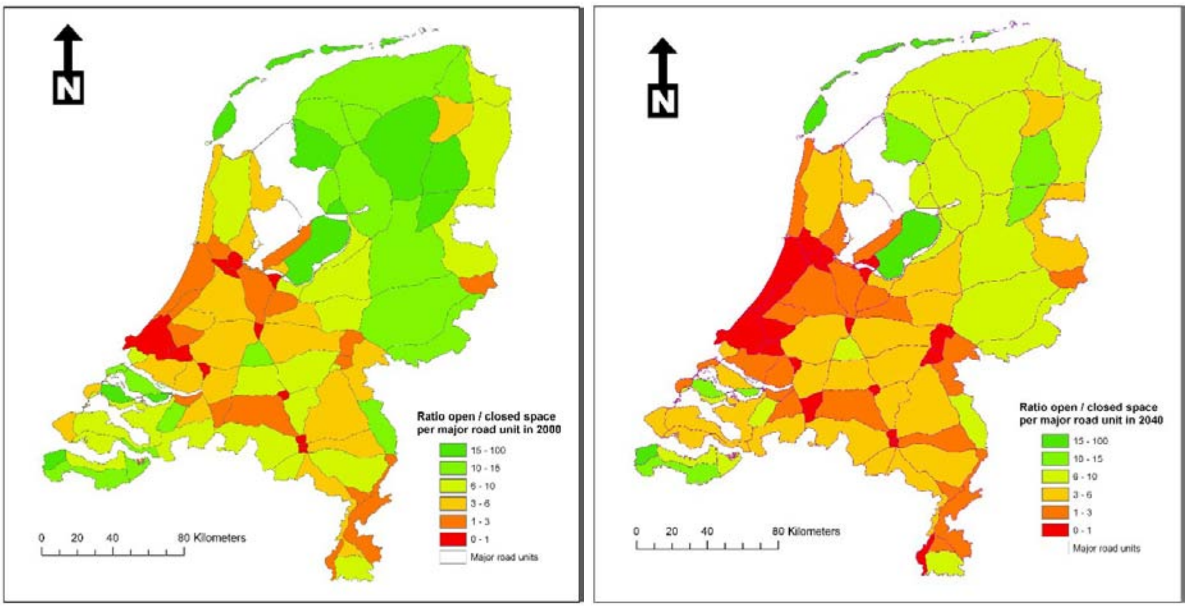



*Figure 19* Distribution of ratios open / built-up space per major road unit in 2000 and 2040. Source: AMD: Degree_of_open_space.mxd, Layernames: Road units 2000/Ra_OSURrdu00 and Road units 2040/ Ra_OSURrdu40.

At first sight it seems that dividing areas in degree of openness on the basis of the major road network works out fine. Major infrastructure is known to be both following and promoting urban development. Less known is about the way major infrastructure affects the division (e.g. in different development speeds) and fragmentation of land use and open space. The spatial patterns on the map certainly suggest some kind of ordering principle related to the physical and visual barrier that especially highways create in the landscape. Even though this approach seems to give appealing results it can give false impressions of openness because the calculated values concern summarized values. In several major road units built-up land use classes are mainly concentrated near or along the highways, while closer to the unit center the share of open land use can be very high, a fact which is masked because values are summarized over the whole unit. This summarizing effect can be prevented by choosing units that exclude urban areas that are connected to the unit borders. This implies that we differentiate between non open land uses that divide/fragment open space in different units (including the dividing urban land uses) and non open land uses (residential houses, industrial farm-buildings, roads) that 'perforate' open space (by analogy with the term used by Foreman, 1995, to indicate the opposite, the perforation of forested areas by non-green land use) . The maps in Figure 20 show the resulting ratios of this exclusion. Obviously, the ratio has increased considerably in all road units, but it also shows that a big share of the urban land uses is connected to the major roads and that the remaining area is relatively open, with a ratio comparable to road units in the North East of the Netherlands. This points to a relatively large compactness of the non open areas.

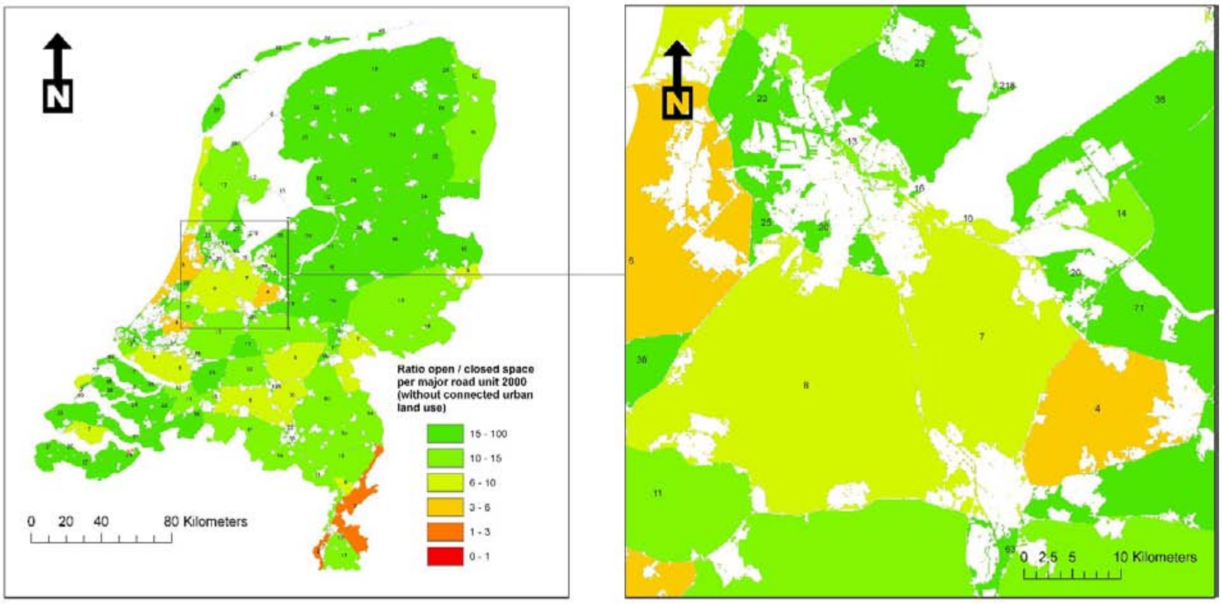



*Figure 20* Distribution of ratios open / built-up space per major road unit without connected urban land uses in 2000 for the Netherlands (left) and zoomed in to region around Amsterdam (right). Sources: AMD = Degree_of_open_space.mxt; Layername: Roadunits 2000 without urban borders /raosurrduw00

What these analyses show in particular is that the degree of openness is very sensible to the chosen reference units.

To prevent influences on the degree of openness of particular non uniform sizes and shapes of the reference units chosen, we can follow a more objective approach using gridcell based neighbourhood analysis. In such an approach degree of openness is determined by summing the area of open or non-open land uses within a fixed radius around each location (=gridcell) on the map, using a moving window neighbourhood analysis.

We explored circular neighbourhoods with three different radii, of 1500, 2000 and 2500 meters. These distances refer roughly to distances that are considered for visual impact (e.g. see for 1500 meter Veeneklaas, 2006 and for 2500 meter Roos-Klein Lankhorst, 2004).

In Figure 21 the summed area of non open land use in a circular search radius of 2500 meter is displayed for the years 2000 and 2040. What is particular clear from these maps is the high spatial correlation between the concentrations of non-open land use and the major road network especially around the road junctions. The maps confirm also the image sketched earlier that most of the areas outside the visible concentrations of non open land use have quite high degrees of openness.

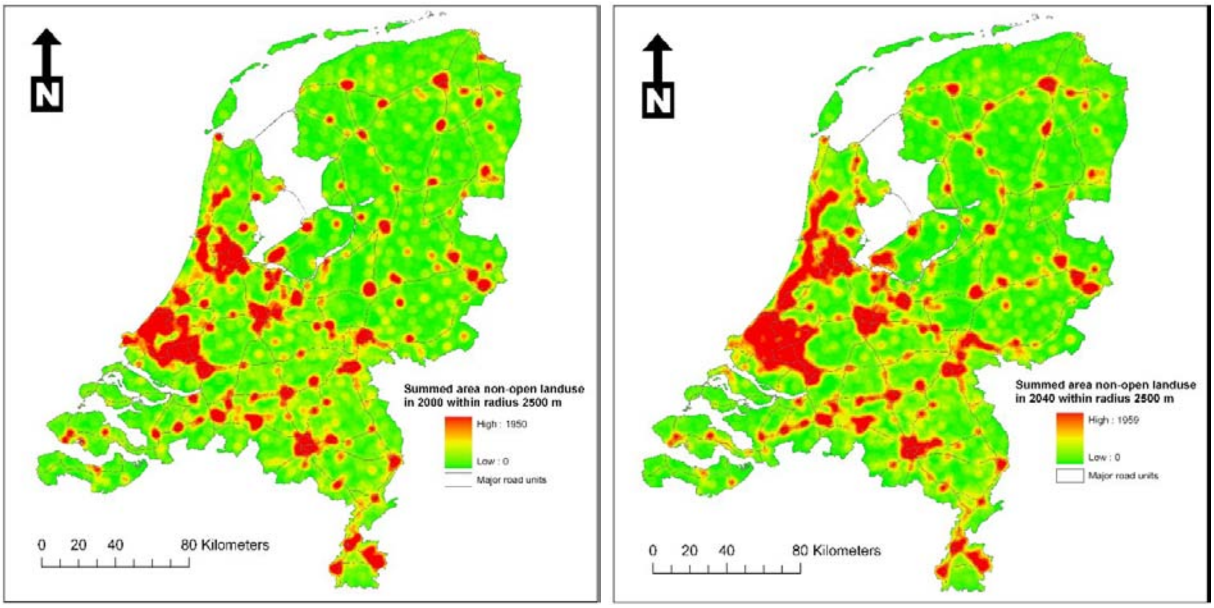



*Figure 21* Summed non-open land use in radius of 2500 meters for 2000 (left) and 2040 (right)

A disadvantage of this neighbourhood based method is that it doesn't lead to clearly confined and discrete open spaces. In other words, you cannot point out an area and state its degree of openness. The visible patterns on the map can only indicate where there is more and where there is less open space available in a circular neighbourhood of specified distance. The results can however be reclassified to a limited number of classes to derive a map with different zones of available open space.

In this way we produced a map with 7 classes of open space availability from built-up to very open (with class borders laid at 1, 5, 12.5, 25, 50 and 75% of non open land use in the total area of the radius). Figure 22 shows the reclassified map for the year 2000, based on a 1500 meter neighbourhood radius. Because we consider the major roads as non open land use that divides different stretches of open space it is important they are represented well in the rasterized land use maps. Therefore we have forced them upon the land use model maps as lines of connected gridcells of 1 or 2 cells wide (depending on the road orientation.)

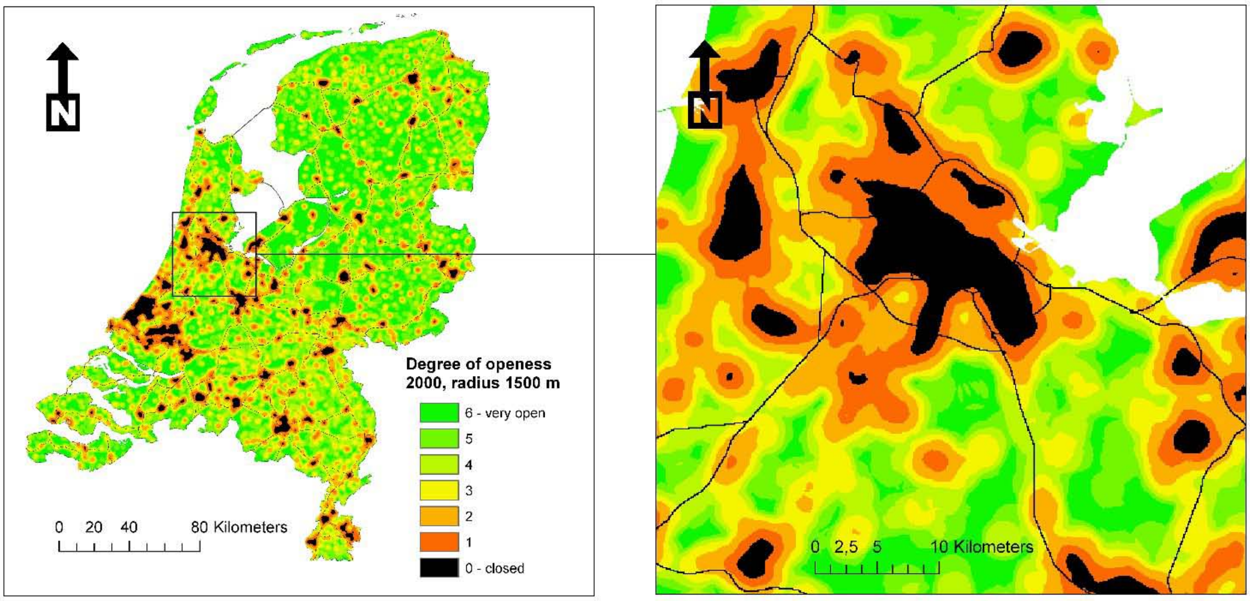



*Figure 22* Degree of openness in 2000 based on reclassified summed non-open land use in radius of 1500 meters

Because this method works with neighbourhoods the pattern of non open and open land uses directly influences the degree of openness of a location. This principle is illustrated in Figure 23. While built-up areas within the urban fabric of the city are classified as hardly open (class 1), the open areas within the urban fabric are classified as built-up areas, because of the domination of surrounding non open land use.

