Land use scenarios for greater Copenhagen - modelling the impact of the Fingerplan

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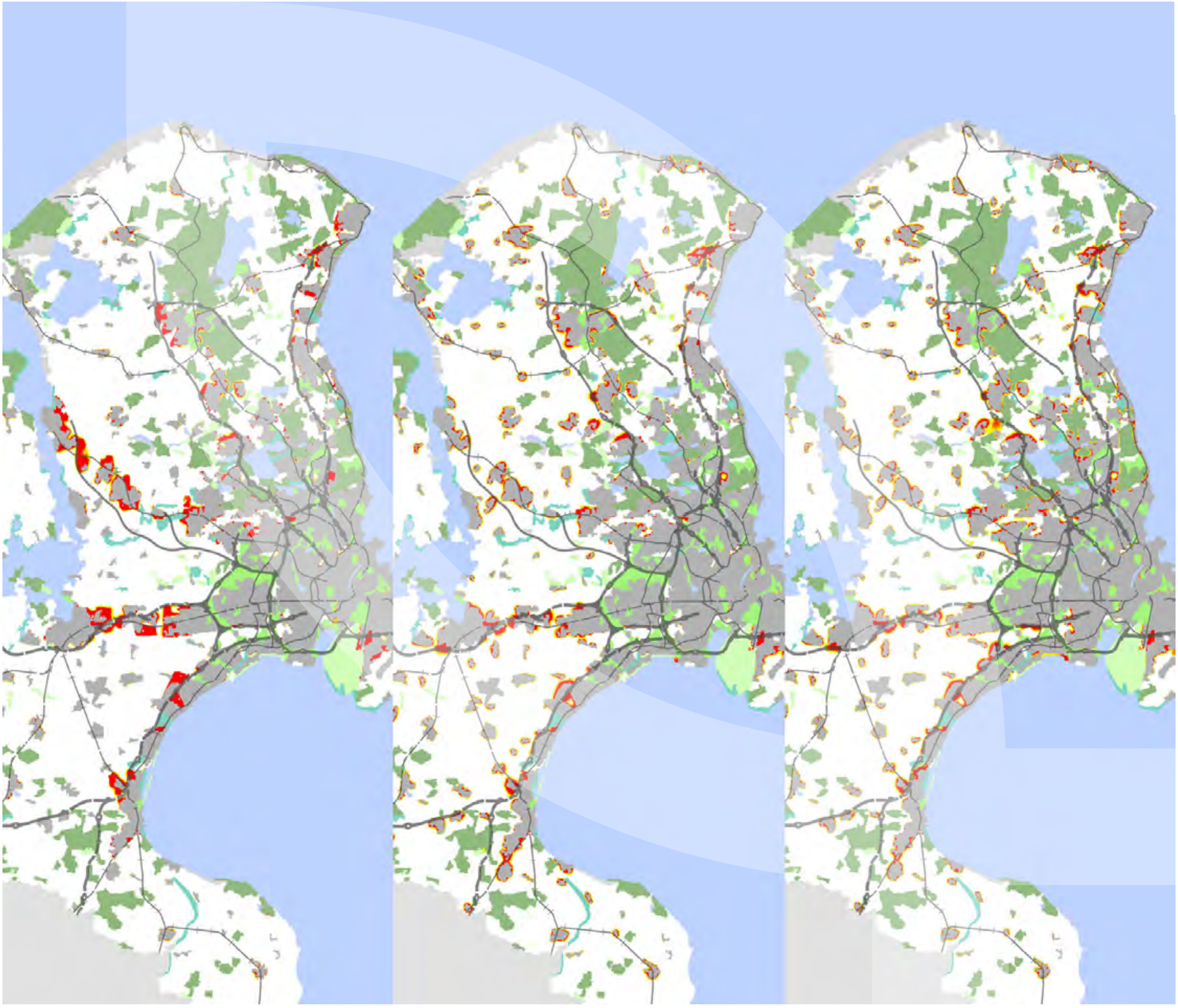

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– Modelling the impact of the Fingerplan

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Abstract

Urban planning and development in Denmark can be characterised by a relatively strong planning framework. Projections of the future demand for urban development as well as decisions on how and where to accommodate this demand are part of the planning process and reflected in strategic- and local development plans. Land use scenarios based on empirically derived dynamics of urban growth are practically never applied. This may be explained by the in-consistency between the logic of spatial master planning - and the organic or driver-dependent character of urban growth assumed by land use modelling approaches. However, modelling approaches do offer a methodology to explore the pressures in an urban region, as well as an approach to understand urban development patterns outside the ‘spatial masterplan’.

In this context we will present the results of a modelling exercise addressing future land use change in the metropolitan area of Copenhagen and the impact of the current regional planning framework, the “Fingerplan 2007”. We applied three different policy scenarios to analyse the different effects on urban growth. For the modelling exercise we applied the Metronamica© model from the Dutch-based Research Institute for Knowledge Systems (RIKS), which uses the same modelling framework as the MOLAND approach, known from various research applications. As we are new to land use modelling, this pilot project also illustrates the possibilities of non-modelling experts to elaborate a practical and useful outcome within a relatively short period of time and with only little resources. The application was kept simple which limited its potential for planning support. However, the approach and the results were discussed with a few experts from the Danish Ministry of the Environment and its value as discussion input recognized. The approach offers a lot of possibilities to discuss urban growth and spatial planning policies, even in a country with a strong planning framework as in Denmark.

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1 Introduction

Planning tasks are getting more complex and an increasing number of policy fields have to be taken into consideration. Modelling tools as well as other planning-support instruments are gaining momentum with this development (Geertman 2006). In Denmark, urban planning and development can be characterised by a relatively strong planning framework. Projections of the future demand for urban development as well as decisions on how and where to accommodate this demand are part of the planning process and reflected in strategic and local development plans. Land use scenarios based on empirically derived dynamics of urban growth are practically never applied, however. This may be explained by the in-consistency between the logic of spatial master planning - and the organic or driver-dependent character of urban growth assumed by land use modelling approaches. However, modelling approaches do offer a methodology to explore the pressures in an urban region, as well as an approach to understand urban development patterns outside the ‘spatial masterplan’.

In this pilot project we discuss the potential of such an approach. The purpose was **to model future development of urban land uses in the** area around Copenhagen **covered by the “Fingerplan 2007” for the next few decades** under different policy scenarios, using the land use modelling tool “Metronamica”, developed by the Dutch-based Research Institute for Knowledge Systems (RIKS). The main research question was if it is possible to evaluate the future impact of a regional planning scheme like the Fingerplan with a modelling tool and to derive useful conclusions for planning practitioners. The hypothesis regarding future urban growth in the region was that the Fingerplan will prevent urban growth considerably outside the Fingers and will support growth close to the suburban train stations.

These questions cannot be answered by a simple forecast as it is hardly possible to account for the complex processes involved. In spatial planning many models are now used within planning support systems (PSS) to explore scenarios and discuss alternative future impacts rather than as pure forecasting tools (Drummond & French 2008). But there are also other arguments for modelling. Epstein (2008) names eight of them:

- Prediction
- Explanation
- Guide data collection
- Discover new questions
- Reveal the simple as complex and the complex as simple
- Train users and educate the public
- Fuel the dialogue

In this project several apply, but due to the nature of a pilot project (we had 3 months of working time), the answer to these issues cannot be dealt with in detail. Instead we focussed on the general potential of modelling with Metronamica in the case area. We focused on getting to a reasonable, first simulation rather than developing a highly detailed model. This limitation is another issue which was discussed throughout the project: Does a small and quick modelling exercise makes sense or is more in-depth research indispensible? What are the technical and conceptual limits of such a quick[1] approach?

[1] The 'quick approach' is meant relative, but it was clear from the beginning that we would not be able to use the model's full capacity and include a range of available extensions like a separate transport model or a regional migration model.

2 The Copenhagen Fingerplan

One of the research questions of this project was how the Fingerplan is likely to affect future land use changes in the Copenhagen metropolitan area. We will therefore shortly introduce this regional planning scheme which has put its stamp on urban development in the region for quite a while.

The first Fingerplan was developed in 1947 (Egensplankontoret 1947). It proposed a future urban development of the metropolitan area of Copenhagen along five suburban railroads. The areas between should be kept free of buildings, forming green wedges and supplying the urban population with close recreational areas. Although the plan was only a report and never close by legally binding, it had a great influence on later regional plans and infrastructure development in the region (Primdahl et al. 2009).

Fig. 1: The Fingerplan from 1947

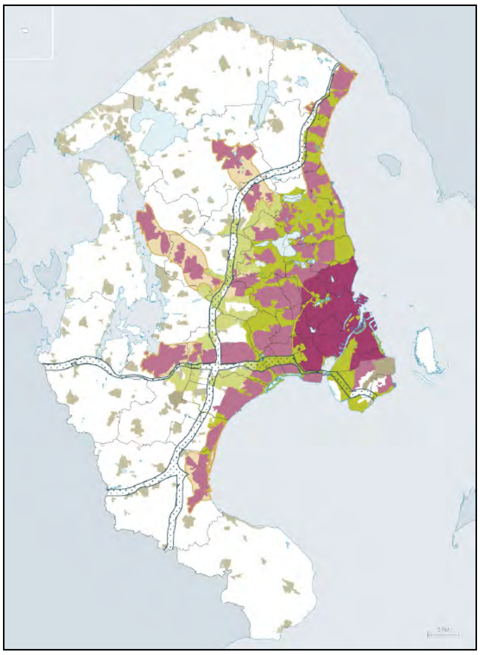

Fig. 2: Fingerplan 2007

The latest regional plan, Fingerplan 2007 (Miljøministeriet 2007), is referring directly to the original plan in an extended regional context. The plan is a national directive based on the current planning act and is therefore a legally binding document. However, it has been much discussed, and the wisdom of this steering tool has been questioned. Currently the ministry has opened for a debate on an adaptation of the plan which should result in a new directive in 2012.

The Fingerplan 2007 structures the region in 4 zones. The inner urban areas (palm of the hand), the outer urban area (fingers), the green wedges and the remaining area. The core principle is that only in the palm of the hand and the fingers urban development of regional importance is allowed. In the remaining metropolitan area only developments of local character are allowed while the green wedges must be kept free from any development (Hartoft-Nielsen 2008).

Furthermore, the principle of station-proximity was strengthened, enforcing functions causing person-traffic, such as e.g. big offices, to be located within 600 m from a railroad station, and minor functions to be within 1200 m. Another important principle of the Fingerplan is the ranking of urban development. That means e.g. that areas within station-proximity have to be built-up before areas outside can be. Not all these principles and rules can be implemented in the model – however, the overall guidelines regarding development along the fingers will be included as outlined in section 4.4.

3 Methodology

Land use modelling implies a number of steps and tasks. The parts most discussed are usually running scenarios and evaluating them. These parts, however, require a range of pre-steps which are often invisible to outsiders as illustrated in Figure 3. Also, the tasks “below the sea level” like data collection, model setup and calibration demand most working time (see Annex for a description of the activities).

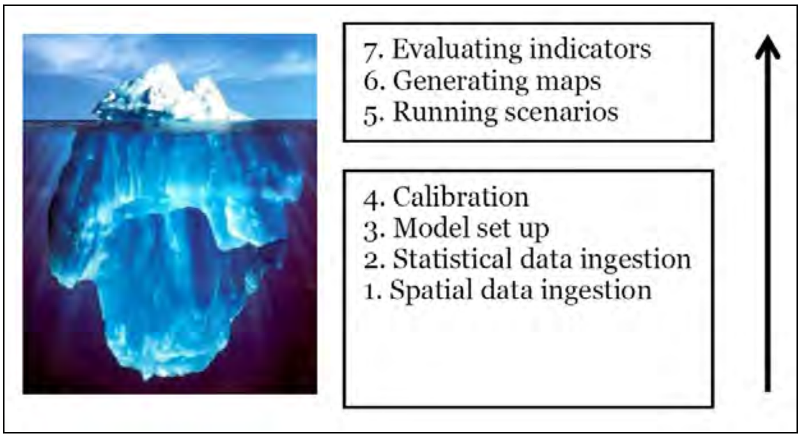

Fig. 3: Representation of underlying tasks behind running scenarios in MOLAND
Source: Mubareka & Lavalle (2010); photomontage by Ralph Clevenger (1999)

3.1 Stakeholder involvement

Additional to these steps we discussed the approach with planning professionals from the Danish Ministry of the Environment – the responsible authority for the Fingerplan. Together with the participants with discussed the modelling approach, input data quality, scenarios and finally the results at two informal meetings. There was positive feedback, but also several critiques were mentioned, especially regarding details on model inputs, model constraints and the scenario setup. It was concluded, that it is important to be clear about which questions can be asked and answered with such an approach, and which not. The general involvement of stakeholders was, due to the character of the project, rather smal. Usually more time should be spent to discuss the different issues with more stakeholders in several workshops.

