

Integration of the MOLAND Model with GeoChoicePerspectives Spatial Decision Support Software for Scenario Evaluation

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ABSTRACT

The land-use model MOLAND was used for simulation of four possible scenarios of future settlement patterns in the Greater Dublin Region until 2026. The results were used for calculation of indicators, which in turn were input into GeoChoicePerspectives spatial decision support software (SDSS) for identification of the best scenario based on users' evaluation of the indicators. The paper demonstrates how a land use planning decision making process can be improved by coupling a land use model with a SDSS. The results presented in the paper are based on a case study which can be repeated for larger regions, other scenarios, a richer set of indicators and a wider group of decision makers.

INTRODUCTION

Dynamic spatial modelling and scenario generation assist policy debates and discussions of future visions. One of the goals of scenario development through land-use modelling is to promote structured discussion and awareness among specialists and decision makers (Barredo et al., 2005). Land-use models such as MOLAND (Engelen et al, 2007) help to simulate alternative scenarios of future urban development. Furthermore multi-criteria analysis of the model outputs can be very useful in assessment of possible consequences, assisting urban planning and related decision-making.

The described approach explores a framework combining the MOLAND model and GeoChoicePerspectivesTM SDSS (Jankowski, 2000) aimed at the analysis of urban growth and land use change in a region. The approach was applied in a case study for the Greater Dublin Region¹ (GDR), Ireland. A number of scenarios of possible development of the Region were modelled; the output land use maps and socio-economic datasets were used for calculation of the related indicators; and finally GeoChoicePerspectivesTM software was applied to improve the effectiveness of the decision making process based on the indicator values and user's preferences.

THE MOLAND MODEL

The MOLAND model was developed as part of an initiative of the European Commission's Joint Research Centre as a response to the challenge of providing a means for assessing urban and regional development trends across Europe. In order to capture the processes effecting the spatial configuration of the area, the MOLAND represents the processes operating at three geographical levels: the Global (the whole area), the Regional (sub-regions/counties) and the Local (cellular units) (Engelen et al, 2007). The combined Global and Regional levels constitute the so-called macro-level of the model, while the Local level represents the micro-level of the model. At the Global level, the model integrates global/aggregate figures taken from economic and demographic growth scenarios considering development in the study area. From these, growth figures for the population and jobs per economic sector are derived and entered into the model as trend lines. Then the Global growth figures are imposed as constraints on the Regional level. At the Regional level consisting of 5 counties in

¹ The GDR is comprised of the Dublin, Kildare, Meath, Wicklow, and Louth counties.

case of GDR, a dynamic spatial interaction based model (White, 1977) arranges for the allocation of Global growth as well as for the interregional migration of activities and residents based on the relative attractiveness of the counties. Then, at the Local level the detailed allocation of economic activities and people is modelled by means of a Cellular Automata based land use model. Thus, estimates of the population will be provided for within residential and estimates of the economic activities will be provided for within commercial, industrial and service land use types. The land use type assigned to any given cell is determined by an algorithm which aims to satisfy the demands for land use in each time step (Engelen et al, 2007). The following main elements of the model are determining whether a cell is taken in by a land use or not:

- Suitability: a composite measure determining the physical, ecological and environmental appropriateness of cells to support a land use and the associated economic or residential activity. It is presented by one map per modelled land use class.
- Zoning: specifies whether a cell may or may not be taken over by a specific land use. It is usually based on planning documents.
- Accessibility: describes the accessibility of a cell to transport network.
- Neighbourhood rules: express the dynamic impact of land uses in the surroundings of a location. For each cell a set of rules determines the degree to which it is attracted to, or repelled by, the other land use cells present in the neighbourhood.

Based on these elements the model calculates the transition potential for each cell for every simulation time step (Figure 1). Cells are changed to the land use for which they have the highest potential until regional demands are met.