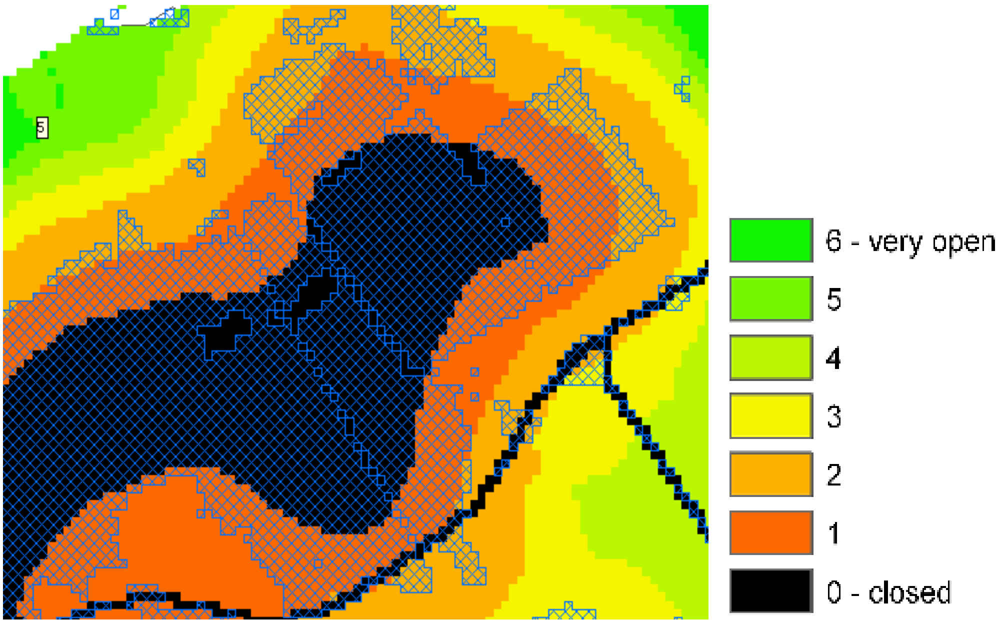



*Figure 23* Degree of openness overlayed with contour of urban area (crosshatched area)

We conclude that the degree of openness can be measured in different ways and that shape and scale of measurement units can have profound influence on the results. Degree of openness can be used as a general indicator for evaluating changes in openness and in combination with other indicators. For more specific policy related uses and scale levels it should be applied with great care.

# 8. Functional spatial configuration metrics

## *8.1 Landscape cluttering*

### 8.1.1 Introduction

The visual quality of open space is particularly important for its perceived aesthetical values that can influence the mental health of its users. Indirectly it is also important for the recreational value of open space, as visually attractive open space generates stronger recreational activity, influencing both the mental and physical health of its users. Although there are common values at a universal human level regarding degree and scale of openness (Fry et al., 2009), the visual quality of open space remains a subject with a highly subjective nature. It is therefore that we do not attempt to capture aesthetical qualities on the basis of type, composition and patterns of land use, but that we focus on land use elements and compositions that might negatively affect existing visual qualities. This refers to the concept of landscape cluttering which is further explained here below. The followed approach assumes that there is a certain background value of open space that is mainly dependent on the degree of openness and specific land use composition and disregards many other factors influencing the visual perception of open space, such as the presence of recognizable elements and landscape patterns of cultural-historical value or patterns and shapes of geomorphologic value. These values are however captured in separate (change) indicators describing the cultural-historical and geomorphologic values of open landscapes (see section 8.3.1).

### 8.1.2 Definition of landscape cluttering

One important aspect that explains the visual quality of open spaces as perceived by humans is the degree of landscape cluttering. Although not a typical Dutch phenomenon, the term itself and the attention for the phenomenon in Dutch spatial policy and the public debate are. Until recently few attempts have been made to clearly define the term landscape cluttering and to measure its spatial dimensions. An extensive but useful definition of landscape cluttering is given by Veeneklaas et al. (2006):

*"Landscape clutter is an intrusive increase in the level of variety in a landscape, combined with a lack of coherence. People experience variety as pleasant as long as it is limited to diversity within an appropriate pattern. Clutter is variety that does not suit the landscape, as well as the presence of elements perceived as intrusive. The process of cluttering expresses itself in a cluttered landscape, i.e., an area which makes an overall disorderly impression and where various land use exist side by side without clear coherence and/or where many intrusive elements can be seen.*
*Cluttering is a process perceived as unintentional, creeping, that is, as the unintended outcome of different people trying to pursue different interests, rather than as the outcome of a well-defined plan or design. It is associated with neglect, degradation, untidiness and a general lack of concern for the quality of public spaces."*

According to the research of Veeneklaas et al. (2006) that was validated on the basis of expert field observations, the perceived degree of cluttering is directly dependent on the number and clustering of both green and artificial elements and their visual impact. The perception of cluttering is further influenced by:

- the land use diversity. The more divers landscapes are in terms of user function the higher the probabibilityis that they are experienced as cluttered. Considered land use functions to measure land use diversity are agriculture (and internal diversity), housing, recreation, non-agricultural activity, public services and infrastructure (see further indicator land use diversity of open space)

- the degree of openness of landscapes: the more open landscapes are, the more they are considered sensitive for the impact of cluttering

Van der Wulp (2009) elaborated further on the work of Veeneklaas et al. (2006) by exploring more land use categories that can potentially increase landscape cluttering and by evaluating them by the general public. This research confirmed the earlier work of Veeneklaas et al. (2006), but with more detail and with a more extensive scientific foundation.

In the subsequent paragraphs each of the influence factors described above is explained in more detail, followed by its way of implementation.

### 8.1.3 Visual impact and distance of cluttering elements to its observers

One of the questions considering visual impact is which and where possible observers of open spaces are located. We consider all human observers that can experience the open space. Although the highest number of observers will probably view the open space from its edges or dissection corridors (e.g. from the train or from a major road), we also consider other observation points such as footpaths, local roads and bicycle lanes. Considering the dense road networks in the Netherlands this means in practice any location. As we have to base our analysis completely on spatial analysis of land use maps we will have to conceptualize visual impacts of clustered elements in open space based on interpretation of land use classes from different distances. The premise used here is that the visual disturbance (and possibly other forms of disturbance, noise, smell, light, etc) of an non open land use class stretches further than its exact physical limits. This influence can be accounted for in our model through a weighted moving average. The use of this technique for spatial analysis has amongst others been described by Burrough and McDonell (1998). This method computes a distance-weighted average for a group of data-points. By applying a moving window analysis we can simulate the visual impact of clustered elements on the map, because for each possible location from which the landscape can be observed the visual impact of nearby elements is summed within each moving area of visual impact (radius 1500 meter: Veeneklaas, 2006 or 2500 meters: Roos-Klein Lankhorst, 2004) and is weighted with their visual impact (based on land use class).

Impact weights are, as far as possible, based on the visual impact ranking of disturbing elements in the research of Van der Wulp (2009), see Figure 24. From the classes distinguished in Figure 24 the three classes with the highest impact can be distinguished separately from our datasets (note however the limitations in the use of the land use class infrastructure here below). Also the least impacting class detached houses can be approximated by choosing the classes residential – rural and residential low density. Further, the class high-rise buildings can be approximated with the choice for the class residential high density.

The remaining classes are either point objects as windmills and transmission towers or recreational classes. The point objects are not represented in the land use model dataset and can also not be approximated any other way (apart from adding extra data layers, which makes no sense as the models applied lack mechanisms to simulate these land use classes.
The recreational classes, riding schools and golf courses, can however be approximated with the choice for the land use class recreation, which includes different types of recreation a.o. sport

facilities. That this class also includes other categories of recreation (campings, allotments, amusement parks, zoo's, playgrounds and so on) we don't see as an objection, in the first place because not all possible categories of disturbance have been investigated by Van der Wulp et al. (2009) and secondly because intuitively can be felt that none of these classes can be expected to have a positive contribution on the landscape experience.

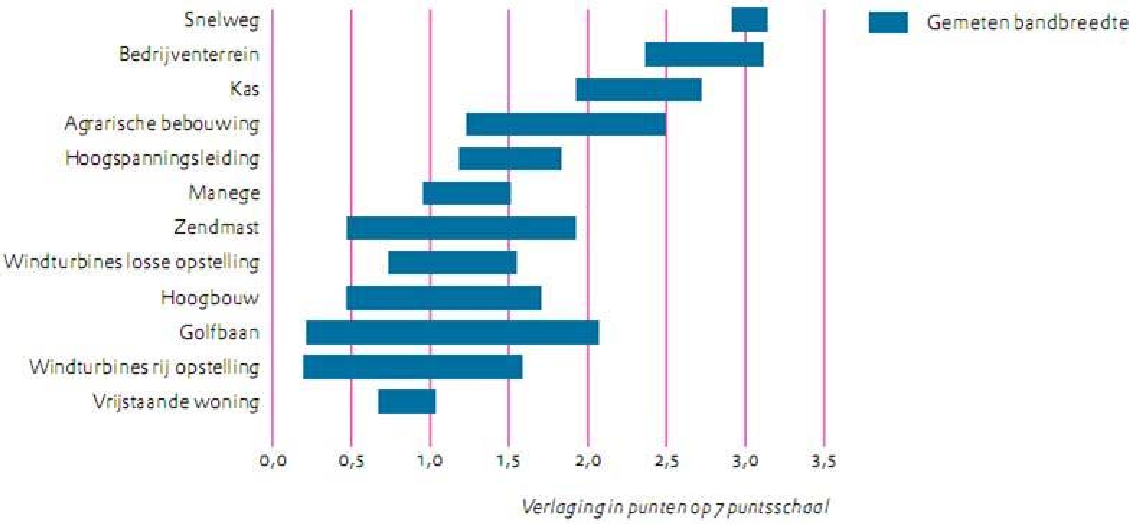



*Figure 24* Impact of different types of disturbing elements on landscape appreciation (Source: Van der Wulp, 2009)

Following the relative differences in impact scores between the different disturbing elements we assigned the following weights to the land use classes listed below in
Table *8*.

*Table 8* Assigned weights for different categories of visual disturbing land use

| **Land use** | **Weight** | **Example** | **Land use** | **Weight** | **Example** |
|---|---|---|---|---|---|
| Infrastructure - Highway | 5 |  | Recreation | 3 |  |
| Commercial | 4.5 |  | Residential – high density | 2.5 |  |
| Greenhouses | 3.5 |  | Residential (low density and rural) | 1.5 |  |
| Intensive livestock farming | 3 |  | Bio fuel crops | 1 |  |

High vegetation, although presented in the research of Veeneklaas et al. (2006), as contributing to visual cluttering, is not included in the above list of disturbing elements because this class (which can also decrease cluttering by camouflaging more disturbing objects) cannot be distinguished separately in our basis dataset. Instead we included a separate class of high vegetation, that of biofuel crops. This extra class is however not added in the principal testing of this indicator, but only as a separate study to test the usability of this indicator for the evaluation of open space landscape effects of large scale cultivation of biofuel crops.

To take into account the effect of distance between observer and the observed we tested two different simple distance decay functions incorporated in the applied neighbourhood analysis to account for respectively progressive and more gradual lowering of visual impact on larger viewing distances up to 2500 meter. By employing distance decay in the weighted focal sum neighbourhood function the extra visual impact of clustered objects is better simulated, as grouped objects with short mutual distances will result in higher average impact values. The result is an intuitive map in which the visual impact of disturbing elements is expressed by their spatial extension and colour gradients.

The distance decay functions are implemented as a custom neighbourhood within the focal statistics neighbourhood function using a user-defined file, called a 'Weight Kernel file'. We constructed a Kernel file in which the value of every cell position is determined by its distance to the central cell, which is the number of cells times 100 meter for the perpendicular cells and according to the Pythagoras based distance for the diagonal cells.

For the progressive function were we want to have the highest values for the cells close to the central cell, thus a stronger distance effect at close range, we took the inverse Pythagoras based distance values and multiplied these by thousand to get integer values.

Weight = 1000 * (1/(SQRT((Xdis)2+(Ydis)2)))

In Figure 25 (left) the resulting cell values are indicated (until a distance of 500 meters around the central cell) and (right) the distance decay curve for a maximum distance of 2500 meters.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 141 | 156 | 171 | 186 | 196 | 200 | 196 | 186 | 171 | 156 | 141 |
| 156 | 177 | 200 | 224 | 243 | 250 | 243 | 224 | 200 | 177 | 156 |
| 171 | 200 | 236 | 277 | 316 | 333 | 316 | 277 | 236 | 200 | 171 |
| 186 | 224 | 277 | 354 | 447 | 500 | 447 | 354 | 277 | 224 | 186 |
| 196 | 243 | 316 | 447 | 707 | 1000 | 707 | 447 | 316 | 243 | 196 |
| 200 | 250 | 333 | 500 | 1000 | 0 | 1000 | 500 | 333 | 250 | 200 |
| 196 | 243 | 316 | 447 | 707 | 1000 | 707 | 447 | 316 | 243 | 196 |
| 186 | 224 | 277 | 354 | 447 | 500 | 447 | 354 | 277 | 224 | 186 |
| 171 | 200 | 236 | 277 | 316 | 333 | 316 | 277 | 236 | 200 | 171 |
| 156 | 177 | 200 | 224 | 243 | 250 | 243 | 224 | 200 | 177 | 156 |
| 141 | 156 | 171 | 186 | 196 | 200 | 196 | 186 | 171 | 156 | 141 |

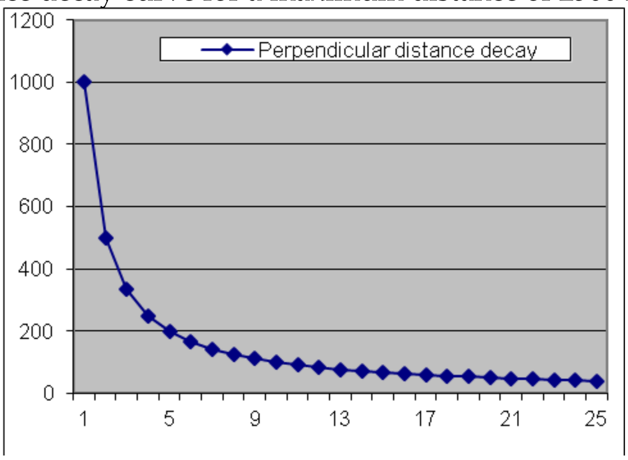



*Figure 25* Cell values (left) and distance decay curve (right)

To make the procedure easier it is also possible to produce first an Euclidian distance grid of the right dimensions with ArcGIS and modify it using map algebra ((1 / Eucdistance grid) * 10000)).