3.2 Modelling with “Metronamica”

The modelling tool used for this project is Metronamica developed by RIKS (2010a). It was used in a number of cases studies by RIKS and other institutions (Rutledge et al. 2008;van Delden et al. 2010;Wickramasuriya et al. 2009). The modelling framework MOLAND, which is used by the EC’s Joint Research Centre (Barredo et al. 2003;Petrov, Lavalle, & Kasanko 2009), uses the same modelling framework as Metronamica which was originally developed by White, Engelen & Uljee (1997).

Metronamica is based on a cellular automaton (CA). CA models combine elements of macro- and micro-simulation (Macy & Willer 2002). They consist of a regular grid of cells which change their status by a simple set of rules. In our case each cell is attributed with one type of land use. For each time step (one year) transition rules are applied to each cell and might result in a land use change. Transition rules can include rules about attractiveness of other land use types in the neighbourhood, transport accessibility, suitability considerations and zoning. Furthermore a random perturbation is introduced to account for uncertain developments, producing small amounts of “noise” in the model. The different rules are multiplied with each other, resulting in a unique value of transition potential (RIKS 2010a, 191). All cells are ranked by their transition potential for each land use and are then filled starting with the cell with the highest potential until all demands are satisfied.

The core elements of each CA are transition rules based on neighbourhood characteristics. In Metronamica these are derived from distance-decay functions, illustrating the attractiveness of the neighbourhood of one land use to another. E.g. residential land use could be set to be attracted to be close to highways because of accessibility. Areas too close to the highway would however be repulsive because of noise and air pollution. A typical rule derived from calibration is that land uses are attracted to other cells with the same land use, i.e. residential /urban use is attracted to existing urban /residential cells.

The transition rules are derived from calibration, usually done by trial-and-error and by the modeller only. There are attempts to quantify these rules empirically (see e.g. Hagoort, Geertman, & Ottens 2008;Hansen 2010). However, for outsiders this might appear like a black box and even for the modeller it is often hard to understand how the rules influence the result.

The driver of land use change is the projected change of population and employment (and its respective land uses) during the modelling period. Different projections (e.g. population growth or stagnation) as well as different rule sets (e.g. zoning regulations) can be used to set up several scenarios.

3.3 Scenario plots

Metronamica offers a range of options to introduce different aspects of scenarios including different growth assumptions, different infrastructure settings and different zoning, allowing the introduction of complex storylines. For this pilot project we decided to focus on different spatial policy scenarios only, keeping growth assumptions and infrastructure settings the same across the scenarios. The assumptions on growth and infrastructure are described in section 4.1.

After a meeting with experts from the Ministry of the Environment we decided to implement three policy scenarios which can be illustrated along an axis from stricter to weaker planning regulation (Figure 4). The Fingerplan scenario includes the full implementation Fingerplan 2007 with it different zones. Further it includes planning regulations on nature protection. In the

Green Wedges scenario only the area designated for green wedges in the Fingerplan 2007 is implemented as well as nature protection, but excluding coastal area protection. The Only Nature scenario includes neither any regulation from the Fingerplan nor coastal protection. Only the strictest regulations on nature protection are implemented, including Natura 2000 areas, Danish nature areas (§ 3 of the Danish Nature Protection Act, da:Lov om naturbeskyttelse) and listed areas (da:Fredede områder).

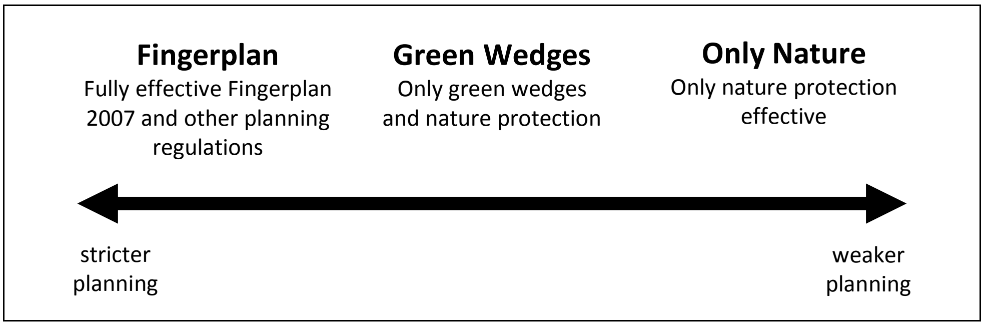

Fig. 4: Three Policy scenarios

The Green Wedges and especially the Only Nature scenarios are hardly realistic, and neither is the full and strict implementation of the Fingerplan 2007. The model scenarios thus serve to illustrate various ‘extreme’ policy scenarios and accordingly the spatial consequences of such hypothetical scenarios.

4 Model inputs

Before simulating future land use (= Exploration), the model parameters and transition rules have to be calibrated by analyzing the past development, comparing the actual land use change between two points in time with the results of a simulation of the same period (Figure 5). The exploration of future land use is then based on the rules derived from the calibration. So for this project two models were set up:

- Calibration for the years 1990 – 2006
- Exploration of future land use based on scenarios for the years 2006 – 2040

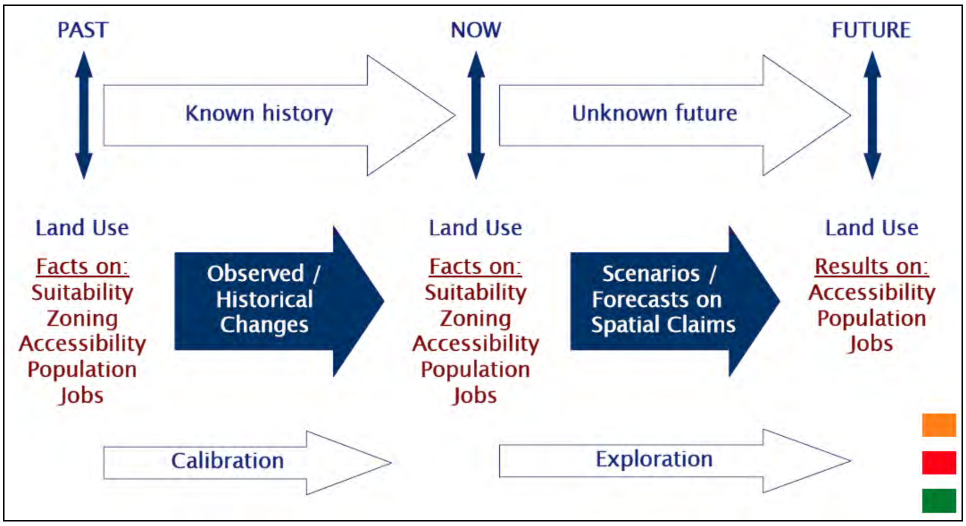

Fig. 5: Two simulation steps: Calibration and Exploration
Source: RIKS (2010b)

4.1 Land use data

The most important data for a land use model is a land use map. For Copenhagen, only the CORINE data base (EEA 2010) is providing data for more than one point in time (1990, 2000 & 2006), covering the region in 100 m cells resolution. Another land use classification of Denmark is AIS (Areal Information System) provided by the Danish Ministry of the Environment. AIS is more detailed than CORINE – especially in urban areas –, but it exists so far only for 1998. The derived land use classes as shown in table 1. We kept more detail in urban classes as we are interested in urbanisation. Other classes, such as e.g. agriculture or natural areas, are more aggregated.

The projection of future land use needs is based on the population projection of Statistics Denmark (DST 2011) as well as on the previous development. The DST projection shows a continuous population increase, reaching 2 158 000 inhabitants in 2040; 315 000 more than in 2006. To derive the amount of cells from population numbers we calculated the average land consumption of new population in the calibration period 1990-2006. In that period around 110 m^2 of land were transformed into continuous/ discontinuous urban fabric per new inhabitant. The overall ratio in 2006 amounted to 270 m^2 of continuous/discontinuous urban fabric per inhabitant. The growth in urban areas per inhabitant in the period was thus smaller than the ratio accumulated over the years. Densification and urban renewal policies up through the 1990'ies may have a share in this. However, other urban land uses such as commercial area increased faster. But as we do not have any projections on the development of jobs or on other issues, we assumed a similar development as in the calibration period (see Figure 6 and Table 1).

Tab. 1: Land use in the modelling area

#	Name	CORINE classes	Land use in hectare (= 100 m cells) 1990	2000	2006	2040
0	Agricultural areas	211-244	174.154	172.375	169.070	?
1	Forests	311-313	34.747	34.602	34.606	?
2	Semi natural areas	321-335	7.372	7.738	7.702	?
3	**Continuous urban fabric**	111	2.853	2.853	2.853	3.051*
4	**Discontinuous urban fabric**	112	45.063	45.329	46.380	49.601*
5	**Industrial or commercial units**	121	5.237	5.539	6.189	8.000*
6	**Mine, dump and construction sites**	131-133	732	1.281	1.395	1.800*
7	**Green urban areas**	141	5.896	5.860	5.965	6.300*
8	**Sport and leisure facilities**	142	3.445	4.032	5.516	7.000*
9	**Summer houses**		7.584	7.642	7.673	7.800*
10	Transport units	122-124	4.239	4.338	4.433	4.433
11	Wetlands	411-423	4.683	4.637	4.532	4.532
12	Water bodies	511-512	8.086	8.178	8.177	8.177
13	Sea and ocean	521-523, 995	304.032	303.719	303.632	303.632
	Total		608.123	608.123	608.123	608.123

** Assumed changes*

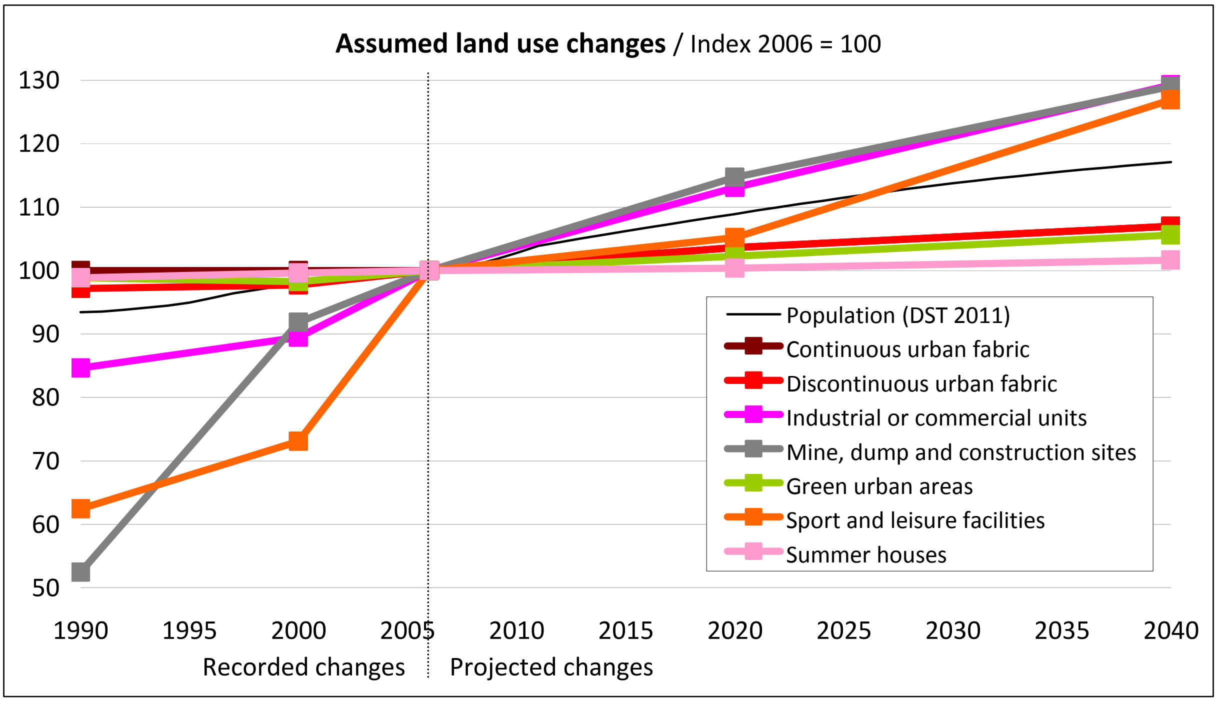

Fig. 6: Assumed land use changes of function classes

An exception is "sport and leisure facilities", which mainly consists of golf course. Golf courses boomed in the recent decade, but due to the financial crises and a current saturation of consumer demands, it is very unlikely that any new course will be established until 2020. This means that 5230 ha of non-urban land is expected to change into urban land (land use classes 3-5 in table 1) until 2040. This number of hectares (or cells) is the basis for all three scenarios.

Metronamica has a technical limit of around 50 different land use classes. However, to keep the model robust the number of land use classes should be kept low. For this project we kept more detail in urban classes as we are interested in urbanisation. Other classes, such as e.g. agriculture of natural areas, are more aggregated. Table 1 shows the final choice of land use classes, their origins in CORINE and the number of hectares (=cells) they cover.

Some changes of the CORINE data where done manually as for example the extraction of summer house areas from the CORINE class 142 sport and leisure facilities into a separate class by using AIS data and orthophotos. Summer houses constitute an important land use class in the case area and are different regulated in the Fingerplan than golf courses or marinas, which are also included in class 142. Further some corrections of wrongly allocated land use have be done (see Annex).