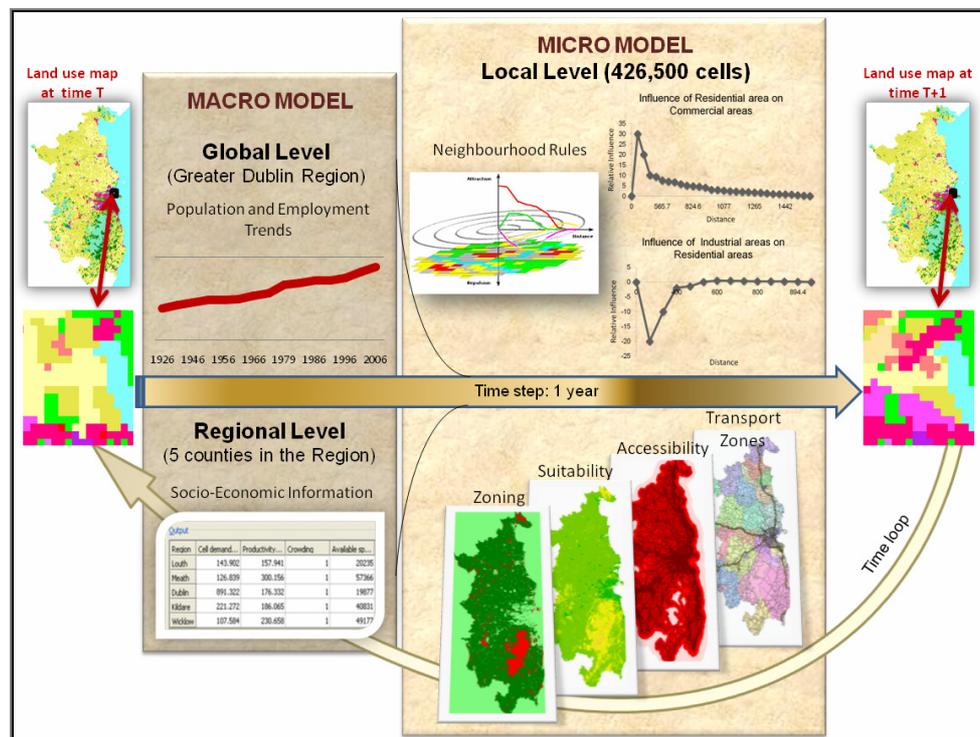


Figure 1: Land use transition in MOLAND.

In the scope of Urban Environmental Project (UEP) the MOLAND was calibrated and applied for the GDR (Shahumyan et al, 2009).

SCENARIOS

The urban fabric of the GDR has expanded rapidly over the past 20 years. In an effort to coordinate development across the region the “Regional Planning Guidelines: Greater Dublin Area 2010-2022” are currently in the reviewing process and as part of it a strategic environmental assessment was undertaken to evaluate the effect of several future settlement patterns on the region’s environment. In collaboration with Dublin and Mid-East Regional Authorities (D&MERA) the MOLAND model was used to simulate four scenarios of possible settlement patterns for the GDR for the period 2006-2026 (Brennan et al, 2009):

1. Continued trends - “business as usual” future, exploring a continuation of the current, dispersed settlement pattern.
2. Finger expansion of Metropolitan Footprint (MF) - development is encouraged in MF, strongly directed along key transport corridors.
3. Consolidation of key towns and Dublin city - strong consolidation policy, whereby growth was focused within the existing MF and towards a limited number of key towns in the Hinterland.
4. Managed dispersal - development is focused within the existing MF, in designated towns on key public transport routes as well as continuing to build the critical mass of county towns.

All scenarios were run from 2006 till 2026. Figure 2 presents the initial land use map of 2006 used in the simulations. It has 200-meter resolution and 24 land use classes.