This produces a grid (eudis2500inv) with values between 0 and 100[10]. Next the grid is converted into an ASCII grid named eudis2500_inv100.txt (with some small modifications, rounding and removing NODATA values) that can be read as a Kernel file in the focal statistics function. The result is named 'clut25suminv' and displayed in Figure 26.

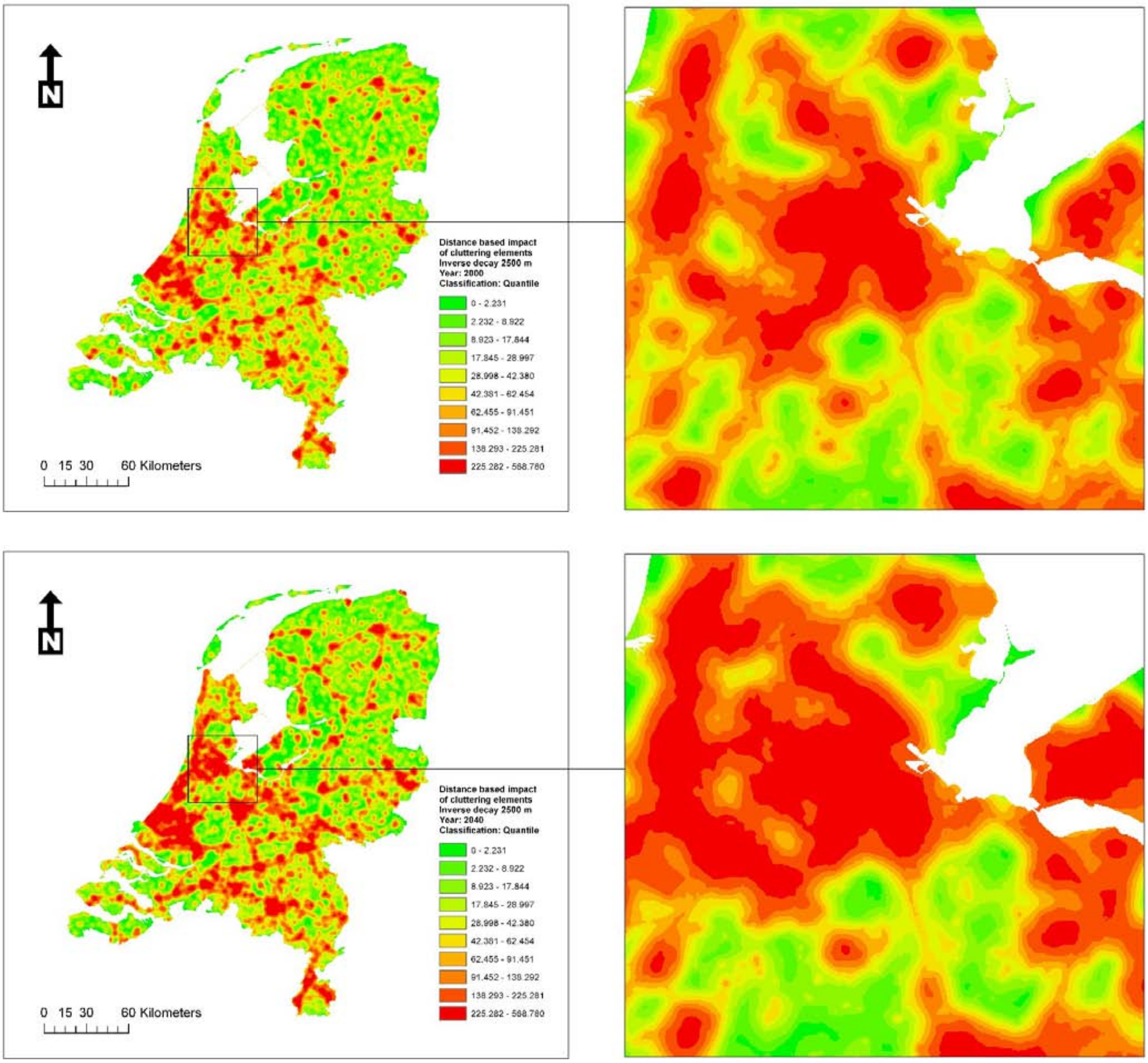



*Figure 26* Distance based impact of cluttering elements, inverse decay 2500 m, year 2000 (above), 2040 (below) classification: quantile

[10] See ArcGIS Model builder model 'make-Kernel-function.tbx'

For the gradual decay we followed the same procedure but used a simple linear function:

Y = (-x + 2500) / 25

This procedure also results in a grid weighting values between 0 and 100, named 'clut25sumlin' and displayed in Figure 27.

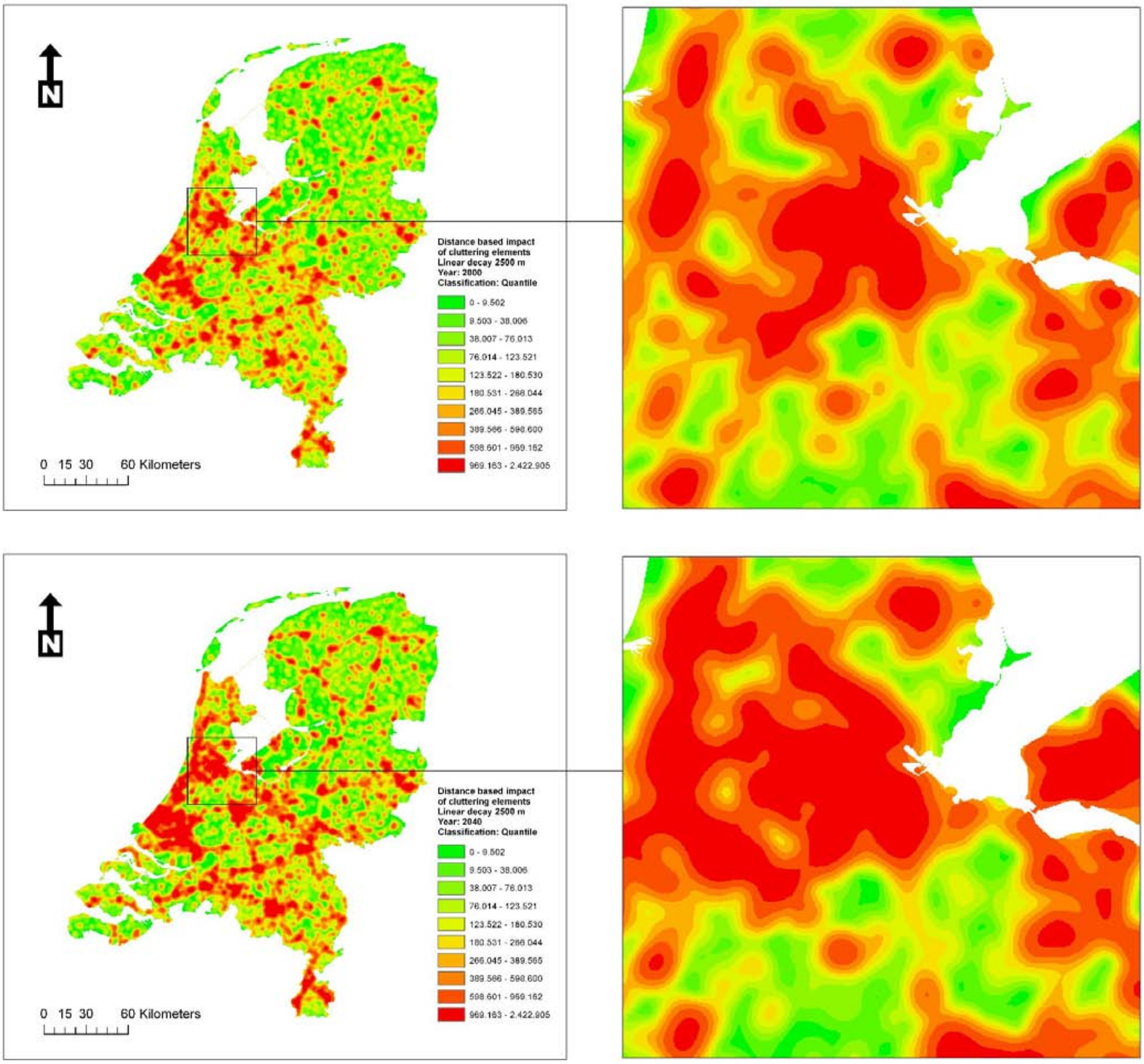



*Figure 27* Distance based impact of cluttering elements, linear decay 2500 m, year 2000 (above), 2040 (below), classification: quantile

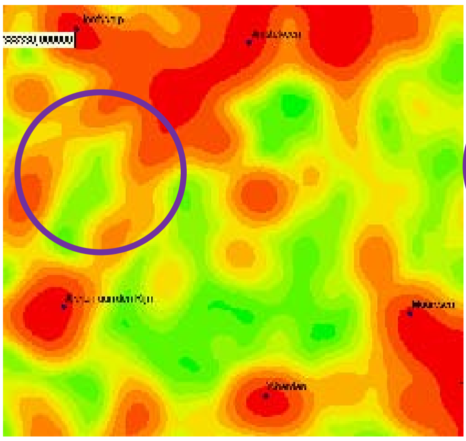
Comparing the two figures we conclude that the result based on the inverse distance decay gives a more pronounced image that better reflects the visual impacts of the most disturbing elements. On the other hand the more smooth images produced by the linear distance decay make the comparison between 2000 and 2040 easier. Figure 27 shows for example very clearly that the already urban areas that are represented with the highest disturbance rates in the map of 2000 have extended considerably in 2040, while some of the cluttered zones within the open spaces (e.g.

South of Amsterdam) show up weaker in the 2040 map. As urban sprawl is anticipated in the applied W-scenario and subsidies for the preservation of the characteristic values of the agricultural landscape are unlikely (Riedijk et al., 2007, pp.32-33) a decrease of openness is expected as the general trend in this scenario. Therefore an increase of openness instead, could be interpreted as an indication of weaker representation by the land use model of some of the smaller (in area size) land use classes in 2040. However, if we look at the growth percentages of the different clutter classes in Table 9 we don't find a clear confirmation of this expectation, as a majority of the land use classes (residential, recreation and greenhouses) show an increase in patch numbers and, less often, a decrease in patch size. This would imply that the increases in patch numbers of these classes take place in a different or much more concentrated way than they did before, e.g. in the already cluttered city edges.

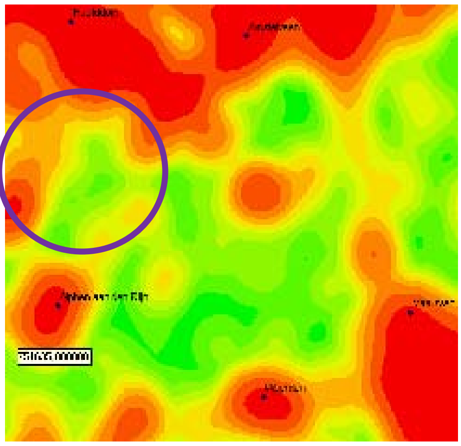
*Table 9* Area per cluttering land use type in 2000 and 2040

| Land use type | 2000 | 2040 | % area increase | % change Number of patches | % change Average patch size |
|---|---|---|---|---|---|
| 0 - Residential – high density | 96929 | 134058 | 38,3 | 127,9 | -39,4 |
| 1 - Residential – low density | 196766 | 242290 | 23,1 | 15,3 | 6,7 |
| 2 – Residential – rural | 31468 | 94840 | 201,4 | 122,8 | 35,2 |
| 3 – Recreation | 31180 | 48878 | 56,8 | 136,0 | -33,3 |
| 4 – Commercial | 79158 | 102183 | 29,1 | -9,1 | 42,0 |
| 9 – Greenhouses | 15330 | 22279 | 45,3 | 164,5 | -45,1 |
| 10 – Intensive livestock farming | 14453 | 15203 | 5,2 | -76,8 | 352,4 |
| 11 – Infrastructure – Highway | 32630 | 89678 | 174,8 | -40,5 | 358,2 |

This is for example true for class number 2, residential rural (that shows the highest area increase of all classes) where the number of patches has increased strongly and is accompanied with an increased average patch size as well. Recreation on the other hand has less increased in terms of total area, but strongly increased in terms of number of patches that have decreased in average size. A similar trend can be seen for the greenhouses, a strong increase in number of patches, but a decrease in average patch size. Intensive husbandry on the other hand has grown little in total area, shows a decrease in number of patches and a remarkable large increase in average patch size (ca. 350%). Finally, also infrastructure shows a large total area and average patch size increase, but a decrease in number of patches.



2000



2040

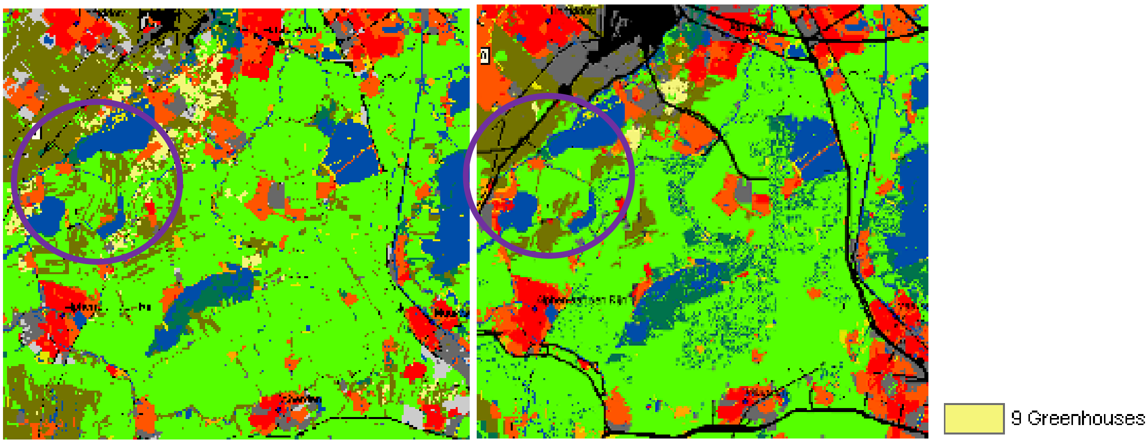



*Figure 28* Decrease in cluttering (inside purple circle) explained by decrease of green houses

For the following calculations of the final cluttering degree we will use the inverse distance function with a maximum radius of 1500 meters.