In Metronamica land use classes have to be further defined as either vacant (here 0 – 2), functions (3 – 9) or features (10 – 13). Functions are active classes for which the demand is set as a modelling parameter. For calibration the demands of new cells between 1990 and 2006 is taken directly from the land use data from 2000 and 2006. Vacant classes are passive and do not have a specifically set demand. When the demand for functions is satisfied, the remaining cells get filled up with vacant land uses[2]. Feature classes are land uses which do not change. They can however have an influence on the transition potential of neighbouring cells.

4.2 Accessibility

Accessibility has an important influence on urban development and location strategies. In Metronamica, inserted infrastructure is used to calculate the accessibility of cells. This is done by calculating the distance (with a decay effect) of each cell to a certain infrastructure, e.g. highway ramps or railroad stations. The different infrastructures can be weighted differently for each land use. E.g. for high density urban fabric a metro station could be set very important, while that is not the case for industrial areas. On the other hand, the latter might be more attracted by highways.

Infrastructure can also be used to calculate a fragmentation indicator of patches. E.g. a highway can be set as a barrier, splitting natural areas and increasing their fragmentation. We mainly introduced transport infrastructure in this model (see Annex for details), but it is also possible to include any other form of infrastructure as e.g. schools, hospitals etc.

[2] Metronamica calculates a completely new land use map for each year. Most cells stay usually the same land use as their calculated transition potential from neighbourhood attractivity, accessibility, zoning etc. is too low to induce change.

We included the following transport infrastructure:

- Metro / s-train stations (including stations of the "Kystbanen", line along the Øresund)
- Other railway stations
- Highway ramps
- Major roads
- Other roads
- Copenhagen City centre (Rådhuspladsen)

Different (or changed) infrastructure layers can be introduced for each modelling step (=year). For calibration we had exact information on the opening of e.g. s-train station. To account for future accessibility changes a number of planned and discussed new transport infrastructure projects are introduced into the model (see also Fig. 17:). Those include (assumed inauguration year):

- Metro Cityring (2017)
- Frederikssund Highway – extension to Måløv (2020)
- Lightrail along Ring 3 (2025)
- New s-train stations and a few other stations (2025)
- Connection over Roskilde Fjord at Frederiksund (2025) and other new major roads (Ring 5 etc.)
- Frederikssund Highway – extension to Frederiksund (2030)

The information on the spatial location of the planned infrastructure was derived from the WebGIS database of the Fingerplan 2007 (http://miljoegis.mim.dk/cbkort?profile=miljoegis_hovedstad02).

4.3 Suitability

Another factor influencing the transition of cells is suitability. Usually data on elevation and slope are included here; but also soil quality could be an issue when the model focuses on agricultural change. We chose not to include any layer on suitability as we assume that it does not have a crucial influence on the issues we are interested in. The suitability defined by zoning regulations however is included, but in a separate module of the model.

4.4 Zoning

Metronamica allows the introduction of different zoning maps with different start and end points. According to the zoning category a cells falls into, a factor for its transition potential is assigned. The zoning plans introduced for calibration are listed in Table 2. Not all zoning plans have an impact on all land use functions (an example is shown in the Annex). The categories each zoning plan is working with the following categories:

- Actively stimulated (factor 1.5 – 3)
- Allowed (factor 1)
- Weakly restricted (factor 0.5)

- Strongly restricted (factor 0.001)[3]
- Unspecified (no influence on transition potential)

These categories can only be chosen when setting up the model, although the factors can be altered later and also for each land use.

Tab. 2: Zoning regulations used for calibration

English definition	*Danish definition*	*Source*
Protected nature area (Danish Nature Protection Act §3)	Beskyttet natur (Lov om naturbeskyttelse §3)	Miljøportalen http://kort.arealinfo.dk
Listed areas	Fredede områder	Miljøportalen
Natura 2000 Birds directive	Natura 2000 Fuglebeskyttelsesområder	Miljøportalen
Natura 2000 Habitats directive	Natura 2000 Habitatområder	Miljøportalen
(Ramsar-convention areas do not occur in case study area		Miljøportalen
New planned residential and commercial areas	Ny bolig og erhvervs områder	Regionplan 1989, Amtsplaner 1993, Regionplan 2001
Golf courses	Golfbaner (4.2.2 Allerede båndlagte arealer i ny grøn ring og kileforlængelser)	Regionplan 2005
Potential Mining areas	Graveområder	Regionplan 1989, Amtsplaner 1993, Regionplan 2001
Green wedges	Gønne kiler	Regionplan 1989
Coastal protection zone	Kystnærhedszone	Miljøportalen

Note: Plans located higher up in the table overrule other plans when they have zoning information of the same cell.

For the exploration the Fingerplan 2007 was introduced. As written in section 2, the Fingerplan 2007 zones the metropolitan area into 4 major areas (palm of the hand, fingers, green wedges and rural areas) and some minor areas. For the model we adjusted the delineation slightly into 7 zones:

- Urban areas in palm of the hand and in fingers
- Other areas inside the fingers and urban areas in municipality centres outside fingers
- Summer house areas
- Other urban areas
- Rural areas
- Reserved Transport corridor and airports
- Green wedges

These zones mainly influence new urban fabric or new industrial/ commercial areas. Urban areas in the palm and the fingers are set to stimulate development, while development in the green wedges is restricted. A part of the Fingerplan is also the reservation of area for a future transport corridor.

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[3] Strongly restricted would usually require a factor 0 (than the whole transition potential of that cell is 0). However, in seldom cases development also occurs in these areas. With a factor of 0.001 the probability is set extremely low, but it is not completely impossible – e.g. when the cell gets a very high value from random perturbation.

Parts of this corridor are within the Fingers and are restricting development on land which otherwise would allow it. We therefore removed restriction in these areas from 2025.

Additionally a zoning layer for mining areas is included. The Fingerplan 2007 does not have any regulation on mining; this is done by the regions. We used data from the Regionalplan 2005 which is valid for 12 years; so we introduced this layer until 2017 in the model.

4.5 Random perturbation

Another element to influence the transition potential of a cell is by introducing some randomness to the model. The idea is not to change the general dynamics resulting from the other factors, but to allow some deviation from the ‘normal’ in a few cases. The introduction of random perturbation will typically also result in more realistic urban forms, consisting of some irregularities.

In Metronamica there is only one random perturbation for all land use class, i.e. that it is not possible to have some land use classes being located more randomly than other. The random factor also depends on the other model parameters: If a model is very strong constraint by zoning etc. it is necessary to introduce a higher factor to have some effect than if the model parameters are allowing more choice beforehand. In our calibration a factor of 0.6 gave the best result which lies on the middle lower end of typical random factors used other Metronamica applications.

5 Results

5.1 Calibration results

Calibration is an iterative process, shifting between the adaptation of the model characteristics, e.g. the adjustment of a certain neighbourhood function, and the validation of the simulation compared with the recorded land use changes. There are some recommendations on how to pro-ceed through calibration. However, due to the nature of a model based on a cellular automaton (CA), it is always necessary to go back and analyse issues which were calibrated earlier. Every introduction of a new rule demands more time for validation and adaptation.

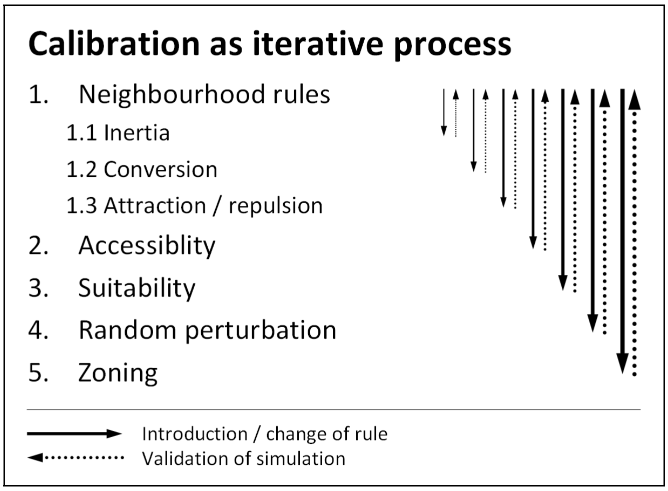

Fig. 7: Calibration as iterative process

Still, it will never be possible to have a perfect simulation as there are too many uncertainties which cannot be accounted for. This is especially true for a complex system like an urban region. The aim is therefore not necessarily to model as close to the reality as possible, but to have a realistic model. Visual inspection of the simulated maps is of course an important method to validate the result, but the modelling tool and the Map Comparison Kit[4] offer a wide range of methods to qualify and quantify the results.

Here it is important to differentiate between global, focal and local measures. Global measures compare the global performance of the model, e.g. the total number of cells in a certain category that has changed – in the model and in real life. Focal measures compare the similarities in a certain radius of a cell, e.g. if a certain land use is in the close neighbourhood but not exactly on the same location as in the recorded data. Local measures analyse the analogy of single cells.

For global measures the easiest way is a contingency table, comparing the occupation of cells of each land use class. Table 2 is a combination of two contingency tables. It shows how high the deviations of the simulated changes are compared to the recorded changes for each land use class function. E.g. in the simulation 44 cells more than in the recorded data got transformed from Forests to Discontinuous urban fabric. Compared with the total number of new discontinuous urban fabric cells (1317) this is only a minor part. All relations without any value have the same number of transformed cells in the simulated as in the recorded data.

[4] For the comparison of maps, RIKS developed the software “Map Comparison Kit” which can be downloaded for free on http://www.riks.nl/mck.

Tab. 3: Land use changes to function classes 1990-2006 / Simulated vs. recorded changes

		Deviation of simulation from recorded changes 2006						
		Continuous urban fabric	Discontinuous urban fabric	Industrial or commercial units	Mine, dump and constructions sites	Green urban areas	Sport and leisure facilities	Summer houses
1990	Agricultural areas		77	71		-18	-23	-44
	Forests		51			2	12	11
	Semi-natural areas		-36	1	-24	7	7	
	Continuous urban fabric	-5	1			1		
	Discontinuous urban fabric	62	-82	-52		8	-1	
	Industrial or commercial units	20	-23	-6		11	0	
	Mine, dump and constructions sites		4		55		-22	
	Green urban areas	1	-44	4		9	1	
	Sport and leisure facilities			-4	-31	9	29	
	Summer houses		-1	-14			-2	33
Total change 1990-2006[(5)]		0 (78)	1317 (1239)	952	663	69	2071	89

Local assessment can be done with Kappa statistics. Kappa measures the agreement of two items – in this case the cells in two land use maps by class. The difference from a simple percentage calculation is that Kappa includes the agreement by chance, i.e. how much better is the model than a completely random map. In the Map Comparison Kit a sub variant exists, called “Kappa Simulation” (see also van Vliet, Bregt, & Hagen-Zanker 2011). Here the random map is constrained as only newly changed cells are included in the comparison. Unchanged cells, which in a land use model usually are the vast majority, are not included. Kappa Simulation calculates a global measure of correspondence resulting in values between -1 and +1. Values above 0 mean that the simulation explains more than the random constraint map and therefore explains some land use change. There exist no other absolute thresholds for that measure[6] and the results are obviously dependent on the level of complexity of the modelled system. Our final calibration which was basis for the scenario simulation reached a value of around 0.31.

The challenge with calibration in this particular case is to filter the “natural” logics of urbanisation from influences of contemporary spatial plans, which have a strong influence on spatial development in Denmark. It is hard to find out by which combination a certain development is caused, or if some “natural” logics are even opposed to planning logics but are invisible due to the stronger influence of planning. Hence, the question: how would the

[5] The cell demands for each class are based on the recorded changes and are therefore the same in the simulation. Only for the two urban fabric classes the cell demand was calculated from population development figures and afterwards allocated to the two classes (numbers in brackets).

[6] However, from experience of modellers at RIKS working with similar land use models, 0.2 has significance and above 0.4 is quite a good calibration result.

region look like without any planning is a tricky one to answer. In our calibration, when excluding all regional plans and only keeping the strict nature protection zoning, we get a Kappa Simulation value of around 0.17. So the model still explains some land use change even without information on planning.

However, Kappa Simulation alone cannot describe the model's goodness of fit. Other parameters like e.g. patch size and form are important when the aim is to model as realistic as possible instead of as accurate as possible. Different Focal measures which include a fuzzy approach take that into account and were used during the process of calibration but will not be discussed further here.

Fig. 8: shows the result of the calibration compared to the actual changes occurred. There is some overlap, however, several areas are wrongly allocated. The difficulty with the modelling of urban areas was, that they in the model occur cell by cell while in reality the often occur in patches or clusters of several cells. Some of this could be modelled with the inclusion of zoning maps. However, it stayed a challenge. Another issue on is the focus of new urban area in the southern area of the region in the simulation, while in reality a considerable part of new urban areas appeared also in the northern part. This might be a result of the use of zoning data in the simulation. E.g. in the regional plans from 1993[7] no new areas for urban land use were allocated in the northern part because earlier allocated land seemed sufficient.

There is also a relatively high variance/uncertainty within the calibration (see Figure 10). The result of the calibration could certainly be further increased, though with a considerable amount of time. We stopped we calibration at that point to continue with the work on scenarios

[7] At that time separate regional plans were produced for the different parts of the regions as there was no metropolitan planning authority existing between 1989 and 2000.