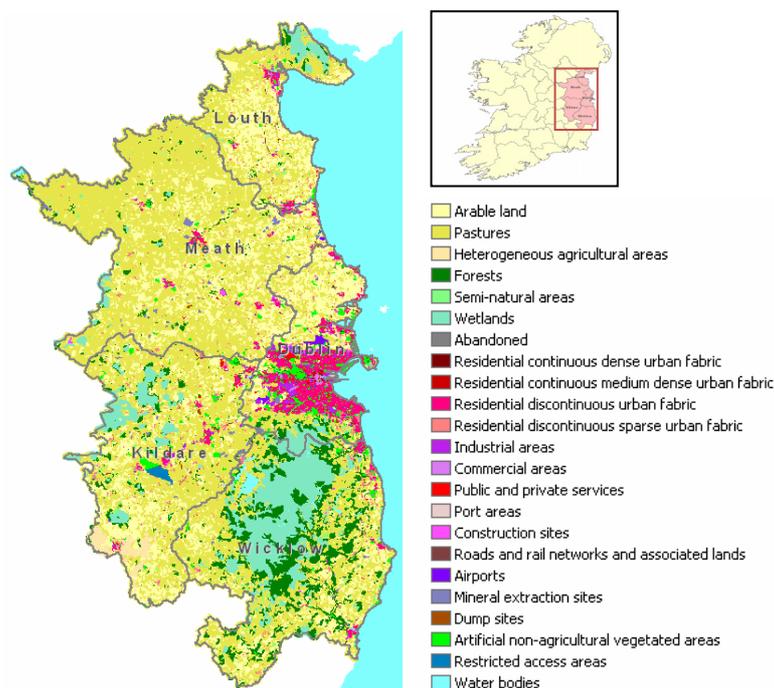


Figure 2: 2006 land use map of the GDR.

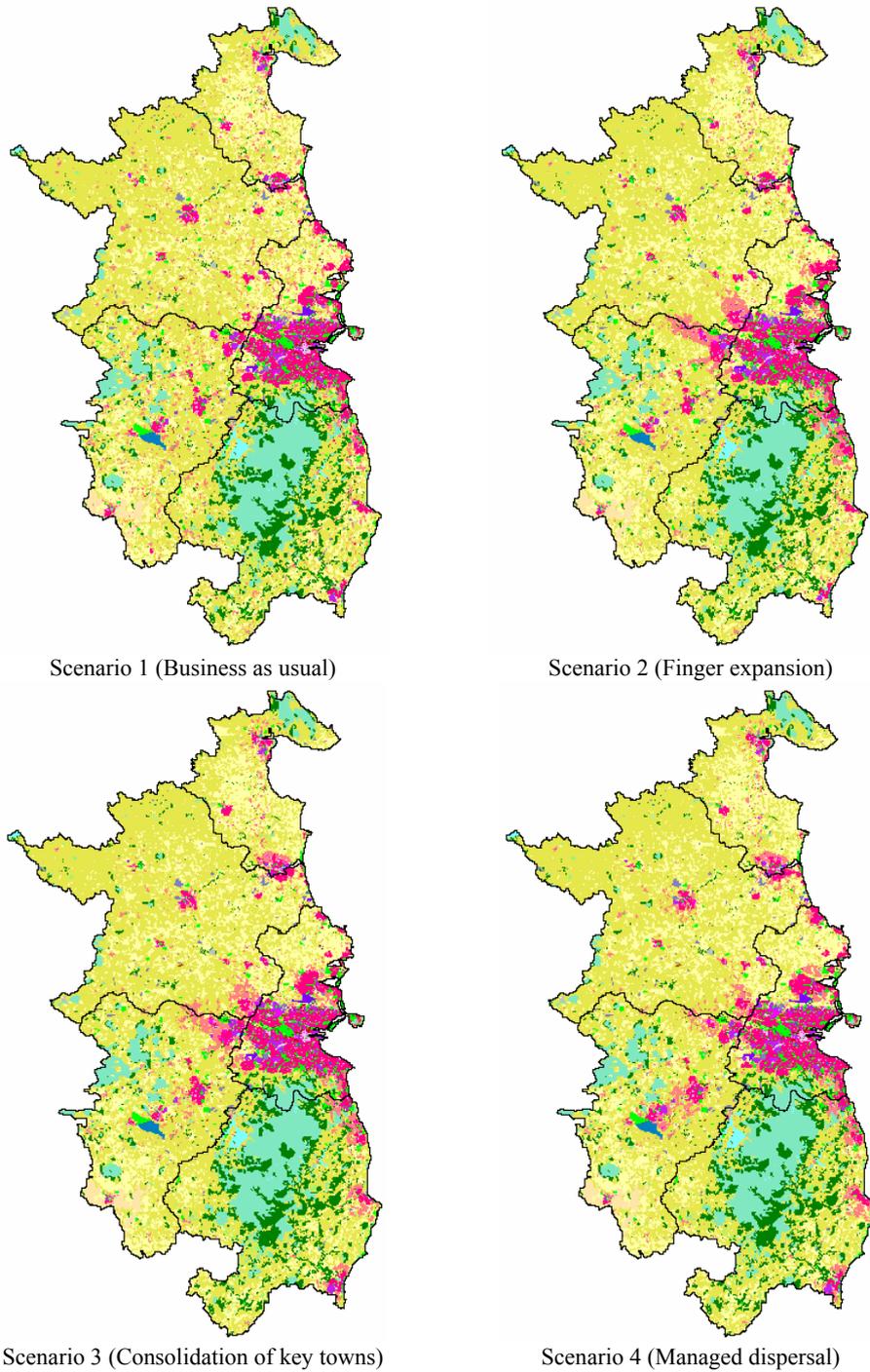


Figure 3: 2026 land use maps of GDR generated by MOLAND for simulated scenarios.