### 8.1.4 Land use diversity

From the land use classes that are suggested to evaluate land use diversity (Veeneklaas et al., 2006, pp. 58: different types of agriculture, residential, recreation, non agricultural commercial activity, infrastructure, public services) most classes can be distinguished in our datasets. However, the internal diversity of agriculture we can only evaluate using 4 different land use classes. Further, we cannot distinguish a land use class that specifically indicates public services. Non-agricultural activity on the other hand is simply interpreted as being one or more of the following land use classes: recreation, residential land use, commercial land use and infrastructure. We base the diversity index therefore on the following 8 classes:

- residential (0,1,2) ->1
- recreation (3) -> 2
- commercial (4,5) -> 3
- arable land (7) -> 4
- grassland (8) -> 5
- greenhouses (9) -> 6
- intensive livestock farming (10) -> 7
- infrastructure (11) -> 8

All other classes will be reclassified as a background class (class number 9).

Several indicators have been developed within the research domain of landscape ecology to quantify landscape composition, originally meant to measure plant and animal species diversity. Logically, several of these metrics, such as the popular Shannon's diversity index, are sensitive for the occurrence of rare classes (species), which is however undesirable for our purposes as we do not want too much influence of underrepresented classes to the index. Instead we need a diversity indicator that takes into account both the diversity (richness) and proportional contribution (evenness) of different classes. Therefore we have chosen to use Simpson's diversity index which is less sensitive to richness and places therefore more weight on the common land use classes. For a short review on other available metrics to quantify landscape composition we refer to Ritsema van Eck and Koomen (2007). Another advantage of this index is that its interpretation in much more intuitive than e.g. Shannon's diversity index, because the index represents simply the probability that any 2 randomly selected grid cells would be different land use types.

Thus, a value of zero would mean the presence of only one land use type in the selected area while a value approaching one would mean the presence of the maximum number of land use types that are as proportionally as possible distributed over the selected area. The index is calculated as

$$S = 1 - \sum_{i=1}^{m} P_i^2$$

where $P_i$ is the proportion of the landscape occupied by land use class i.

In the standard mode of the programme Fragstats (version 3.3) the index is calculated for the entire dataset, resulting in a single value. For our selection of 8 different land use classes described here above (all other land use classes reclassified to one background class, which is treated as a separate class by Fragstats) this results in the value of 0.72 for the year 2000 and a value of 0.75 for the year 2040, thus a small increase in total land use diversity (for these selected classes) for the Netherlands.

We are however not interested in the diversity on the national scale but only in the diversity on a local scale, i.e. within each neighbourhood radius for which the cluttering impact is calculated. This is achieved by selecting the moving window analysis type in Fragstats, which means that for each gridcell location the land use diversity is calculated within a chosen neighbourhood. As we work with a neighbourhood radius of maximal 1500 meters we should calculate in principle the diversity index for a neighbourhood radius of 1500 meters because this is the neighbourhood area in which the impacts of cluttering elements are evaluated and these impacts depend a.o. on the land use diversity in this neighbourhood area. However, most visual impact is generated from the most nearby cluttering elements by the use of a distance decay function and therefore the land use diversity is most relevant for this area. We are in other words most interested in the land use diversity in the direct vicinity of the landscape observer. To take care that the land use diversity of the most nearby area weights more than the diversity of more distant areas we choose a relative small neighbourhood with a maximum distance of 500 meters. Another reason for choosing this distance is the agreement with the 1km size of the sample grids used in the research of of Veeneklaas et al. (2006).

In Figure 29 and Figure 30 the distribution of the Simpson index diversity values is mapped for the years 2000 and the scenario year 2040. In general the urban edges are represented well with high diversity values in the maps but also regional differences in diversity are clearly visible, note for example the lower diversity values in the central north (parts of Noord-Holland, Utrecht, Flevoland and Friesland) and southwest (Zeeland). Also changes between 2000 and 2040 are clearly visible, for example the decrease of land use diversity in North East Groningen.

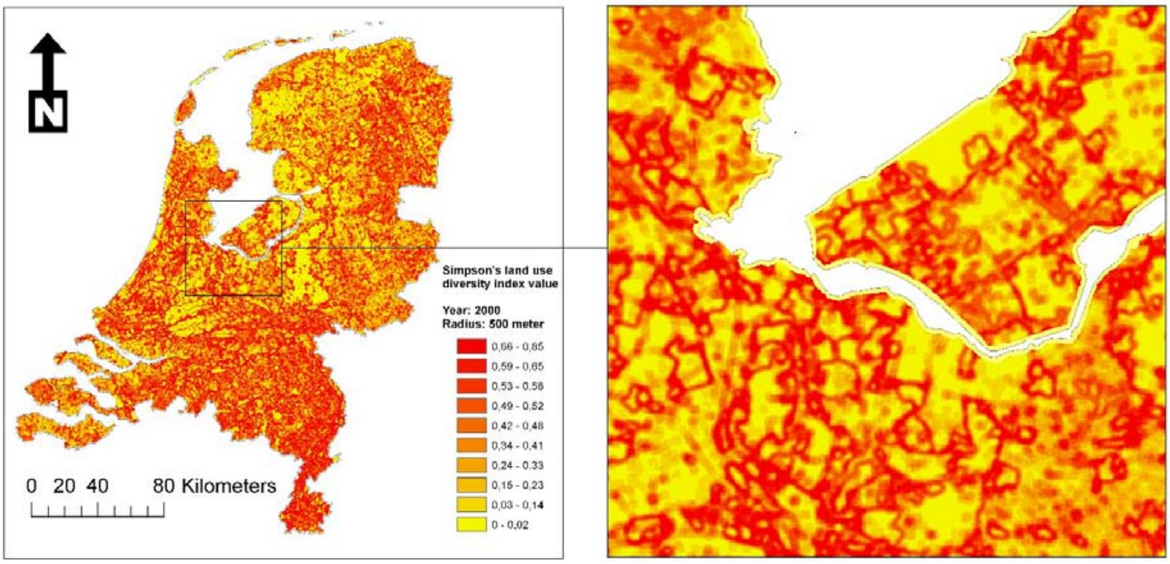



*Figure 29* Simpson's diversity index land use 2000, 500 m radius

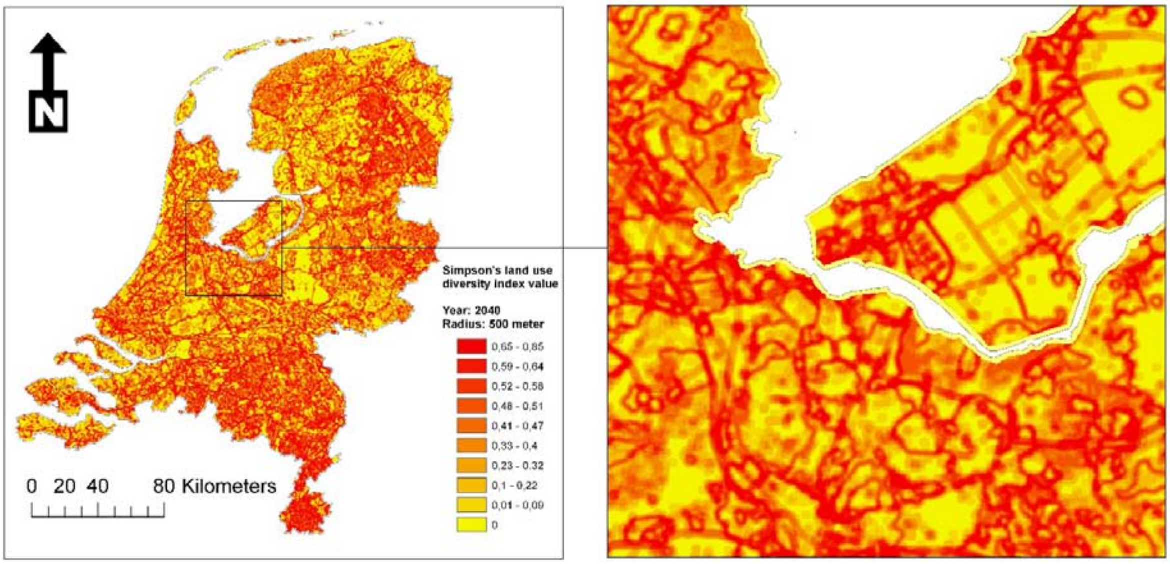



*Figure 30* Simpson's diversity index land use 2040, 500 m radius

### 8.1.5 Degree of openness

As has become clear from section 7.2 the degree of openness can be defined and operationalized in different ways. Our objective here is to use an indicator for openness that is relevant for assessing the degree of cluttering in a landscape. Therefore we would preferably use the same interpretation of openness as has been used by Veeneklaas et al. (2006, pp. 60) who clearly have a visual interpretation of openness with their references to the open fen meadow landscapes and the 'zeeklei' landscapes of e.g. Province of Zuid-Holland. The latter used to be very wide and empty landscapes with little high vegetation and large depths of view dominated by arable farming. We decided to use an existing indicator that is already incorporated in the Land Use Scanner model for openness based on a visual interpretation of openness (Roos-Klein Lankhorst et al, 2004) with four classes for openness ranging from open to very open. Note that this indicator can only describe openness for the initial situation and cannot be used to model openness in future situations. This implies that this component of the landscape cluttering indicator assesses the impact of cluttering elements on a previous state of openness. We think this is justified because the way man perceives the landscape also includes the historical image of the landscape. In other words, when people rate the degree of cluttering of a landscape it is probable they will also take into account the image of how the landscape has once been.

Combination of results

Each of the three components above results in a value per gridcell which have to be combined to obtain a compound value for landscape cluttering. As Veeneklaas et al. (2006) state that approximately 75% of cluttering scores can be explained on the basis of the number and accompanying impact of disturbing elements and ca. 25% of the degree of cluttering can be explained by the land use diversity (see paragraph 0) and also the openness of areas has a modest influence on the measured perception of cluttering, we decided to weight components 1 to 3 in paragraph 1.1 as follows:

1: 10%
2: 20%
3: 70%

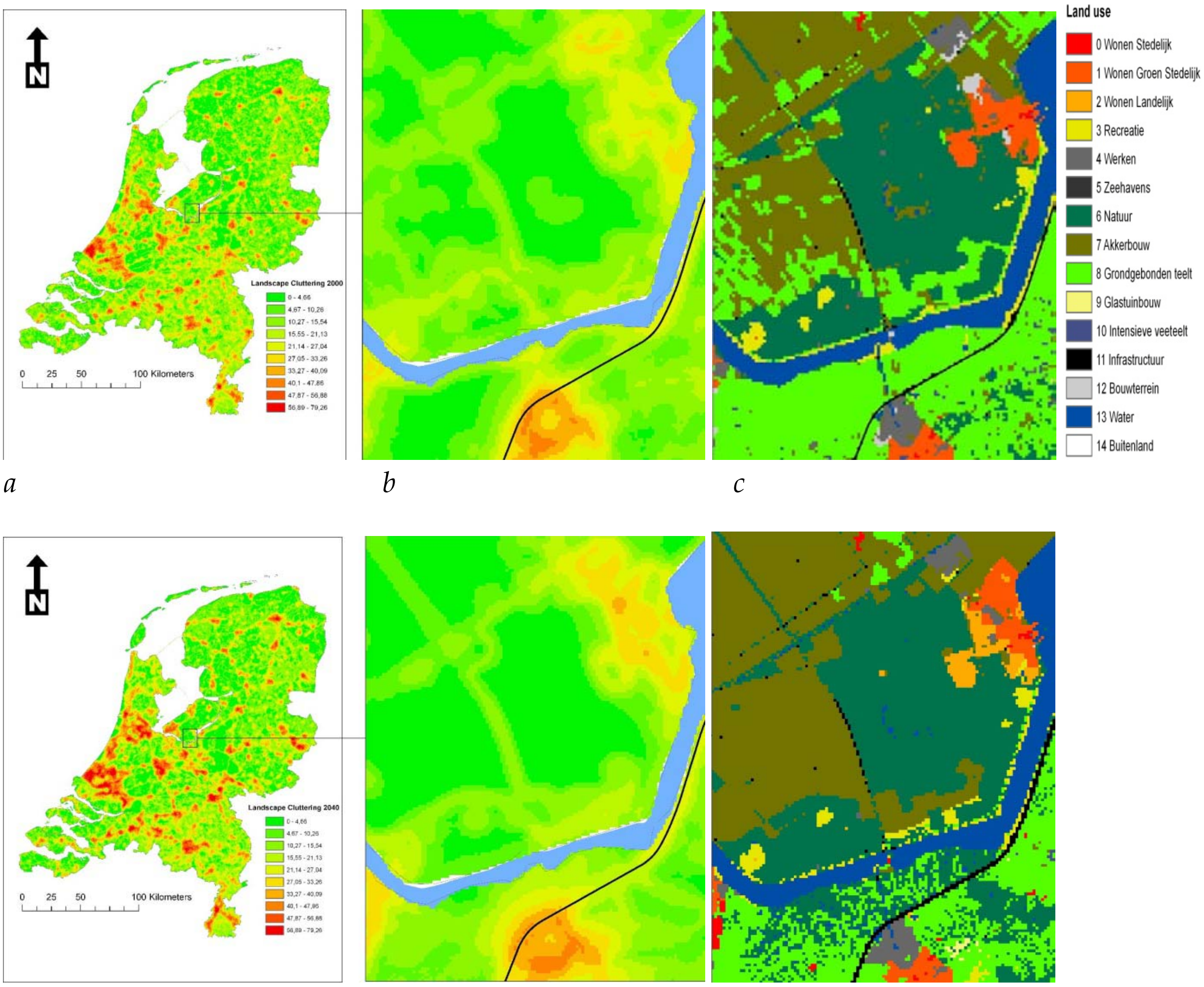
Component 1 is expressed as a map named '**plus_times_00**' with two possible values: 0 or 1,1
Component 2 is expressed as a map named '**div9_00si500**' with values ranging between 0 and 1
Component 3 is expressed as a map named '**clut25sumlin**' with values ranging between 0 and 2.115.255

These concern the input maps for the calculation of landscape cluttering in 2000, similar maps are prepared for 2040 with the only difference that the maximum value of component 3 is 2.422.905. This value is used to normalize both maps for 2000 and 2040 to values between 0 and 100.