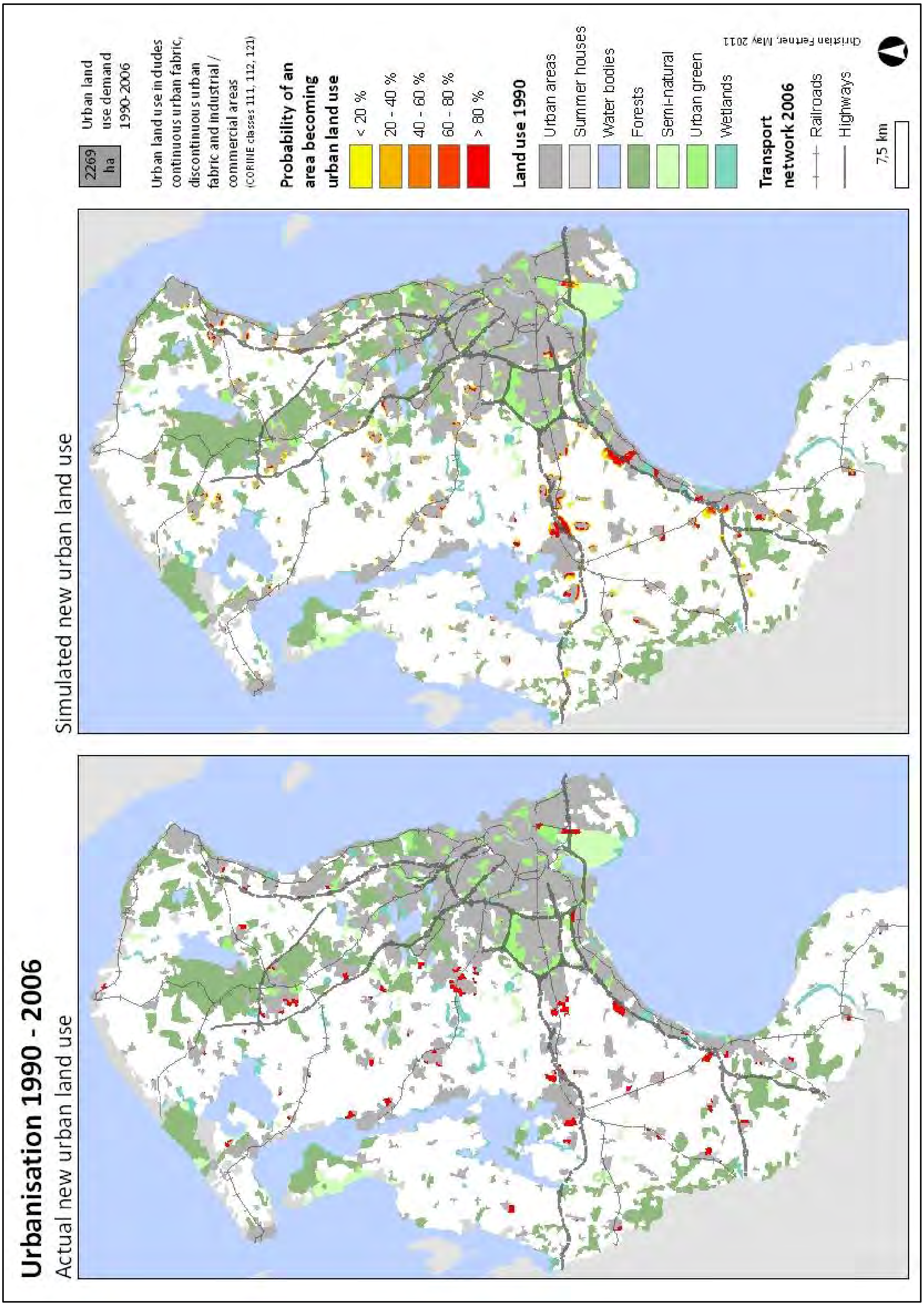

Fig. 8: Urbanisation 1990-2006 – Recorded changes and model probability

5.2 Scenario results

This modelling exercise focuses on the transformation of non-urban land use into urban land use on the background of different policy scenarios. The growth assumptions, as described in section 4.1 and in table 1, result in a total urban land use demand of 5230 ha until 2040. Urban land use includes continuous and discontinuous urban fabric as well as industrial/commercial units (land use classes 3-5 in table 1). Table 4 summarizes the trends of major land use changes in each scenario related to issues of the Fingerplan including station proximity. The exact changes refer to one model run and are subject to some uncertainty as discussed in section 6.1.

Tab. 4: Land use changes 2006 – 2040

Scenario Policies set	**Fingerplan** Full Fingerplan 2007 and other plans effective	**Green wedges** Only green wedges and nature protection	**Only nature** Only nature protection
New urban areas[8] outside Fingers	-46 ha	2347 ha (45 % of total increase)	2879 ha (55 %)
New urban areas in rural areas	2 ha (0 %)	1841 ha (35 %)	1381 ha (26 %)
New urban areas in green wedges	-50 ha	-38 ha	1070 ha (20 %)
New urban areas in coastal buffer zone	1858 ha (36 %)	1721 ha (33 %)	1749 ha (33 %)
New urban areas within 600 m from station[9]	578 ha (11 %)	362 ha (7 %)	422 ha (8 %)
New urban areas 600-1200 m from station	1222 ha (23 %)	654 ha (13 %)	781 ha (15 %)
New urban areas not within station proximity	3430 ha (60 %)	4204 ha (80 %)	4027 ha (77 %)

The maps in Figure 9 show the probability of urbanisation after 100 model runs for each scenario. E.g. cells which are dark red have become urban land use in at least 80 of the 100 runs; i.e. the chance of urbanisation is above 80 %.

[8] Urban areas include “continuous urban fabric”, “discontinuous urban fabric” and “industrial and commercial units”; the case study increased in total with 5230 ha of urban areas from 2006-2040

[9] Only railroad stations (s-train, metro etc.) within the finger-structure are included.

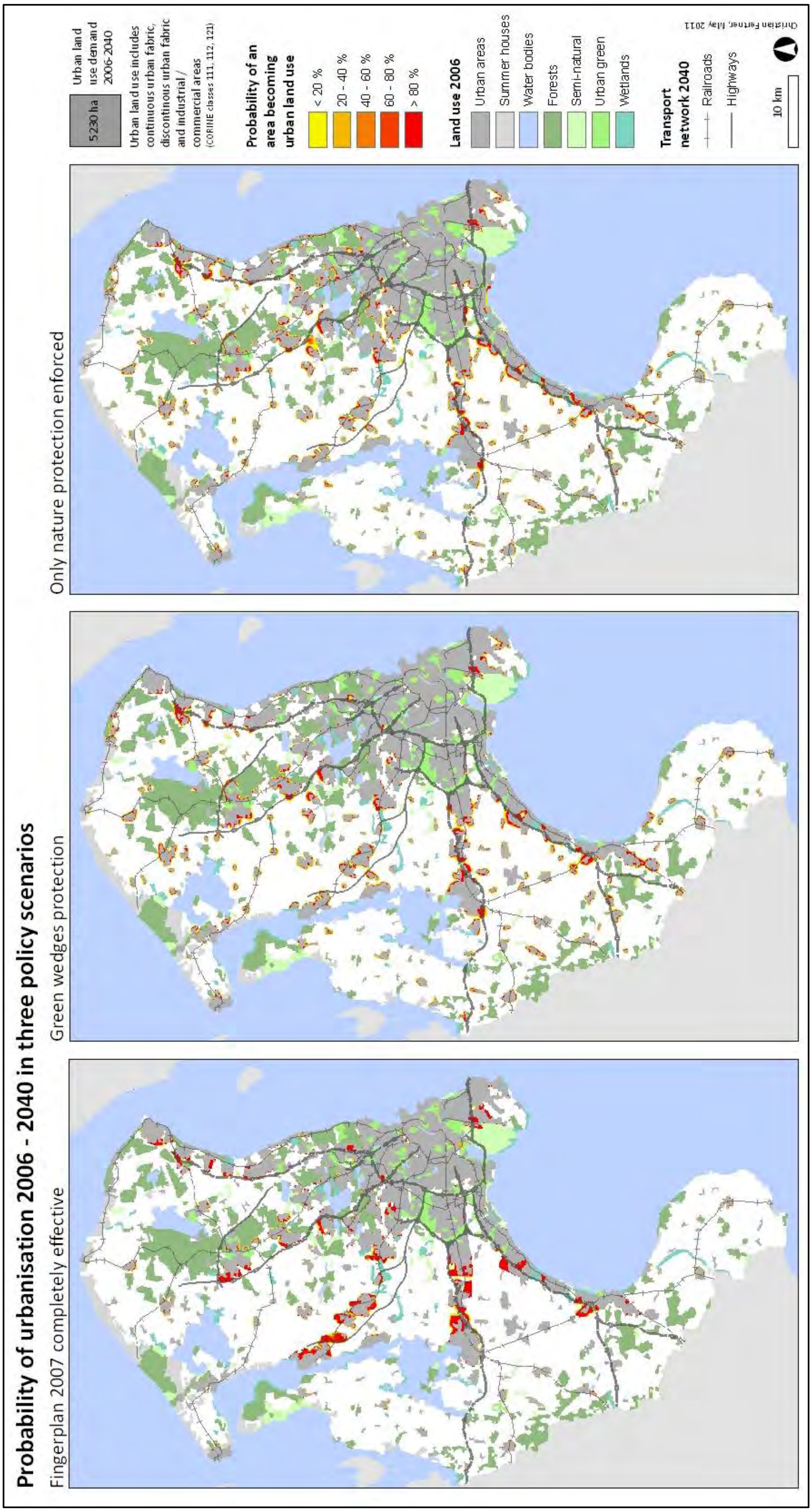

Fig. 9: Probability of urbanisation 2006 – 2040 in three policy scenarios

Scenario "Fingerplan"

The first scenario illustrates urban growth in the region when the current Fingerplan as well as other zoning regulations are fully implemented and will be kept the same in the next decades. From Tab. 4: we can conclude that the assumed increase of urban land use can be accommodated in the areas assigned for urbanisation within the Fingers[10], filling about one third of the open space in the Fingers. Most of the open space is available in the Finger towards Frederikssund in the Northwest. However, our growth assumptions are only moderate. Key characteristics of urban development in this scenario are:

- A third of the development will happen within the 3 km coastal buffer zone. That is because the Fingerplan assigns urban land also in coastal areas.
- Rural areas11 will be kept rural
- More new urban areas than in the other two scenarios (34 % vs. 20-23 %) will be within a 1200 m radius from a train station.

Scenario "Green wedges"

In the "Green wedges" scenario the Fingerplan 2007 is reduced to the protection of the green structure; nature protection is enforced, coastal area protection is not.

- About half of the new urban areas occur outside the Fingers, most of it in rural areas. The protection of green wedges presses development towards the rural areas.
- Coastal buffer zones are slightly relieved as more areas are open for development now compared to the Fingerplan
- In this scenario the amount of new urban areas within station proximity is lowest as highly accessible areas in the green wedges are protected, but areas in the countryside, often remote to stations, are not.

Scenario "Only nature"

The "Only nature" scenario only applies the strongest nature protection regulations. Coastal area or the green wedges are not specifically protected:

- Less rural areas than in the "Green wedges" scenario get urbanised due to the possibility of development in the green wedges close to Copenhagen, including areas close to the coast.
- A considerable amount of new urban development happens within the existing green wedges protection zone, probably due to proximity of these areas to existing urban areas. 1070 ha (20 % of all new urban areas), or 3 % of the green wedges will be urbanised, and the scenario shows the fragile status of urban green structures if they are not protected.

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[10] In total the Fingerplan (Palm of the hand, fingers and regional towns) include 65,265 ha. In 2006 47,396 ha (73 %) were urban; 12,198 ha (19 %) were agricultural area; the rest were parks, natural areas or other open areas. Our growth assumption of 5230 ha could easily be accommodated in agricultural land inside the Fingerplan.

[11] Rural areas as defined in the Fingerplan 2007, excluding areas defined as towns outside the Fingers.

The hypothesis introduced in the beginning of this report, that the Fingerplan will prevent urban growth considerably outside the Fingers and will support growth close to the suburban train stations, could be verified. However, the results of the scenarios are also a result of the assumptions put into the model in the first place. So a proper verification is not possible. Although when comparing the three scenarios some conclusions can be drawn: The Fingerplan can accommodate the projected growth in the scenarios; protection of green wedges is necessary; and for the green wedges to be effectively protected we also need the rest of the Fingerplan – otherwise urban areas will spread into the countryside. Still, even this result has to be taken with caution, as this project was designed as a pilot and experimental project, limited in time and resources. We will discuss the limitations of this approach in the following section.

6 Conclusions

6.1 Limitations of the modelling approach

A model is always a simplification of reality. Hence, several limitations apply which are important to consider when discussing the results of a modelling exercise. We can differentiate between two kinds of limitations: Limitations due to the structure of the modelling system, and limitations due to our own project setup. Some can be part of both. E.g. zoning regulations have to be simplified so that they can be translated into model parameters and some regulations cannot at all be illustrated in the model. But they are also simplified to limit the complexity of inputs and to distinguish effects more clearly. This limitation is caused by the modeller and not the model itself.

Grid representation and single cell status

The basis of the Metronamica modelling environment is a cellular automaton, which implies a cell grid space. The grid space simplifies the reality, but the more crucial limitation is that each cell can only contain one specific land use. It is not possible so far to combine more information in one cell, e.g. the share of different land uses or information on activities (for a possible approach see van Vliet et al. 2011). In reality, however, many cells are mixed to a certain degree. Such a cell status can only be introduced superficially – as a separate land use category – which would probably not come closer to reality. Especially the issue of urban renewal, which accounts in the Copenhagen region for the majority of all building activities and absorbs a lot of demands for new buildings, is not incorporated in the model, only in the sense that the absorption of a part of the urban growth is reflected in the gross amount of expected new urban land per inhabitant.

Neighbourhood effect smoothes cell allocation

Another issue is the allocation of new cells following a transition potential which is based on neighbourhood effects and distance decays. These rules foster the allocation of single new cells dispersed over various locations which have the highest potential. In reality however, e.g. new urban areas get established as bigger patches or clusters instead of single cells. This effect is currently hard to model.

Calibration as a mean for exploration studies

Besides the difficulties of modelling real changes, the way of using calibration to set up explorative studies can be seen as critical, as it assumes that e.g. land use change will follow the same rules in the future as it has done in the past. Van Vliet (2011) points this issue out by writing that *"there is the implicit assumption that the behaviour of spatial actors (as expressed in model parameters) remains constant over time. This is certainly reasonable, over a limited period, but […] over time, extrapolations become more uncertain (or speculative)."* However, for the typical simulation period of about 30 years this approach seems reasonable (van Vliet 2011).

Resolution decisive to which dynamics can be modelled

The resolution is not an in-built model limitation, but a choice of the modeller. However, depending on the size of the modelling area, RIKS recommends cell resolutions between 50 and 500 m for an urban region model. Smaller resolution are more accurate but not necessarily useful to model on such a scale. On the other hand, at a resolution of 100 m like in this project, some dynamics become invisible, as e.g. the dispersed development of new houses in ex-urban or rural areas.

Model uncertainty

As the model has a random factor in-built to account for uncertain events, each model run deviates from another. This is even strengthened by the cellular automaton structure, which allows the system to react to small changes when reaching a tipping point. In general this is a setup which is useful for learning. However, depending on the other model parameters, the results might deviate to a large extend between the runs. Figure 10 shows the difference in deviations between the three scenarios. In the Fingerplan scenario the locations of new urban areas are more often the same in each run then in the other scenarios, accounting for the strict zoning regulation introduced in former. The calibration itself also shows a relatively high deviation and surprisingly almost no cells which are always subject to urbanisation after 100 model runs. So the uncertainty in the calibration is relatively high. This could be an indicator – together with one about the goodness of the calibration as e.g. Kappa Simulation – worth to improve in a follow-up study.

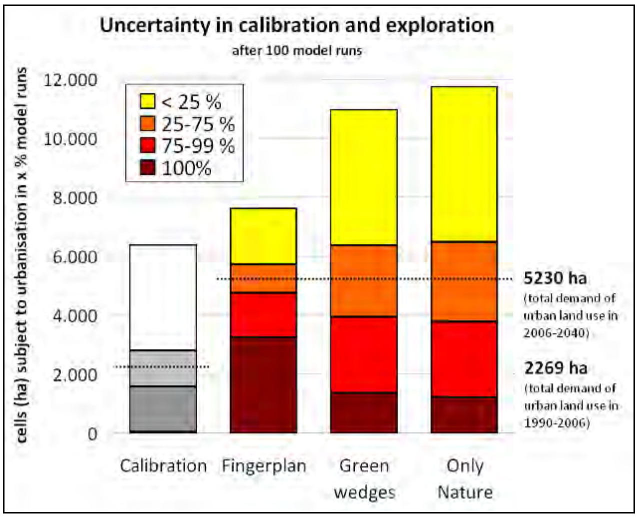

Fig. 10: Uncertainty in the scenarios

Simplification of zoning regulations

One element influencing the transition potential of cells in the model is zoning. Many of these regulations have to be simplified to be inserted in the model and some regulations might not even be possible to translate into model parameters. This is not only because of the given model structure, but also because of data availability. E.g. an important regulation in the Fingerplan 2007 is about the spatial location of person-traffic intensive functions such as big offices. The land use data used here (CORINE) does however not distinguish in that detail. All commercial and industrial land uses are merged in one category.

Another issue is the distinction of urban and rural areas in the Danish Planning Act (§§ 34-38). This regulation protects rural areas from getting built-up without proper planning permission from the municipal council or other authorities (ministries), including the possibility of an Environmental Impact Assessment procedure. In our case that means that even without the Fingerplan, rural areas would be protected to a certain degree. We did however not include this regulation in the model as it is applied locally and site-specific, making it hard to translate into a general regional zoning map.

Scenario plots

As written earlier, scenarios should usually be developed together with stakeholders, including an agreement on how they will be inserted in the model. Zoning regulations can be interpreted differently as can assumptions on growth. In this project we differentiated the scenarios only by different policies, without changing the growth assumptions. This facilitates the interpretation and discussion of the results, but is not accounting for the fact that variations of growth might be unrealistic. E.g. if there is no planning regulation at all, a much higher growth in the amount of urban areas might be expected. Strict planning usually emphasises urban renewal and densification and hence decreases the amount of new urban land use demands.

For the projection of demands in the scenarios we referred to the official population projections from Statistics Denmark. Besides this inbuilt imprecision of such projections, it may be problematic to derive land use demands from population projections only, because even in times of economic crisis or population decrease, new land tends to be built-up. Furthermore, although using a relative conservative assumption on future land use demands with around 5230 ha within 34 years, the consumption in recent years with around 100 ha yearly is even below that. A more intense study of the region including the future need of commercial and industrial areas, would be useful to have a sound basis for the scenarios.

Finally, this study only includes zoning on a regional level. Many planning regulations are however done on municipality level. Areas laid out by the municipalities for future urban land use as well as locally differentiated land use demands would be an issue to elaborate further on.

6.2 Reflections over the project setup

Despite the limitations discussed above, the project setup can be summarized in the following points:

- The pilot project demonstrated the potential of a modelling exercise set up in a relatively short period of time and only with little experience in the field
- The application was kept simple because of limited resources, which limited its use for planning support
- Stakeholder involvement was very little; other potential partners like a regional authority (Region Hovedstaden) or the representation of the municipalities (KL/KKR) were not included
- Understanding and capacity in modelling increased

- Calibration is time-intensive – some more time could have improved the results; but the limit was good in a sense that we could also focus on the other parts of the modelling process
- Comprehensive material for further discussion was produced

The crucial point is, how to use the results and the material in the right way. After having set up a model, the temptation to use it for whatever question arising is very high. Practically this is possible, as the model is just an instrument which can be adapted in many ways. However, the model setup was done for a specific purpose: to model urbanisation in the case area to evaluate different zoning regulations. Using it for other purposes, e.g. deforestation or soil sealing is only possible to a limited extent as these processes work differently. Also, the results are not a general forecast of future land use change, but they are useful to discuss the overall performance of the Fingerplan and the general processes of urbanisation in the region. They are not an 'all-in-one solution', but an input for a wider debate.

Furthermore, the visualisation of the scenarios also enables non-professionals to get engaged in the discussion. Figure 11 shows the outcome of a small internal seminar held on 25 May 2011 at Forest & Landscape. Before the results of the modelling project were presented, the 11 participants were asked to point out (with stickers in yellow and red according to the legend) the hotspots of urbanisation until 2040 in a scenario with the Fingerplan and one without. Their guess is not that far from the modelling results, showing a more dispersed development in the scenario without the Fingerplan.

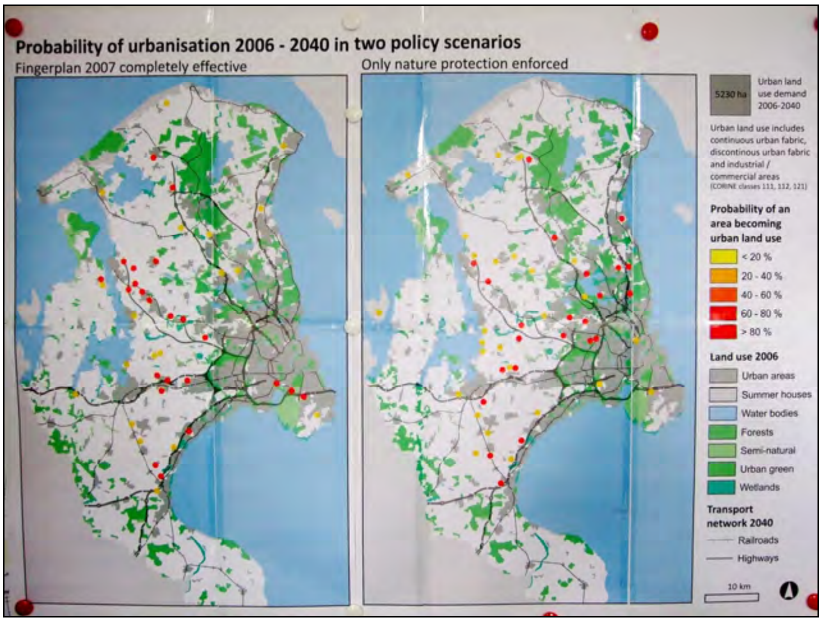

Fig. 11: Guesses by participants of internal seminar

6.3 Perspectives

The project has demonstrated the potential of such an approach and its use as input for a wider policy debate. Looking beyond the project's results, several possibilities for a further model development could be put forward:

- A refinement of the model, including calibration and exploration and working on the limitations mentioned above
- A more detailed analysis of the results with other indicators, e.g. different development in each finger or impact on accessibility
- A different set of scenarios, e.g. extension of the Fingerplan, different infrastructure or different growth assumptions
- An extension of the model with other modules, e.g. regional migration (differentiation of land use demands across regions), transport model (traffic congestion) or water (sewerage capacities)

The approach would also be interesting to use in a different case study in Denmark. The conurbation in East Jutland would be an obvious case, with a strong growth of urban areas but lacking a common regional planning scheme. The impact of future urban growth management initiatives or transport infrastructure projects could be analysed. But also the Copenhagen case could be extended to the whole island of Zealand to look at changes going beyond the area covered by the Fingerplan. Finally also the Øresund Region would be an interesting case, adding issues around the development of a cross-border city-region.

7 Acknowledgements

The contact to RIKS (www.riks.nl) in Maastricht was established during our joint engagement in the EU-FP6 project PLUREL (www.plurel.net). We would like to thank the staff at RIKS for their help and in particular Jasper van Vliet for his teaching and support. Thanks to Peter Hartoft-Nielsen and Jan Engell from the Danish Ministry of the Environment for their valuable comments on the project's setup and results.

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Annex A: Project organisation

The project ran from February 2011 for about three months. Christian Fertner was employed for 3 months fulltime to work on the project; Gertrud Jørgensen and Thomas Sick Nielsen supervised the project. The project was financed by the Centre for Strategic Urban Research (CSB) / Realdania Research. Modelling land use was new to the project team, although Christian Fertner has followed a 2-days introduction course to Metronamica (the modelling tool used) prior to this project in June 2010. The project was structured by activities and milestones as illustrated in Figure 12. The activities are partially overlapping as the modelling process also implies "trial and failure" and corrective actions of earlier steps undertaken.

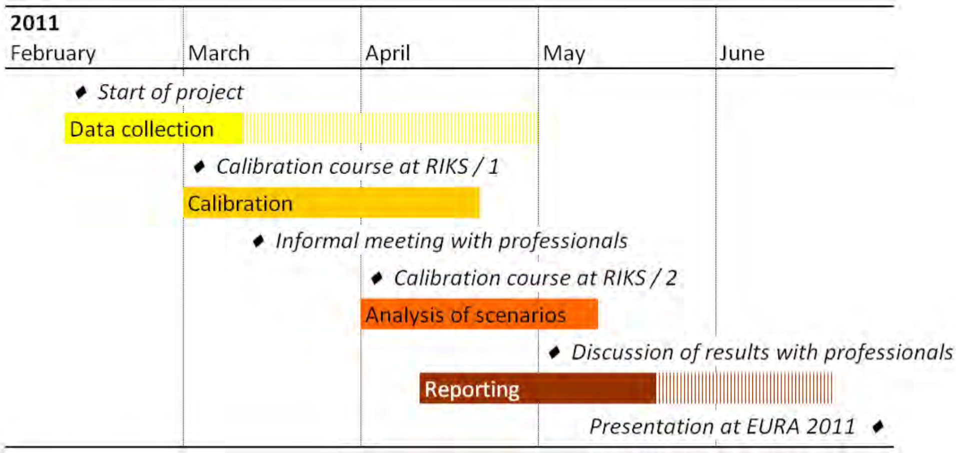


Fig. 12: Project timeline

Data collection, preparation and model setup
Metronamica requires a range of data to be inserted; the most important is a land use map as a basis for simulation. At least one second land use map to a different point in time is necessary for calibration. The input data is described in section 4. The challenge here is to prepare the data to be inserted in the model (e.g. cut, convert, generalize) which is done with GIS software. The setup of the model requires the modeller to decide several framework conditions such as simulation time, resolution and land use categories. In an optimal project setup, these issues should be discussed with potential end users.