The different component values are combined and weighted using the following equation (AGM: 'Cluttering of open space combined'):

((((**clut25sumlin**) / 24229) * 0.7) + ((**div9_00si500**) * 20)) * **plus_times_00**

The resulting maps, named 'clut2000' and 'clut2040' for the degree of cluttering in 2000 and 2040 are displayed in Figure 31 (a, b, d and e) and compared to the original land use in 2000 and simulated land use for 2040 (c and f). The zoomed in area in Figure 31 concerns the most southern part of the Province of Flevoland.




*a* *b* *c*

**d** *e* *f*

*Figure 31* Landscape cluttering in 2000 (a and b) and 2040 (d and e) and the original land use in both time periods (c and f)

By comparing the cluttering patterns on the map in Figure 31 (a and b), with the corresponding land use from which this pattern originates, see Figure 31 (c and d), we can evaluate if the indicator does what it is supposed to do. The visible distribution patterns of cluttering on the map show both the effects of the different rated distance weighted visual impacts of cluttering elements until a maximum radius of 2500 meters and the land use diversity within 500 meters distance of the observer.  The reason that the effect of the land use diversity is visible that well although it only weights 20% of the total is because of the used cartographic classification (natural breaks - Jenks) with smaller class intervals for the lower values than for the higher values. This implies that more subtle variations in the lower range of values are expressed more clearly on the map while only bigger variations in the higher value range (values around cluttering objects) are clearly visible on the map (see frequency distribution and class break values in Figure 32).

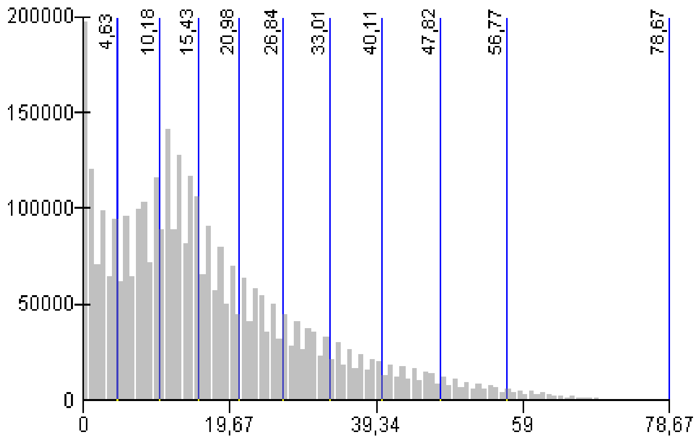



*Figure 32* Frequency distribution map classification (natural breaks - Jenks) for 'clut2000'

One of the things which is revealed by comparing the landscape cluttering maps of 2000 with 2040 is the apparent decrease in cluttering in the central agricultural part of the maps. Comparison with the original land use maps learns that this is the consequence of decreased land use diversity resulting from a more monotone agricultural land use in 2040, mainly pasture instead of a mix of pasture and grassland, while in the area south of Flevoland and the 'randmeren' Eemmeer/Wolderwijd', the opposite takes place, a transition from grassland to a scattered mix of grassland and nature. The question is if the spatial pattern of both these simulated land use transitions is realistic or not. Opposed to these more subtle effects we find a contrary effect in the higher end of the classification, where only the major changes are clearly visible. The consequence of this is that for example the cluttering effect of highways, that we assigned the highest weights will not show up very clearly on the map, also because of their linear shape, occupying only one or two rows of gridcells.

Figure 33 shows how the changes in degree of cluttering in 2040 relate to the areas designated as National Landscapes. In general the degree of cluttering is much lower in these landscapes than elsewhere, but it is also apparent that several of the edges of the National Landscapes are affected by cluttering (e.g. North of Amsterdam). Further, especially around some of the larger cities considerable areas of the National Landscapes are affected by cluttering, e.g. west of Amsterdam, North and South of Utrecht and North of Arnhem.

Figure 34 gives an overview of the changes in landscape cluttering between 2000 and 2040 (by subtracting the 2000 map from the 2040 map). It shows considerable changes in landscape cluttering especially around some of the bigger cities, but also some of the less populated rural areas are affected such as the area in the Province of Friesland between the cities of Harlingen, Leeuwarden, Heerenveen and Sneek. The latter example is however predominantly the consequence of an increased land use diversity caused by a transition from mainly grassland to a shattered mixed pattern of grassland and pasture11. In other areas such as between Amersfoort and Veenendaal where substantial agricultural areas are converted into recreation and intensive livestock farming the increase in cluttering has more obvious causes. In the Randstad instead the most important reason for increased landscape cluttering are the large extensions of residential area and /or greenhouses.

[11] Which would have in any case a large influence on the landscape as this is one of the areas known for its large scale of openness (i.e. almost free from high vegetation or other high objects)

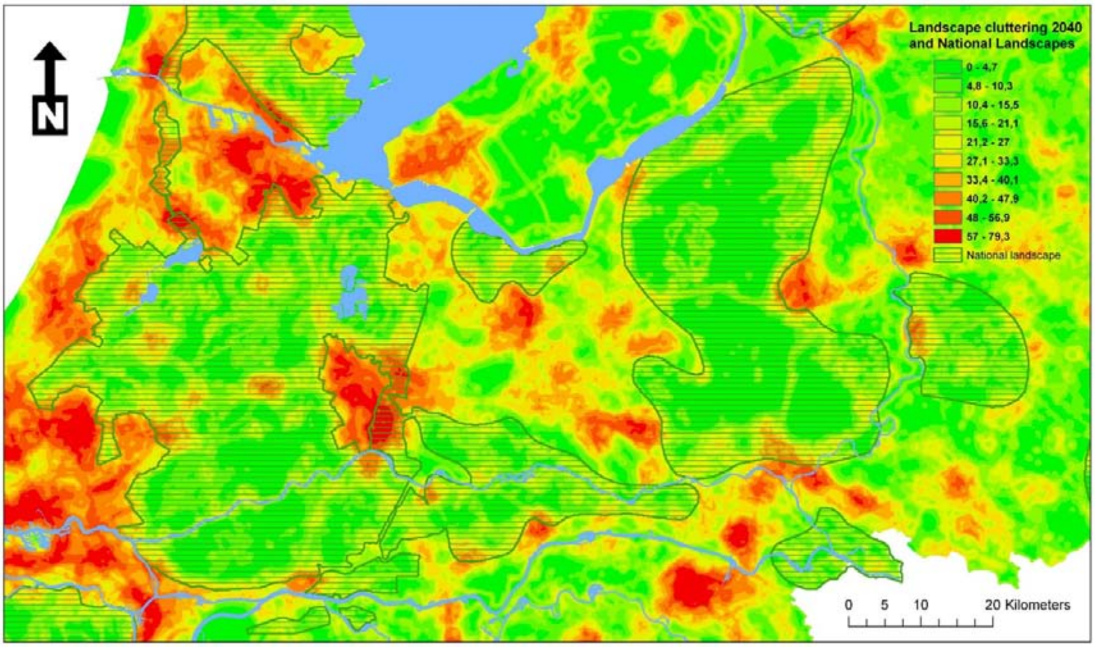



*Figure 33* Landscape cluttering 2040 in relation to National Landscapes

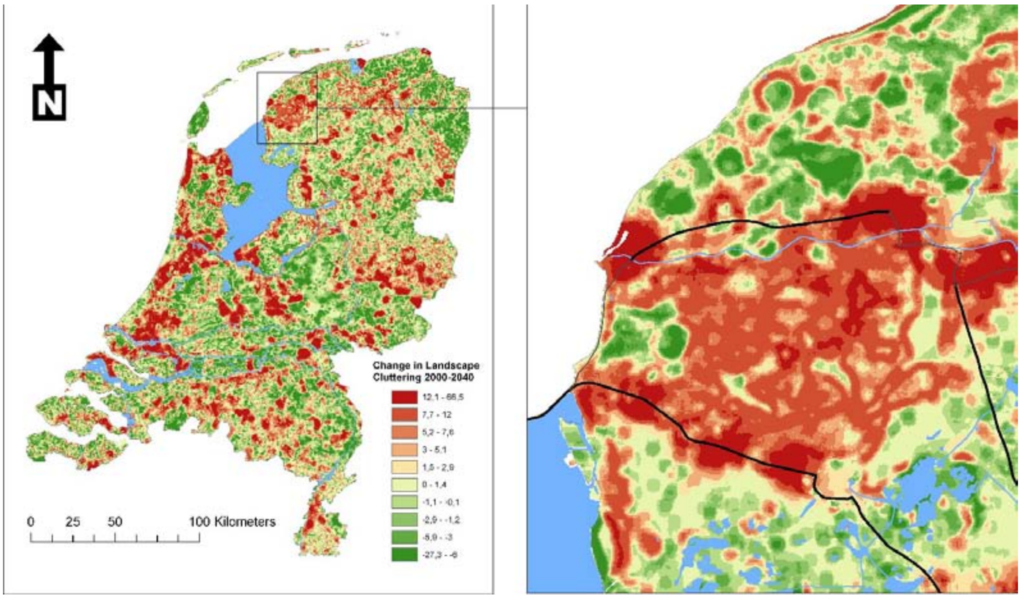



*Figure 34* Change in Landscape Cluttering between 2000 and 2040 (zoomed area between Harlingen, Leeuwarden, Heerenveen and Sneek). Red colors mean increased cluttering, green colors, decreased cluttering.

## 8.2 *Attraction and proximity of open space*

This indicator is supposed to measure some important social values of open space in terms of number of people who can enjoy the recreational, educational, and psychological and health services that open space offers (WHO, 1997).

There is no literature known to the authors that systematically lists the characteristics of open space that are determinative for its social values. We can however deduce some important factors from e.g. medical and social sciences that analyze physical and mental health effects of the proximity of open spaces on population.

- Number of people that have easily access to a certain stretch of open space in terms of travel distance to this space
- Area size of specific open spaces
- Land use diversity: alternation water, forest/nature and grass
- Visual quality of open space and surroundings
- Status of open space (national reserve, National Landscape, etc.)
- Scarcity or exclusiveness of open space

Although these factors seem rather straightforward, their incorporation in an indicator suitable for the utilized land use model data faces several difficulties, which we will discuss hereafter for each of the factors mentioned. A general remark concerns the exclusion of most important city parks in the land use maps (present and future situations) of the Land Use Scanner model. Although easy to add, we did not update the original datasets with these data, which means that the most attractive open spaces in terms of potential number of visitors are not included in this analysis.
Many more factors can be thought of, e.g. the presence of recreational facilities, accessibility by private and public transport, density of footpaths and bicycle tracks, physical accessibility of open space[12] (fences, gates, ditches, etc.) and so on. These are however factors which cannot be easily modelled for future situations and are therefore not considered here.
Further, several Dutch grey literature is available in which the appreciation and need of Dutch citizens for e.g. public green is analyzed (see e.g. Crommentuijn et al., 2007[13]). This research shows that especially the citizens in the Randstad region are less satisfied with the quantity and quality of public green around the cities. Most negatively judged were the lack of silence and the high recreation pressure on the available green.

### 8.2.1 Number of people served

This is a very important factor for this indicator as it connects directly to the spatial policies of different countries in which the access to a minimum area of green open space per citizen is targeted. The main issue here is how to deal with open spaces of different sizes and shapes. Should

[12] This is in itself a complicated issue as for example most parts of agricultural areas are fenced and difficult to access, while at the same time they have an important recreational value because the areas can be explored via country roads and sometimes dedicated bicycle lanes and footpaths between the fields (see e.g. de Vries, 2009, pp. 22).

[13] Belevingswaardenmonitor Nota Ruimte 2006

we base this factor on the maximum amount of people that can reach a specific part of the open space with a given means of transport and within a given travel time or travel distance, or should we work with average numbers of people that can reach any part of the open space under the same conditions of travel time or distance? If we want to give a value to the whole unit of open space, the latter might be more preferable. However, in the case of very large open space units this would mean we base the value of this unit on a large part of the unit that is probably visited only by small numbers of people compared to the parts of the same contiguous spatial unit located more close to more populated areas. It seems therefore more sensible to value individual gridcells of open space and adapt the values of these cells depending of the characteristics (factors size (2), status (5) and scarcity (6)) of the spatial unit they form part of. Other characteristics (factors 3 and 4) will also be cell specific neighbourhood based characteristics. A total value for the whole open space unit can be derived by summing the values of all individual cells.

Although we would prefer to base the potential number of people that can visit any part of any open space on available population data for the Netherlands on sufficient detail level, such as the population data in the dataset 'Wijk en Buurtkaarten'[14] (districts and neighbourhood maps), we are bound to work with data which can be simulated in the land use model. We use therefore the residential land use classes that are used in the model: 'residential - high density' and 'residential - low density'. We don't use the class 'residential – rural' as this class represents only very low population densities. The model documentation does not provide quantitative information about the residential densities used. The only information available is that high density areas are located in the central city districts, low density areas in the green outskirts of cities and the centres of villages and rural density concerns residential areas in rural environments (Riedijk et al. 2007). We assign the following class values to the two selected classes:

1: Residential – low density
2: Residential – high density

We operationalize the amount of people that can potentially take advantage of open space by summarizing the relative amounts of people that are located within certain distances to open space. We assume that beyond certain distances, listed here below, less people are prepared to travel to reach particular open spaces (where possible based on distances reported in literature):

- 0-500 meters by foot (class 5: very attractive)
- 500-1.000 meters by foot (class 4: attractive)
- 1.000-3.000 meters by bicycle (class 3: moderately attractive)

---

[14] Initially we rasterized the original version of the 'Wijk en Buurtkaart 2007'), which was the most detailed population data source we had available, even though it suffers from data quality problems, in particular the Modifiable Area Unit Problem (MAUP), related to the different sizes and shapes of the neighborhoods. This is however a particular problem for the much larger neighborhood units in the rural, sparsely populated areas of the country, for the larger part coinciding with the open space units themselves. The smaller neighborhoods are in general more similar in size and shape and are therefore less affected by this problem. Because the small, densely populated neighborhoods have the largest influence on the average population densities we regard this problem of relatively small importance. However, because we cannot obtain data of similar detail level for the situation in 2040, we decided to opt for another solution.