Calibration
Calibration and validation is the process of trying to simulate land use changes as close as possible to changes that actually occurred within a given time frame in the past. In this process the model is adapted to the specific case, providing the basis for an exploration of future land use changes. A lot of "back and forth" and "trial and error" work is necessary to improve the model stepwise.

RIKS was visited twice for a 3-days working session with Jasper van Vliet. The first session was held 7-9 March 2011 touching on general ideas on modelling, model setup and calibration. The second session was held 11-13 April 2011, focusing on calibration and scenarios.

Analysis of scenarios

When the calibration of the model is of a satisfying quality, explorations/future scenarios can be simulated. Variables that may be changed in different scenarios are often the drivers (population, jobs…) which result in different land use demands. Another option is to implement different spatial policies or also a combination of both, which are used to translate (abstract) scenarios into the model. The analysis and evaluation of the different scenarios then provides the core results of the modelling project.

Meeting with experts from the Danish Ministry of the Environment

In a first informal meeting on 16 March 2011 with Peter Hartoft-Nielsen and Jan Engell from the Ministry of the Environment / Nature Agency, the project was discussed. Issues were the modelling approach, input data quality as well as scenarios. It was suggested on to check CORINE land use data for major errors. Further, three policy scenarios were recommended for exploration:

- A "business as usual" scenario with the Fingerplan 2007 fully effective
- Same as above, but the green wedges are not particular protected
- A Scenario where only listed areas are protected

At a second meeting on 30 May 2011 the results were discussed. There was positive feedback, but also several critiques were mentioned regarding details on model inputs, model constraints or the scenario setup. It was concluded, that it is important to be clear about which questions can be asked with such an approach and which not (see discussion section).

Reporting

Reporting involves technical reporting on the modelling process as well as a discussion of results. In this project this is particular important as the approach is new to us and one important outcome is to gain experience and learn lessons.

Presentation at EURA 2011

The results will also be presented and discussed at the annual conference of the European Urban Research Association in Copenhagen, 23-25 June 2011. On 25 May 2011 the results were also discussed with several colleagues at an internal seminar at Forest & Landscape.

Annex B: Data inputs

General requirements
Data layers on region boundary, land use, zoning and suitability have to be transformed into raster information as ASCII grid or IDRISI byte binary image format. Region boundary, land use and suitability layers must not contain “no data” cells. Infrastructure layers can be imported as polylines or points format.

B1. Regional delineation

The region boundary delineates which area will be included during the simulation. We used the following co-ordinates to delineate the case area:
(ETRS 1989 LAEA)
North: 3 675 000 m
South: 3 570 000 m (total 105 km)
West: 4 430 000 m
East: 4 500 000 m (total 70 km)

This includes the 34 municipalities covered by the Fingerplan 2007. In total this amount to 735 000 cells (100 x 100 m); however, 126 877 cells are outside the modelling area (black area). Also, in Metronamica only cells with land use defined as vacant or function are modelled, feature classes are not modelled (grey area, mainly the sea, see also Tab. 1:). This leaves the model with 287 349 active cells.

Fig. 13: Regional delineation

ArcGIS tips

- Delineate your case study area – must be a rectangle for Metronamica and all following layers must have the same extent.
- ArcCatalog: Create new shapefile for case study boundary, choose Coordinate System ETRS 1989 LAEA if land use data from CORINE is used
- ArcMap: Draw rectangle in editor mode – corners should fit to resolution of your data (eg. 100 m corine => than the the coordinate should round to 100 m in ETRS 1989 LAEA, otherwise cells would be cut on the border)

B2. Land use

The land use data is based on CORINE land use cover at 100 m resolution. Some adaptations have been done for 1990, 2000 and 2006 maps, as shown in Figures 15 and 16. Also, summer house areas were extracted from the land use class “Sport and leisure facilities”, now forming an own land use class.

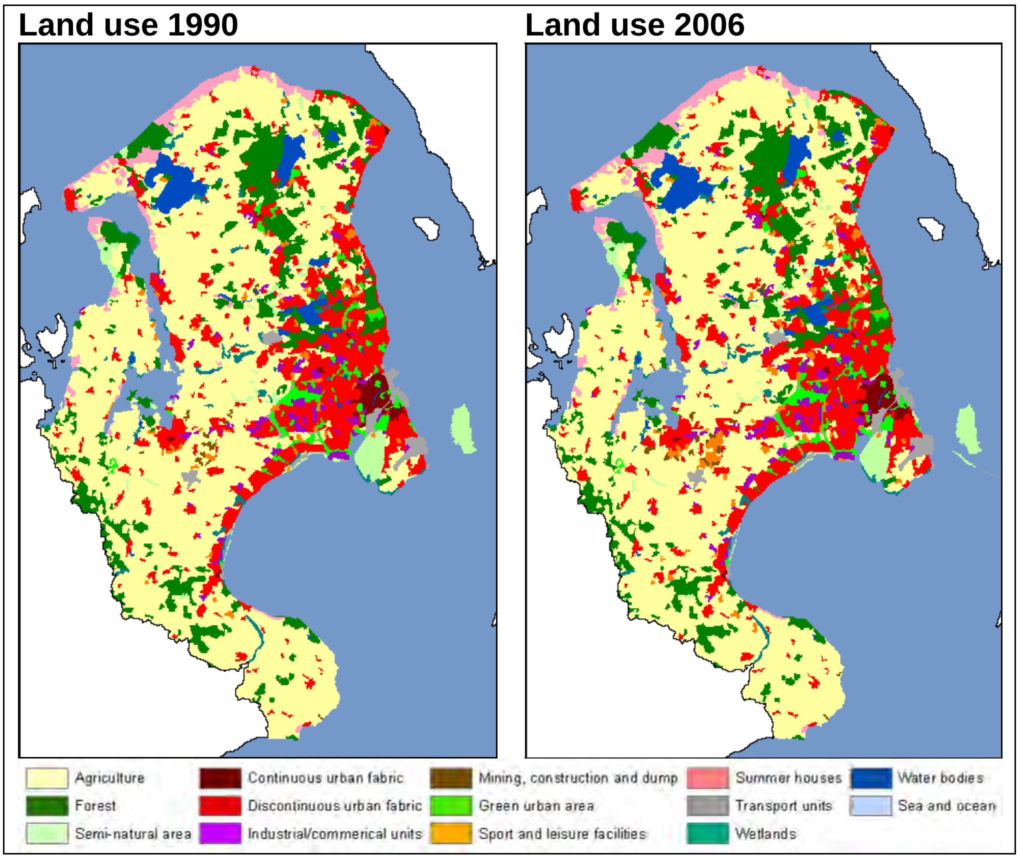


Fig. 14: Final land use maps for 1990 and 2006 used for calibration

ArcGIS tips

- Merge different raster: Spatial analyst tool box ➔ Raster calculation
- Change attributes: Spatial analyst tool box ➔ Reclassify
- Edit pixels directly: Download RasterEditor (http://edndoc.esri.com/arcobjects/8.3/Samples/Raster/Raster%20Editor/RASTEREDITOR.htm)
- Convert into ASCII format: Conversion Tools ➔ From Raster ➔ Raster to ASCII
- Otherwise there is a basic raster editor in-built in Metronamica

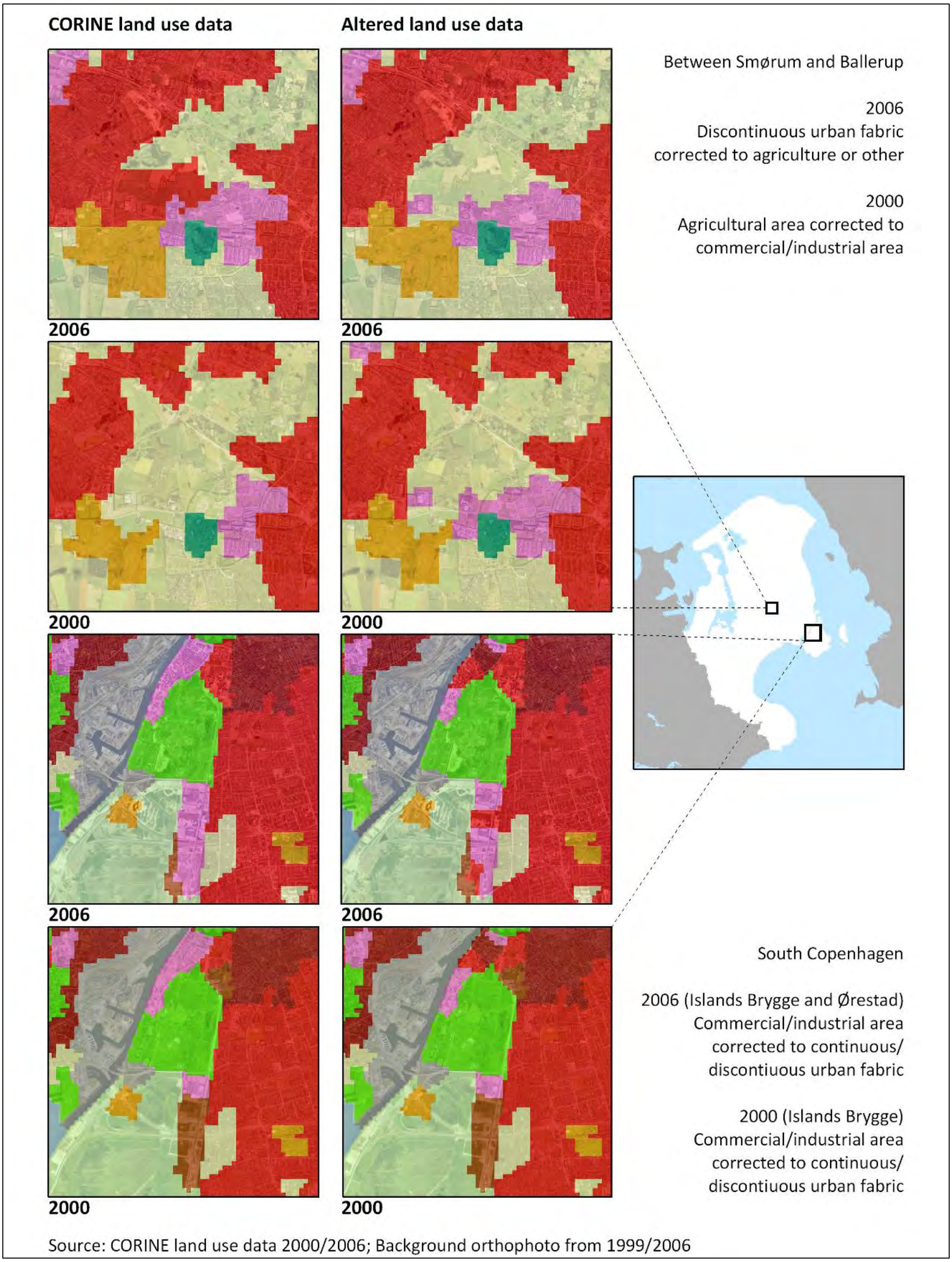


Fig. 15: Altered land uses classifications from CORINE

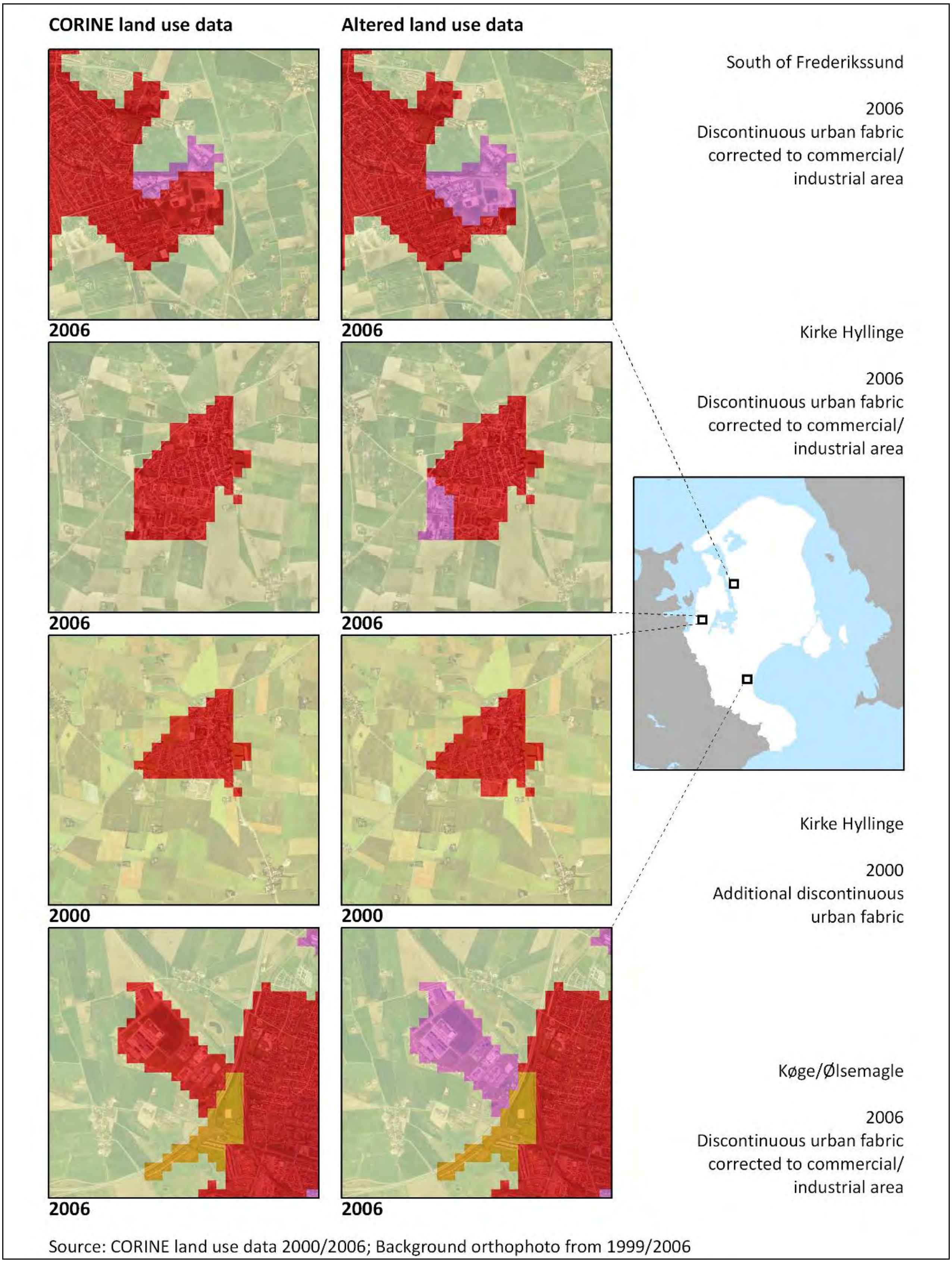


Fig. 16: Altered land uses classifications from CORINE (cont.)

B3. Networks / Transport infrastructure

At lease two files are needed, one for the nodes, one for the network. Both have to contain a column called "Acctype", where the different categories of infrastructure get a number. The files are needed for each point in time where there occurred changes in the network. They can illustrate the whole network or only be incremental to the previous network file used.

Tab. 5: Network classification

Acc-type	**network_nodes.shp**	**network.shp**	***Role in model***	***Source***
0	Metro / S-train / Light rail stations		*Accessibility*	*Moviatrafik; digitization of future projects*
1	Other stations		*Accessibility*	
2	Highway ramps		*Accessibility*	*Digitization*
3		Railroads (all)	*Fragmentation (tunnels/bridges excl.)*	*KMS; FP07*
4		Highways (Motorvej, Motortrafikvej, Til/fra motorvej)	*Fragmentation (tunnels/bridges excl.)*	*KMS; FP07*
5		Major roads (Primær & Sekundær vej > 6m)	*Accessibility*	*KMS; FP07*
6		Other roads	*Accessibility*	*KMS*
9	City centre (Rådhuspladsen)		*Accessibility*	*Digitization*

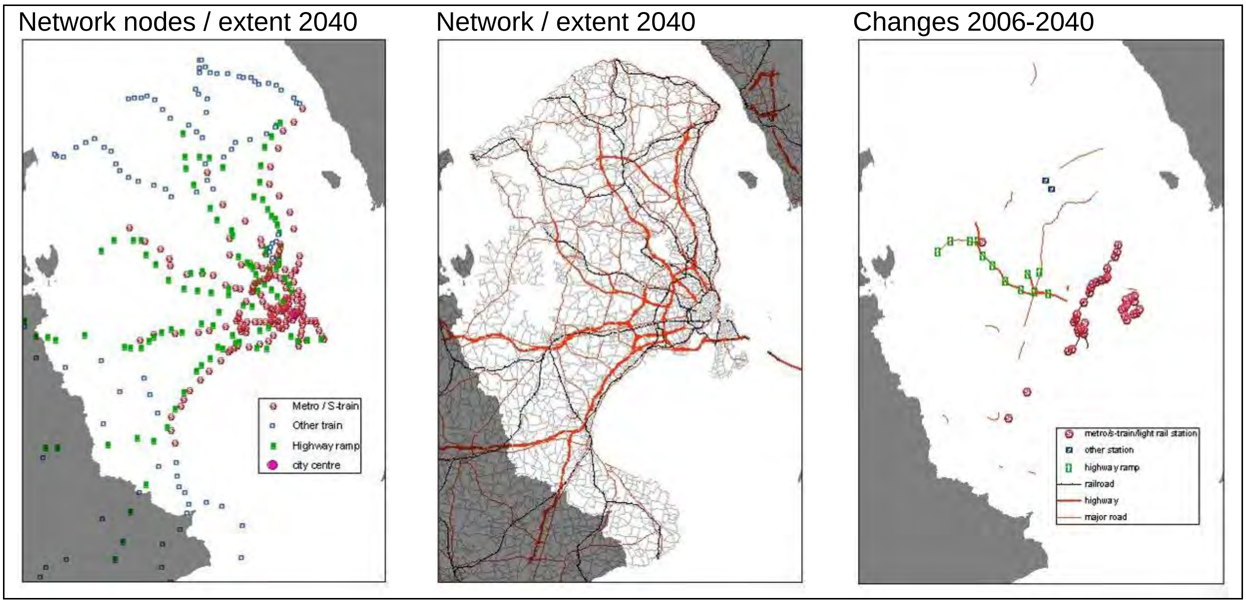


Fig. 17: Network extent 2040

ArcGIS tips

- Different shape files for e.g. road and rail infrastructure can be merged with Data Management Tools ➔ General ➔ Append (the tables should have more or less the same columns before appended)
- Transform shape into right projection: ArcCatalog: Data Management Tools ➔ Projection and Transformations ➔ Feature ➔ Project ➔ Choose same as CORINE (ETRS 1989 LAEA)

B4. Zoning

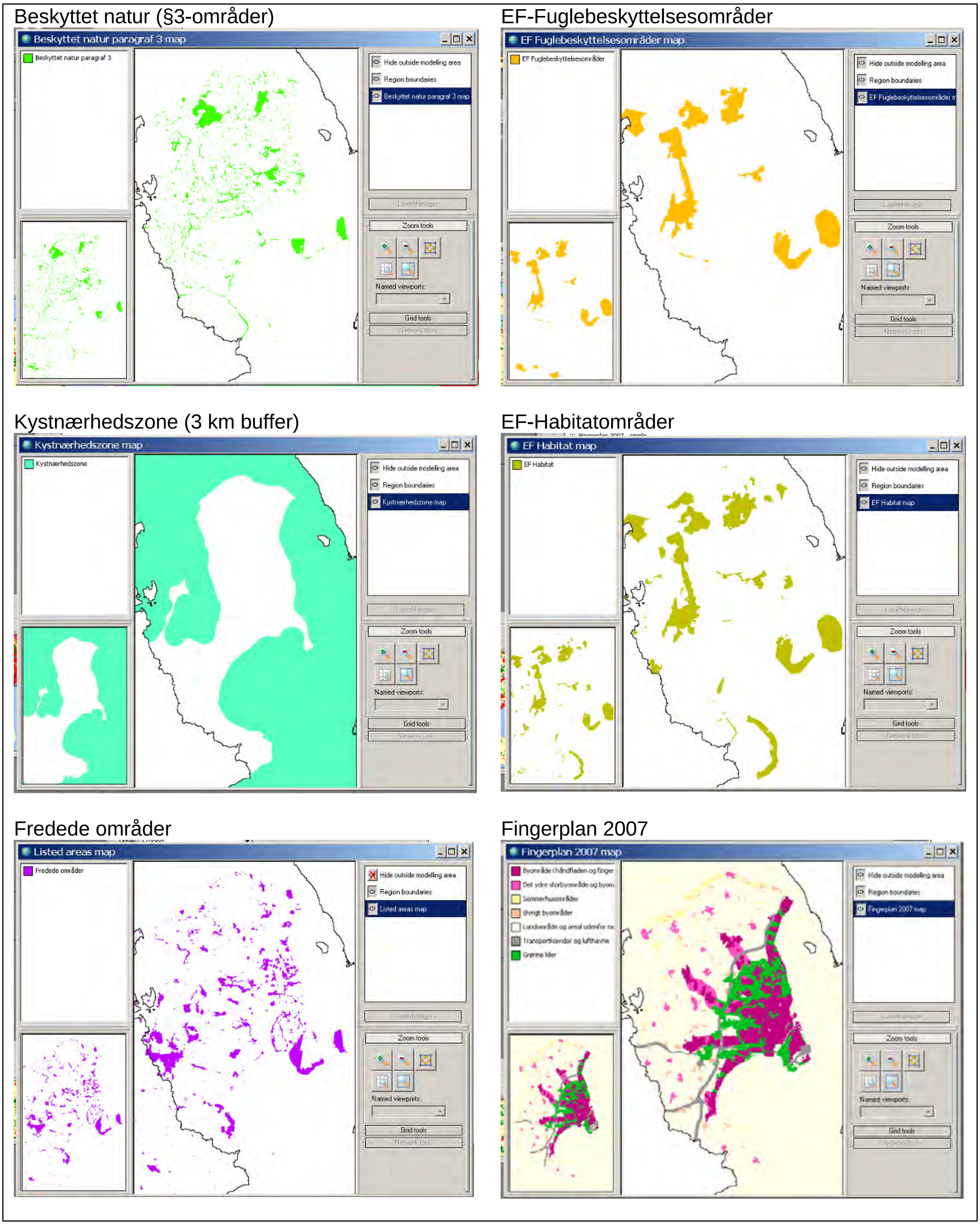


Fig. 18: Nature protection plans / Fingerplan 2007

The regional plans are very comprehensive documents. Very useful information was the location of mining activities, as these otherwise would have been very difficult to model. Additionally we included information on new areas for residential or commercial use as allocated by the regional plans from 1989, 1993 and 2001.

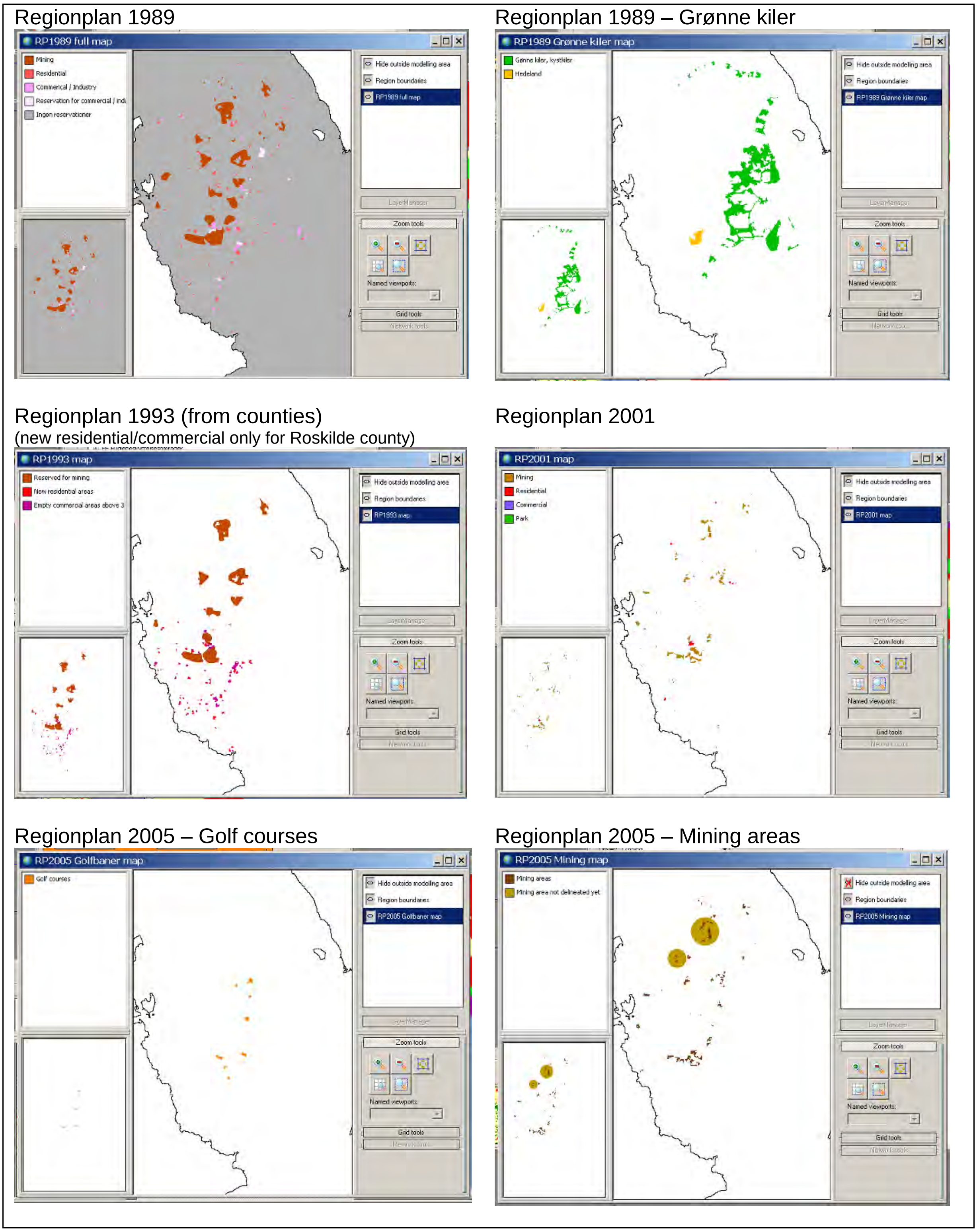


Fig. 19: Regional plans

Annex C: Calibration

C1. Neighbourhood rules

The table below lists the neighbourhood rules derived from calibration, which were also used for exploration. Values at distance 0 (= the same cell) show either the inertia effect (how strong the land use will persist changes) or the conversion effect (possibility of a land use to convert into another). Values at distance 1 or more (= cells surrounding the cell) represent attraction or repulsion (if negative) of one land use on itself or another at distance. Not all possible neighbourhood interaction rules are included, as usually only a few contribute to the neighbourhood effect in the model.