- 3.000-10.000 meter by motorized transport, e.g. car, motor, scooter, public transport (class 2: little attractive)
- > 10.000 meters by any transport mean (class 1: only attractive if open space possesses special qualities (e.g. part of protected National Landscape, nature reserve, UNESCO site, etc.)

Using a moving window neighbourhood analysis (focal statistics) we calculate for each gridcell the average population density in a neighbourhood of the above indicated distances. The larger distances are operationalized using annuli (donut shaped neighbourhoods defined by an inner and an outer radius) to prevent overlapping and double counting of distance classes. Result of these analyses are 4 different maps (the population for the distance class > 10.000 meters is not calculated) in which each gridcell in the previously defined open space units is rated with a class value based on the potential number of people willing to visit the open space for each of the distance classes. By normalizing the population densities in each distance class between 0 and 1 and weighting them with the estimated relative importance of each distance class indicates above (respectively 50, 30, 15 and 5 %) we can evaluate for each location of open space on the map its relative importance in terms of potentially served population numbers (see Figure 35 and Figure 36).

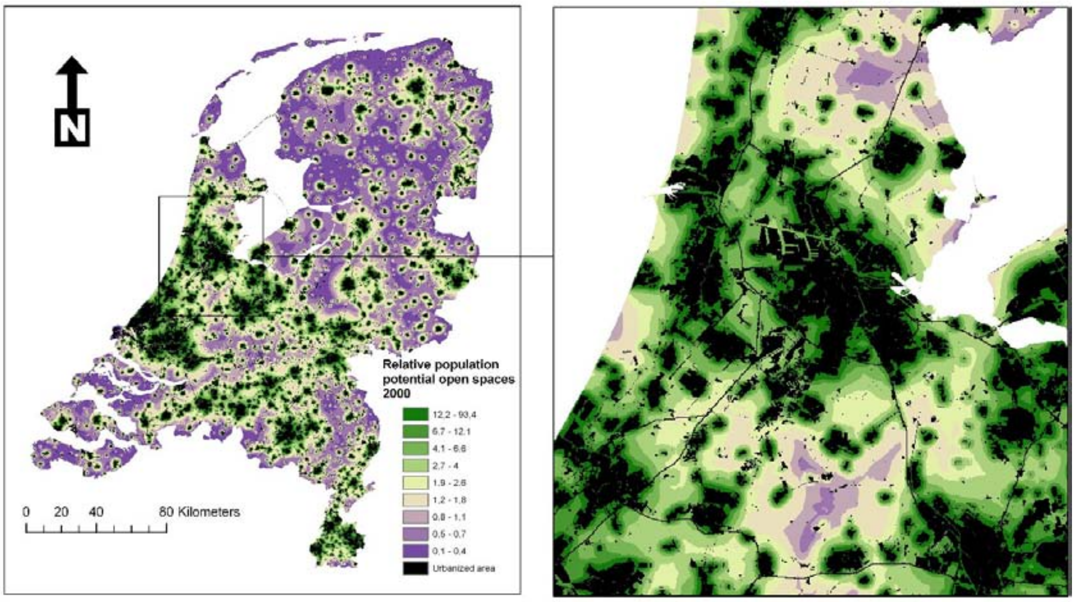



*Figure 35* Potential population for open spaces in 2000 (source 'OSpop00rad10', based on AGM 'Attraction of open space population')

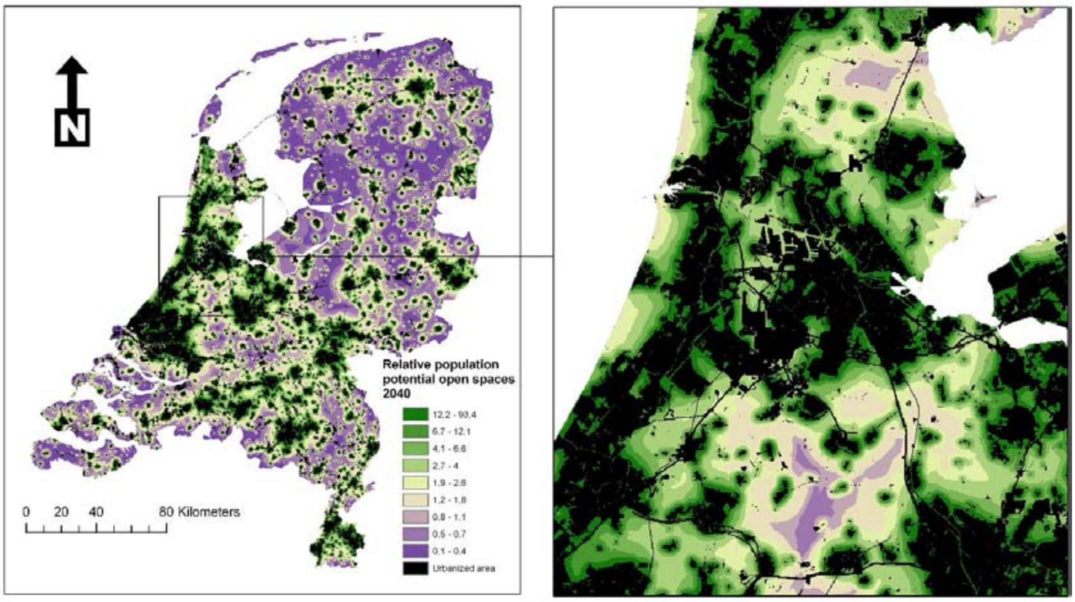



*Figure 36* Potential population for open spaces in 2040 (source 'OSpop40rad10', based on AGM 'Attraction of open space population')

### 8.2.2 Area size of specific open spaces

These area sizes were calculated in section 7.1 and the class number of each open space unit is used to adapt the values of the gridcells that make part of the particular open space units. To the authors no sources are known that rate the social value of open space according to its size. We assume however that most or all social values of open space will increase with increasing unit size. Neither do we know if such an increase will be a linear increase or will follow some kind of function. It makes however sense that the biggest value increase takes place in the range of the smallest open spaces and tapers off beyond certain area sizes, thus following an exponential function. For example an area increase from e.g. 10 to 1000 hectares will increase the open space recreation possibilities from walking to cycling, while a similar area increase, e.g. from 100.000 to 101.000 hectares will not give an similar increase in recreational possibilities. Therefore we have chosen for an exponential increase in size classes but a linear increase for value classes:

1: equal or smaller than 25 hectares
2: between 25-250 hectares
3: between 250-2.500 hectares
4: between 2.500-25.000 hectares
5: between 25.000-100.000 hectares
6: > 100.000 hectares

A map of this size classification for the year 2000 is displayed in Figure 37.

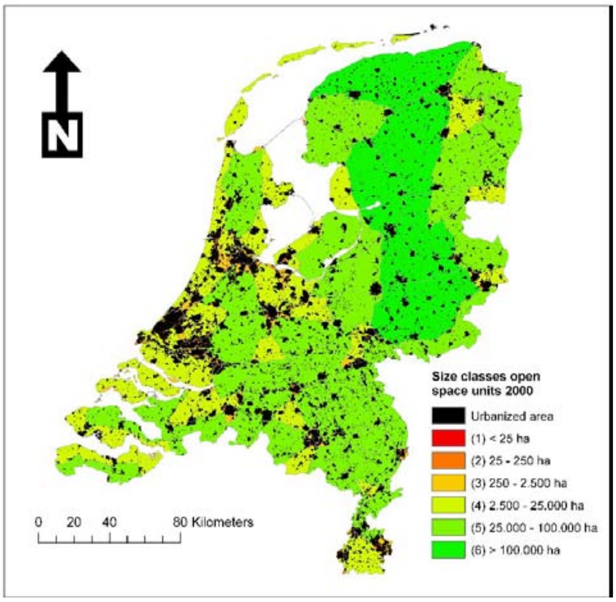



*Figure 37* Size classes of open space units in 2000 (source: 'osrecl00')

### 8.2.3 Alternation water, forest/nature and grass

A good land use mix of water, forest/nature and grass is considered attractive (Braaksma, 2007, pp. 27) and can therefore contribute to the quality of open space. This factor is calculated in a similar way as the land use diversity was calculated in section 8.1., but now by looking only at the alternation of 3 different land use classes: trees, water and grass. Because we don't have a separate class for trees or forest, we will replace this class by the class nature. Figure 38 shows this reclassification for the land use map of 2000. Added value of this indicator component is that it also takes into account the attraction of open spaces that are bordered by large open waters, a factor which is not incorporated in any of the other indicators of this research. This increases for example the attraction values of the relatively small open spaces on the 'Waddeneilanden', that are assigned without this factor very low social attraction values (small, far from population centers, no special protection status).

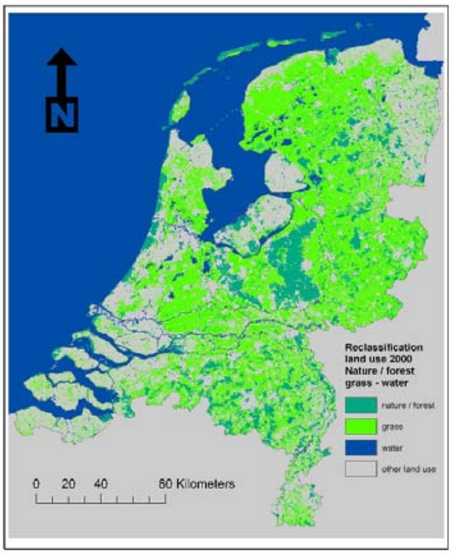



*Figure 38* Reclassification land use map 2000 in water, grass, nature / forest and other land use

Figure 39 shows the variety of these three land use classes measured with the Simpson diversity index (using a moving window analysis with a radius of 2500 meters and other land use as the background value).

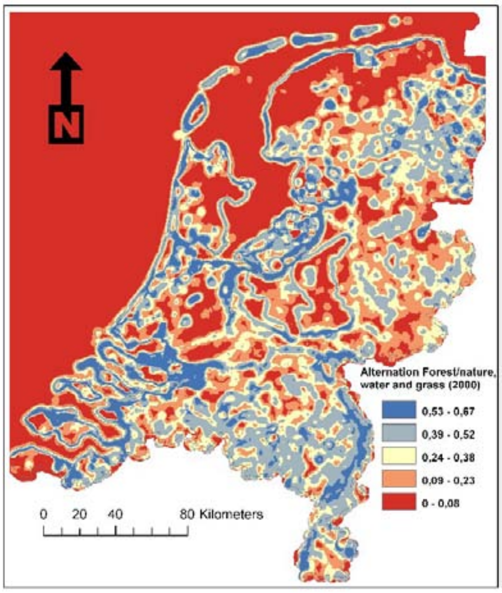



*Figure 39* Alternation of water, forest/nature and grass in 2000

The figure shows that the index is not exactly measuring what we had in mind as for example areas with very little water, forest/nature and grass can get high diversity values (see e.g. the Noordoostpolder), only because all three classes are present in comparable amounts. To correct for this problem we calculate first the proportional presence of these three (summed) classes and multiply this proportion with the Simpson diversity index map of Figure 39, resulting in corrected diversity maps for 2000 and 2040 displayed in Figure 40.

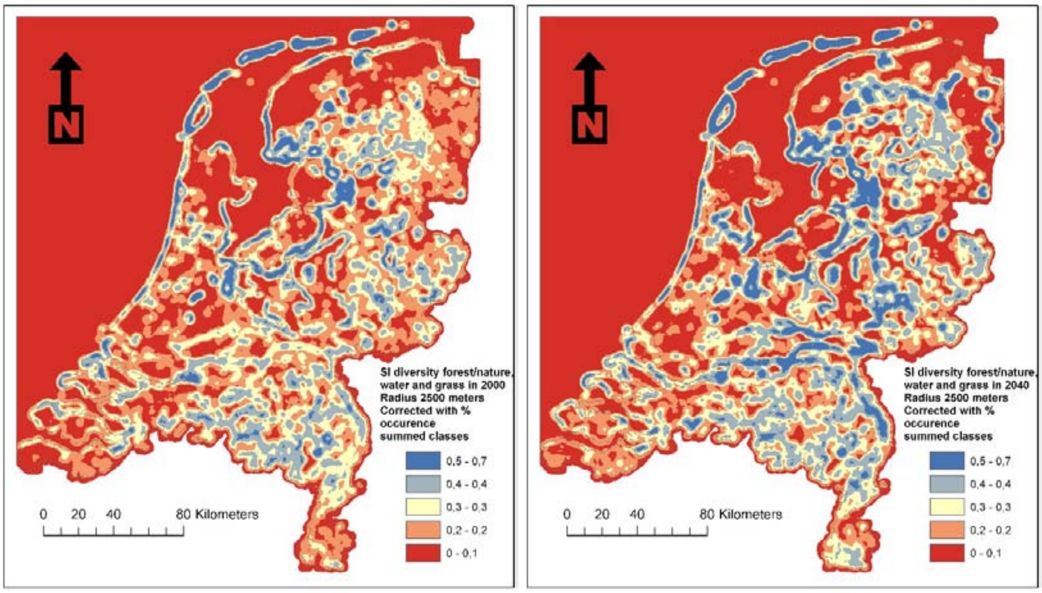



*Figure 40* Corrected Simpson diversity forest/nature, water and grass for the year 2000 and 2040 (source: 'sigg3_00' and 'sigg3_40')

Clearly visible from the maps is for example the increased diversity around the big rivers Maas and Rijn, as a consequence of the development of flood retention and associated nature areas around the big rivers.