Tab. 6: Derived neighbourhood rules

Influence on Continuous urban fabric

Distance	0	1	2	3	4	5
Agricultural areas	0,01	0				
Continuous urban fabric	1000	50	5	0,5	0,005	0
Discontinuous urban fabric	0,01	0				

Influence on Discontinuous urban fabric

Distance	0	1	2	3	4	5
Agricultural areas	2	0				
Semi natural areas and wetlands	1,2	0				
Discontinuous urban fabric	200	7	0,4	0,05	0,001	0
Industrial or commercial units	1,2	0				
Mine, dump and construction sites	0,01	0				

Influence on Industrial or commercial units

Distance	0	1	2	3	4	5
Agricultural areas	0,9	0				
Semi natural areas and wetlands	2	0				
Discontinuous urban fabric	2,5	0				
Industrial or commercial units	100	0,9	0			
Mine, dump and construction sites	0,01	0				
Sport and leisure facilities	1	0				
Summer houses	1	0				

Influence on Mine, dump and construction sites

Distance	0	1	2	3	4	5
Agricultural areas	1,8	0				
Semi natural areas and wetlands	1	0				
Mine, dump and construction sites	15	0,5	0,05	0,005	0	
Sport and leisure facilities	1	0				

Influence on Green urban areas

Distance	0	1	2	3	4	5
Agricultural areas	1	0				
Semi natural areas and wetlands	0,1	0				
Continuous urban fabric	0	5	0,5	0,05	0,004	0
Discontinuous urban fabric	0	1	0,1	0,01	0	
Green urban areas	200	10	0			

Influence on Sport and leisure facilities

Distance	0	1	2	3	4	5
Agricultural areas	2	0				
Forests	-5	0				
Semi natural areas and wetlands	1,8	0				
Mine, dump and construction sites	2,2	0				
Sport and leisure facilities	100	3	0			

Influence on Summer houses

Distance	0	1	2	3	4	5
Agricultural areas	1,5	0				
Summer houses	100	5	0,5	0		
Water bodies	0	1	0,1	0		
Sea and ocean	0	1	0,1	0		

C2. Accessibility

The table below lists the accessibility effect rules derived from calibration, which were also used for exploration. Each accessibility effect is defined by a weight (the importance to this kind of infrastructure for a certain land use) and a distance decay value (its range of influence).

Tab. 7: Derived accessibility rules

Continuous urban fabric

	dist decay	weight
Metro / s-train station	5	1
Other station	5	0.5
Highway ramp	5	0.9
Railroad		
Highway		
Major road	5	0.5
Other road	1	0.1
City centre	20	1

Discontinuous urban fabric

	dist decay	weight
Metro / s-train station	15	0.8
Other station	15	0.6
Highway ramp	15	0.8
Railroad		
Highway		
Major road	10	0.8
Other road	1	0.2
City centre		

Industrial or commercial units

	dist decay	weight
Metro / s-train station	8	0.8
Other station	8	0.2
Highway ramp	8	0.8
Railroad		
Highway	10	0.4
Major road	10	0.6
Other road		
City centre	20	0.8

Mine, dump and construction sites

	dist decay	weight
Metro / s-train station		
Other station		
Highway ramp		
Railroad		
Highway		
Major road		
Other road		
City centre		

Green urban areas

	dist decay	weight
Metro / s-train station		
Other station		
Highway ramp		
Railroad		
Highway		
Major road		
Other road		
City centre		

Sport and leisure facilities

	dist decay	weight
Metro / s-train station		
Other station		
Highway ramp		
Railroad		
Highway		
Major road	20	1
Other road	20	1
City centre		

Summer houses

	dist decay	weight
Metro / s-train station		
Other station		
Highway ramp		
Railroad		
Highway		
Major road	20	1
Other road	20	1
City centre		

C3. Zoning

The zoning layers as illustrated in Figure 18 and 19 have a different effect on the different land use categories. As described in section 4.4, zoning layers are add to the transition potential of one cell by adding a certain value, depending on the zoning status which the cell falls into. The table below shows the influence of zoning in the calibration on the land use category "Discontinuous urban fabric".

Tab. 8: Example of zoning effect in calibration

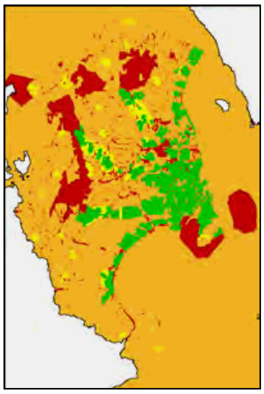
se type: Discontinuous urban fabric

Category	Plan	Zoning status	Start time	End time
Beskyttet natur paragraf 3	Beskyttet natur paragraf 3	Strictly restricted		
EF Fuglebeskyttelsesområder	EF Fuglebeskyttelsesområder	Strictly restricted		
Fredede områder	Fredede områder	Weakly restricted		
EF Habitat	EF Habitat	Weakly restricted		
Golf courses	RP2005 Golfbaner	Unspecified		
Residential	RP2001	Actively stimulated	2001-Jan-01	
Commercial	RP2001	Unspecified	2001-Jan-01	
Park	RP2001	Weakly restricted	2001-Jan-01	
Mining	RP2001	Unspecified	2001-Jan-01	
New residential areas	RP1993	Actively stimulated	1993-Jan-01	
Empty commercial areas above 3 ha	RP1993	Unspecified	1993-Jan-01	
Reserved for mining	RP1993	Unspecified	1993-Jan-01	
Residential	RP1989 full	Allowed		2001-Jan-01
Commerical / Industry	RP1989 full	Weakly restricted		2001-Jan-01
Reservation for commercial / industry	RP1989 full	Weakly restricted		2001-Jan-01
Mining	RP1989 full	Weakly restricted		1993-Jan-01
Ingen reservationer	RP1989 full	Weakly restricted		2001-Jan-01
Gønne kiler, kystkiler	RP1989 Grønne kiler	Weakly restricted		
Hedeland	RP1989 Grønne kiler	Unspecified		
Kystnærhedszone	Kystnærhedszone	Weakly restricted		

Annex D: Exploration

D1. Zoning

Similar to Tab. 8:, the table below shows the effect of zoning on the land use category “Discontinuous urban fabric” in the Fingerplan scenario. The figure to the right shows the zoning effect in the region.



Tab. 9: Example of zoning effect in exploration scenario Fingerplan

se type: Discontinuous urban fabric

Category	Plan	Zoning status	Start time	End time
Beskyttet natur paragraf 3	Nature protection Paragraph 3	Strictly restricted		
EF Fuglebeskyttelsesområder	Nature 2000 Bird Directive	Strictly restricted		
EF Habitat	Natura 2000 Habitat	Weakly restricted		
Fredede områder	Listed areas	Weakly restricted		
Byområde i håndfladen og fingerne	Fingerplan 2007	Actively stimulated		
Det ydre storbyområde og byområde ved kommunecentre udenfor fingerby	Fingerplan 2007	Allowed		
Sommerhusområder	Fingerplan 2007	Weakly restricted		
Øvrigt byområder	Fingerplan 2007	Weakly restricted		
Landområde og areal udenfor modelling area	Fingerplan 2007	Weakly restricted		
Transport corridor inside Fingers	Fingerplan 2007 - Transport corridor	Allowed	2025-Jan-01	
Transportkorridor og lufthavne	Fingerplan 2007	Weakly restricted		
Grønne kiler	Fingerplan 2007	Weakly restricted		
Mining areas	RP2005 Mining	Unspecified		2017-Jan-01
Mining area not delineated yet	RP2005 Mining	Unspecified		2017-Jan-01
Kystnærhedszone	Coastal protection zone	Weakly restricted		

D2. Land use maps for 2040

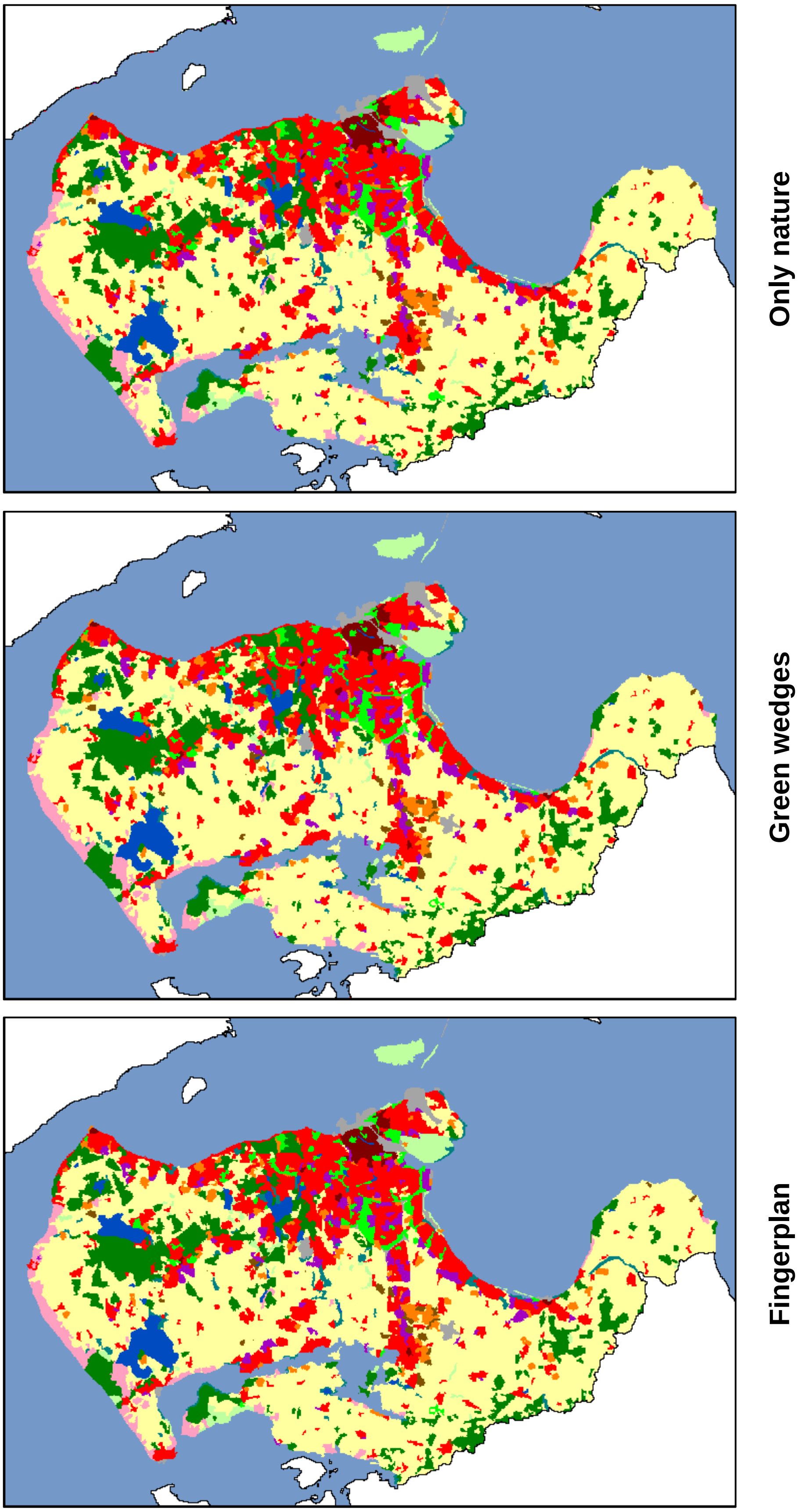


Fig. 20: Land use maps for 2040 in three policy scenarios

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