A point of concern with this indicator component is that it seems to conflict with the component land use diversity of the indicator for landscape cluttering, even though it measures the diversity of a different mix of land uses. A bigger land use diversity can contribute to the degree of landscape cluttering (but only if visually disturbing elements are present in the landscape). A higher variety of the land use classes grass, forest/nature and water can thus on the one hand be attractive, but on the other hand lead to more landscape cluttering if visually disturbing elements are present (see section 8.1 and section 8.2.4).

### 8.2.4 Visual quality of open space and surroundings

Input for this factor will be the output of section 8.1.6, the degree of land use cluttering, represented by the maps named 'clut2000' and 'clut2040', displayed in Figure 31.

### 8.2.5 Status of open space

We assume that people are more attracted to open spaces that are known to have special qualities, expressed in some kind of protection status. We assume that national nature parks and national landscapes have the best known protection status to people and have the potential to attract people from all over the country and abroad. Besides, we expect that also local protection status will increase the (particularly local) attraction of open spaces to people. Therefore we will duplicate the values of the parts of open spaces that fall within the borders of areas with a special status, such as National Landscape, national nature reserve or local protection status (thus all protected areas are assigned the value 2). A map with the Dutch national parks and national landscapes is displayed in Figure 41.

Inputs:
- map National Landscapes
- map National nature reserves

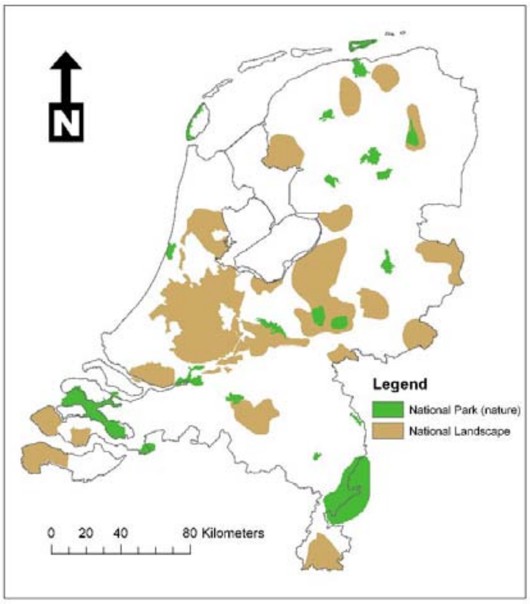



*Figure 41* National parks and landscapes (source: 'protected2')

Obviously, this list of input maps can be replaced or extended with other maps indicating land scape quality aspects. In this study however, we have limited ourselves to the two input maps mentioned here above.

### 8.2.6 Scarcity of open space

The general idea behind the factor scarcity is that the social value of a certain stretch of open space increases when it is more exclusive (high scarcity), i.e. there are no or few alternatives to choose from. Best examples of these kind of open spaces are naturally city parks, such as the Vondelpark and the Sarphatipark in Amsterdam. These parks are small in size, which increases their scarcity value, and there is not much nearby alternative open space around, which increases their scarcity further.

Vice versa, the more stretches of open space can be found in a defined area of open space the less important the individual stretches become, especially when they are smaller in area size (although the latter factor increases the individual scarcity). The area surface of individual patches is therefore important for the calculation of this factor. Although intuitively it might seem logical that the process of fragmentation of open space leads to a higher scarcity of remaining space this is not always the case. If we look at the categories of fragmentation of natural areas defined by Forman (1995) that we adapted in section 2 we see that the process of dissection, e.g. when an unit of open split is dissected by a road in two new units of open space that have together the same area as the initial unit, will lead netto to a lower scarcity of open space. More important however is that all other fragmentation categories lead however to decreased areas of open space and therefore in general to higher scarcity.

To explain the concept of the scarcity calculation I use the example in Figure 42. As scarcity depends both from the area of the open space units (the smaller the scarcer) and the number of open space units (the less, the scarcer) the scarcity of open space is lowest in Figure 42a (largest area and more than one unit), while Figure 42b is more scarce than Figure 42c because the same area consists of only one (not fragmented) unit. The easiest way to calculate the scarcity of a large number of different sized units within a given area is first to calculate the total area of open spaces and normalize these between 0 and 1. Next we calculate the total number of open spaces within the same area and normalize these as well between 0 and 1. Next we multiply these normalized values with each other and get the scarcity of open space in the specific area. For the example in Figure 42 this calculation looks as follows:

Total area: (a) 250, (b) 200, (c) 200
Normalized area: (a) 1, (b) 0.8, (c) 0.8

Number of units: (a) 2, (b) 1 (c) 2
Normalized numbers: (a) 1, (b) 0.5, (c) 1

Multiplication: (a) 1 (b) 0.4 (c) 0.8


*Figure 42* Example different sizes and numbers of open space units (a: left image, b: central image, c: right image)

The result is indeed that (b) is the most scarce and (a) is the least scarce. Note that in general users of open space prefer to have more and larger options to choose from, but that the value of individual units of open space rises when they are scarce (therefore the single unit of 200 ha in Figure 42b have higher values (and scarcity) than the combined value of two open space units in Figure 42c. Thus, if an existing open space unit is fragmented into two pieces, but the combined surface remains equal, both half's of the open unit become less important and also their summed value will be less than the original value of the single piece of open space.

Operationalization:

As distance to open space is an important factor we only consider open spaces within walking distance and use therefore a moving window analysis (focal statistics in ArcGIS) with a neighborhood radius of 1000 meters. We count the number of open space units in this neighborhood, using the 'variety' option in this ArcGIS function. Next we sum the total area of open space units in this neighborhood of 10 kilometers. Subsequently we normalize both maps and multiply them with each other, see AGM 'Attraction of open space scarcity'. Figure 43 and Figure 44 show the resulting scarcity maps in 2000 and 2040.

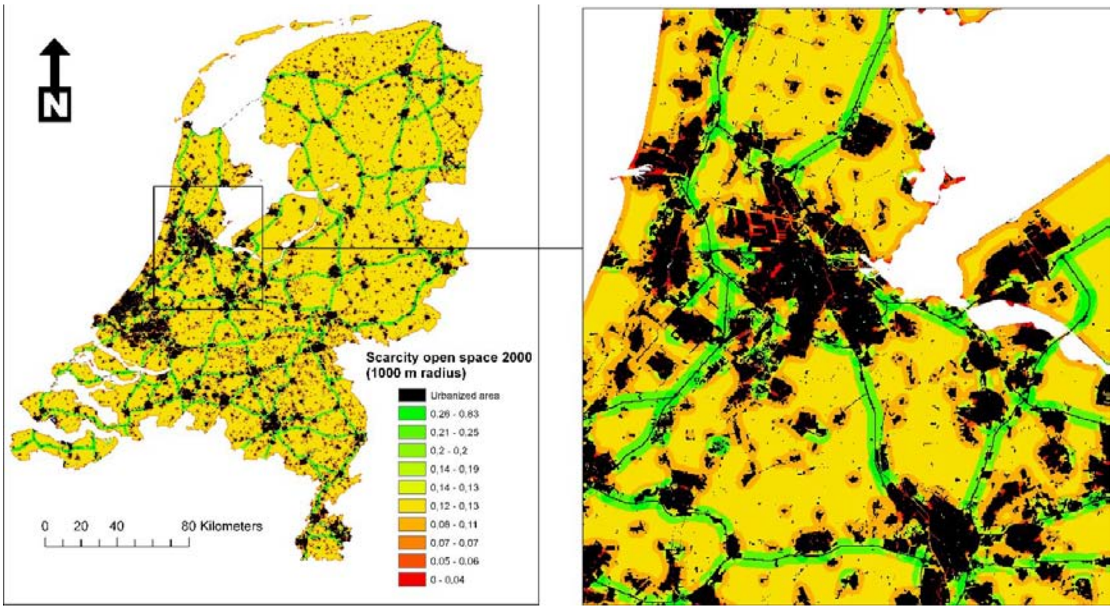



*Figure 43* Scarcity nearby large open spaces 2000 (source: 'scarcity00', 1 km radius)

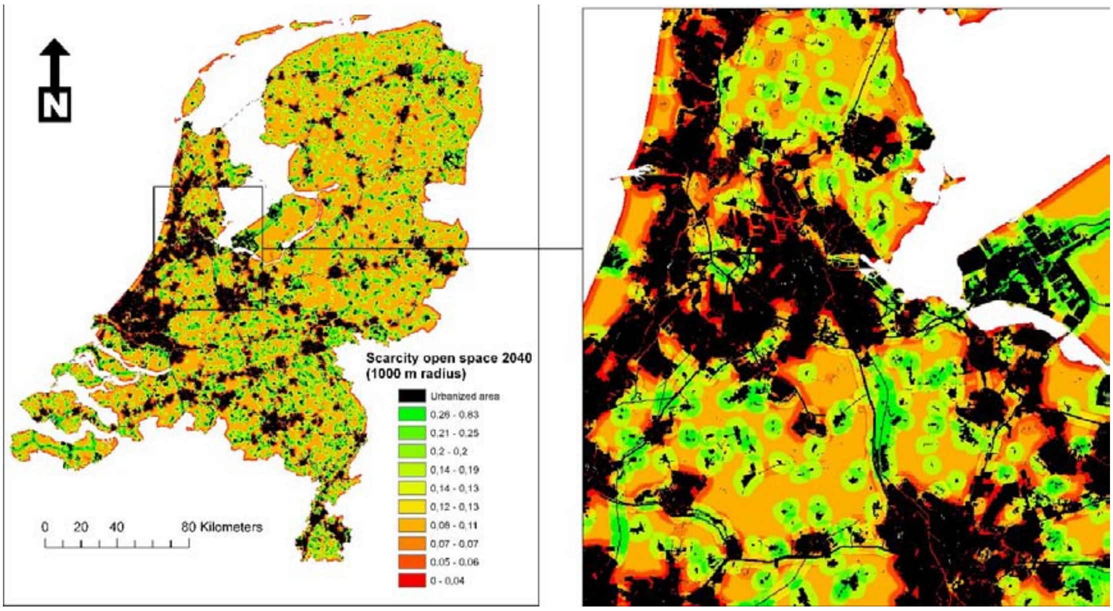



*Figure 44* Scarcity nearby large open spaces 2040 (source: 'scarcity40', 1 km radius)

The resulting maps show that along the city borders the scarcity for nearby large open spaces is relatively high (there are higher numbers of open spaces available, but in general these are small in size), while in the country side the scarcity is as expected reasonable low. The lowest scarcity is however found alongside the highways, i.e. the linear dissecting elements, which is logical because at these locations we find in the 1000 meter radius more than one large open space that can be accessed. In general the differences in scarcity are rather small because the opposing effects on scarcity of number of units and size of units are in many cases neutralizing each other (in the country site there are few , but very large units, while near the city borders there are many, but in general small units. An exception is formed by open spaces within the urban fabric, such as city parks, these show the highest scarcity (i.e. a number close to zero). The other exception is for the open spaces alongside highways, here the lowest scarcities are found. This corresponds indeed to the way most people experience large open spaces, from their cars.

### 8.2.7 Combined social value of open space

We normalize each of the selected factors that are supposed to have influence on the social of open space with values between -1 and 1 and assign different weights to them before adding them up to a combined value. In *Table 10* the weights are shown that were used for the calculation of the maps shown in *Figure 45* and *Figure 46*. The weights assignment was carried out according to our own judgment.

*Table 10* Layer weights

| Layer | Sign | Weight |
|---|---|---|
| Scarcity large open space | - | 1 |
| Protected landscape | + | 1 |
| Landscape cluttering | - | 3 |
| Land use diversity water, nature/forest, grass | + | 1 |
| Area size open space units | + | 1 |
| Proximity population | + | 5 |

The highest weight (value 5) has been assigned to the 'proximity population' layer because we consider the potential amount of people that have access to open spaces by foot, bicycle or motorized transport, the most important variable in this indicator. The second highest weight (value 3) has been assigned to the variable landscape cluttering as, we consider the visible quality of the landscape the most determining factor for the actual use of open spaces by the potential users at close range of these spaces. All other factors have been rated with similar weights (value 1) as we expect less difference between these variables.

In the 2000 map we see that the highest combined values coincide with the highest values found in the input layer of area size of open units, although locally also in other areas (in protected landscape / nature areas) almost as high values can be found. Apparently the size of the open units is the most discriminating factor in these (less populated) areas.  In the 2040 map however, we see that because of decreased area sizes of the open space units  in the province of Overijssel, the combined social value of the open spaces in a large part of Overijssel have decreased considerably. Further, the influence of the protected state of areas is clearly visible in the combined social value of areas in both 2000 and 2040. Further we see in general that the (parts of) open spaces at short range of populated areas have higher social values and also that the parts of open spaces close to large open waters have in general higher social values because of the higher land use diversity values (alternation water, nature/forest and grass).  Decreases in social values resulting from land use cluttering between 2000 and 2040 are for example clearly visible around cities as Marknesse (Noordoostpolder province of Flevoland), Meppel (province of Drenthe), Steenwijk and Heerenveen (Friesland).

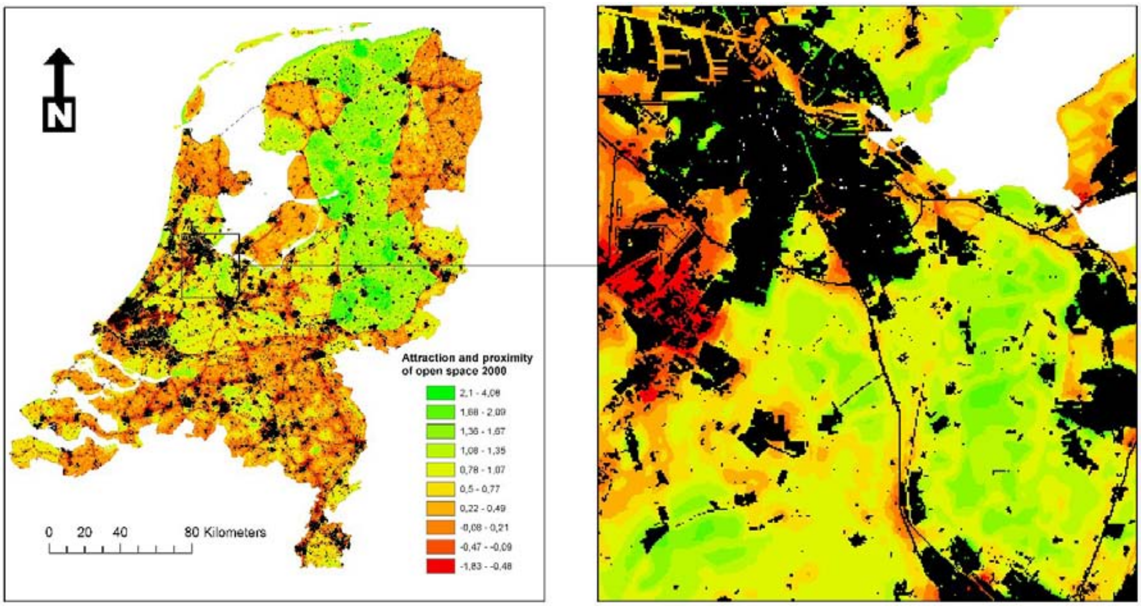



*Figure 45* Combined social value of open space 2000

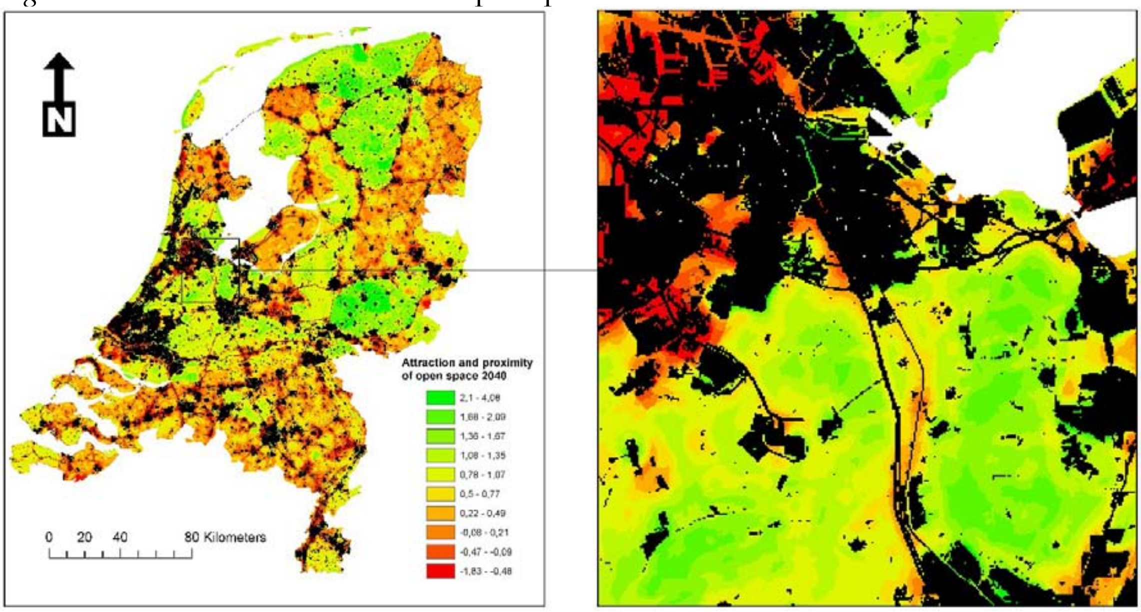



*Figure 46* Combined social value of open space 2040

Table 10 shows the summed values for each of the provinces in 2000 and 2040. The table shows that the province of Gelderland has the largest combined social value of open spaces. Gelderland is however also the largest province, if we correct the figures for province size, we find that in Figure 48 Gelderland has relatively still the highest social values, but almost similar to the values of Overijssel and Friesland. Lowest relative values can be found in the provinces of Zeeland, Noord-Brabant and Limburg, for different reasons. In Zeeland the open spaces are relatively small and, more important, the total population numbers very low. In Noord-Brabant and Limburg we find relatively high population numbers but more dispersed than e.g. in the Randstad and also relatively high numbers of e.g. intensive livestock farming, both contributing to the cluttering degree of the landscape. Between 2000 and 2040 the most striking differences can be found for the provinces of Overijssel followed on some distance by Flevoland with sharp decreases of the combined social value of open space. For Overijssel this decrease, as was explained already before, mainly caused by the reduction of area unit size of open spaces while in Flevoland a combination of factors seems to relate to this decrease. In all other provinces we see however a small netto increase in combined social value, possibly related to relatively compact growths of populations, the factor with the highest weight.

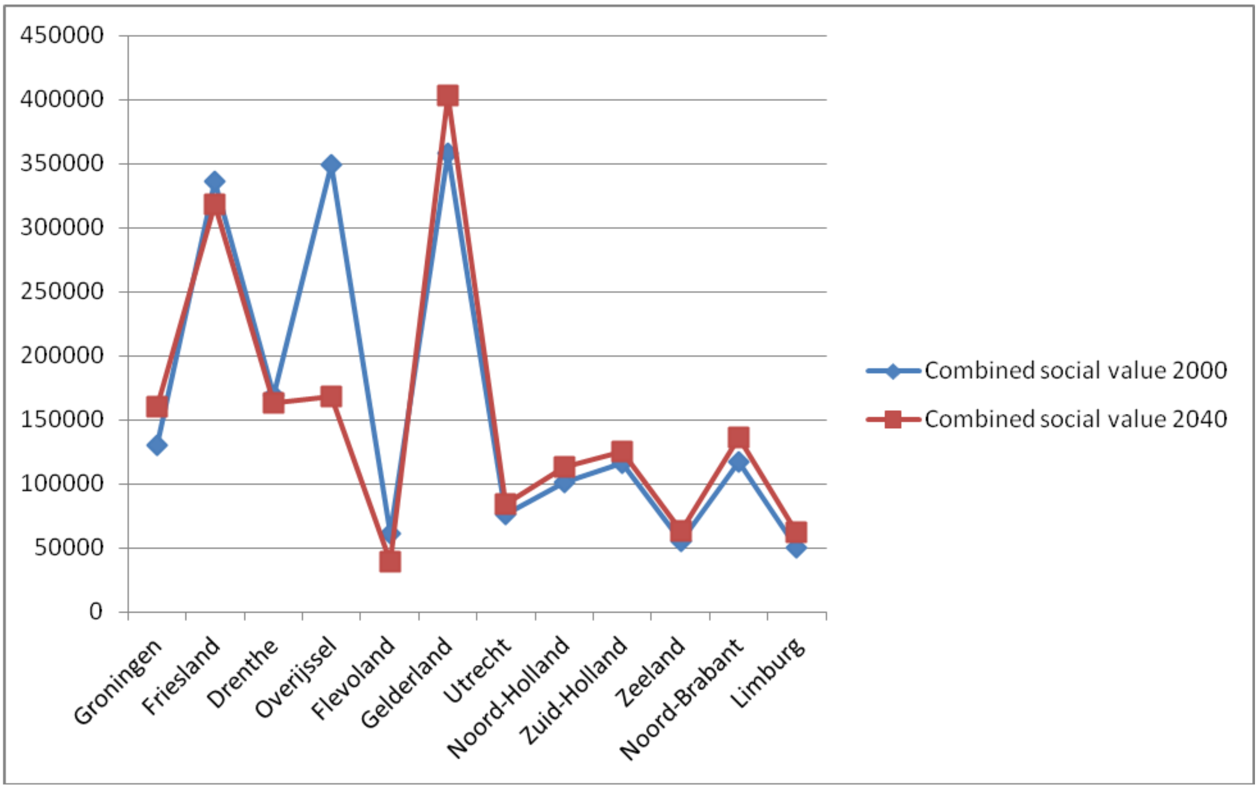



*Figure 47* Combined social value open spaces per province in 2000 and 2040

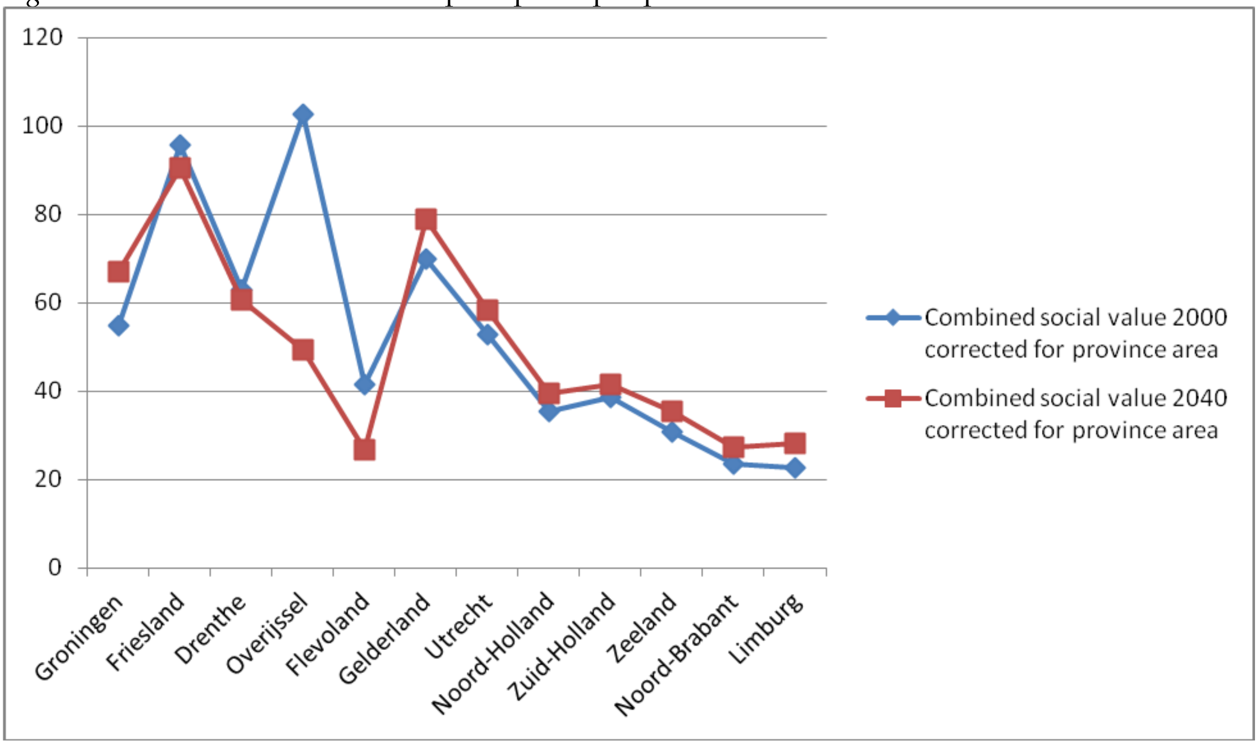



*Figure 48* Combined social value open spaces per province in 2000 and 2040 corrected for province area

# 9. Conclusions and recommendations

The main research objective in this study was to explore suitable spatial indicators for measuring negative impacts of land use change in the period 2000 – 2040 on both quantity and quality of open spaces, where the quality of open space is evaluated from a social, mainly recreational perspective.

From the introducing chapters concerning definitions and concepts of open space and the exploration of possible indicators in chapters 7 and 8 we draw the following conclusions.

*General aspects*

- The multitude of perspectives on and definitions of open space by different users makes comparison of existing research and results often impracticable. For each indicator and evaluation study the chosen perspective on and definition of open space should therefore be carefully stated and explained.

- In comparison to the spatial evaluation of current aspects of landscape quality, the evaluation of quality changes in future landscapes based on land use simulation models is extra problematic, due to the coarse gridcells applied and aggregated land uses and the total lack of additional data of important linear and point shaped landscape elements, such as wind turbines, electricity polls and so on.

- The aggregation problem of linear map elements in coarse sized gridcells, such as important landscape fragmenting infrastructure, should be tackled to prevent the formation of unrealistic large units of open space. Imposing the existing major infrastructure as connected gridcells on the land use simulation maps therefore seems the best solution.

- In absolute area terms the loss of open space between 2000 and 2040 will be, following the land use 2040 W scenario used in the model Land use scanner, approximately 5%. It can be expected however, that the loss in quality of open space can be many, many times higher than this figure.

- The differences in land use classification, data inputs and allocation methods between different simulation periods can have large implications for the evaluation of changes in open space. Certainly a part of the observed differences in open space characteristics is purely the result of methodological differences between two simulation periods in stead of correctly estimated land use change.

*Structural spatial indicators*

- The size and number of open spaces are a good structural indicator for evaluating general national and regional trends in the change of open space. A practical value can be its capability to indicate the total amount of open space available for spatial developments within practical units of open space.

- The degree of openness expressed as a ratio between open space and built-up space appears to be a good structural indicator for evaluating more qualitative changes in open space and comparing e.g. conversion rates from open to built-up areas between different regions, such as provinces.

- For better local evaluations of openness, not influenced by non uniform reference areas, the degree of openness is also analysed using gridcell based moving window neighbourhood analysis. This indicator is particularly useful to evaluate spatial changes in openness within defined units of open space.

*Functional spatial indicators*

- The developed functional indicator for the evaluation of landscape cluttering is a policy relevant indicator which can be directly implemented to evaluate the effect of land use changes on landscape cluttering. However, as the attention for landscape cluttering seems to be a specific Dutch phenomenon, it might be less easy to export and implement this indicator in other countries.

- The functional indicator for the evaluation of attraction and proximity of open space is an internationally policy relevant indicator. However, the lack of standard procedures to measure the access to green and open space, makes it difficult to develop an indicator that will be relevant for multiple countries. In its current form this indicator measures the social value of open spaces and the resulting maps show in general plausible results but also some issues to resolve, e.g. the difference between the Provinces of Friesland and Groningen caused by too much dominance of the indicator component size of open space.

The main recommendations following from results and conclusions are to elaborate further on the indicators with best chances for successful development and implementation, which are the structural indicator degree of open space and the functional indicators landscape cluttering and attraction and proximity of open space.

Another important recommendation is to test and calibrate indicators on the basis of historic maps for current land use configurations and compare the results with more sophisticated evaluations of openness for the current situation.

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