The same population projection of 2026 from the Central Statistics Office was used for all scenarios (CSO, 2008). Bespoke suitability and green belt zoning maps were used in the model to answer the specific requirements of each scenario. In addition, the scenarios required different transportation networks to be derived from existing road and rail datasets along with the future proposed “Transport 21” network². In the case of Scenarios 2, 3, and 4 there were also sub-scenarios for the transport network development and implementation timeline. These sub-scenarios are called 2.1, 2.2, 3.1, 3.2 and 4.1, 4.2 (Brennan et al, 2009).

The generated land use maps presented in Figure 3 were analysed with the Map Comparison Kit software. The comparison shows obvious differences between the Scenarios. Thus, in Scenario 1 urban development by 2026 has dispersed across the region in many small clusters (red cells in Figure 4). The situation is different in the other scenarios; here development by 2026 is concentrated within the MF and key towns (blue cells in Figure 4). Interestingly enough in case of business as usual scenario (Scenario 1) there is no perceivable development in the west of Dublin city, whereas for all alternative scenarios the development there is quite heavy.

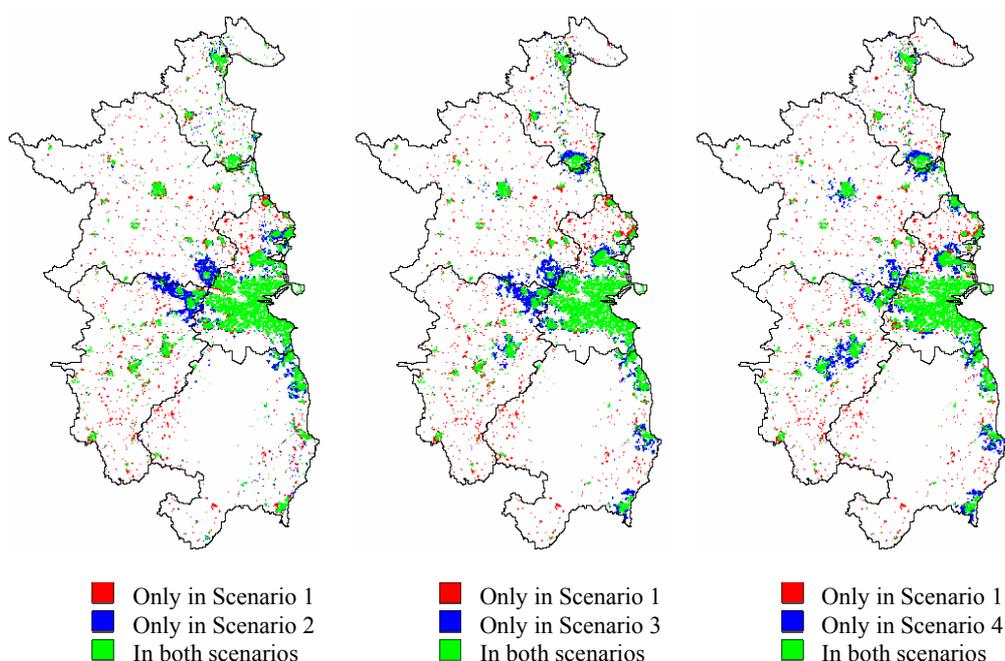


Figure 4: Urban development in GDR till 2026: comparison of Scenario 1 with 2, 3 and 4.

INDICATORS

Though the map comparison gives some indication of the distinctions between scenarios, it is still hard to define which one is preferable considering the complex interconnections resulting in negative impacts for different environmental aspects. Indicators can be used to simplify, quantify and aggregate data on factors such as urban sprawl, green area loss, population change, etc. About 20

² “Transport 21” is a capital investment framework under the National Development Plan of Ireland through which the transport system in Ireland will be developed, over the period 2006 to 2015.

indicators from the following categories were suggested by D&MERA and UEP to use for assessing described scenarios:

- Change in land uses over time
- Green and urban area ratios
- Encroachment in protected areas
- Proximity to particular areas

Indicators were calculated using ArcGIS, FragStats, R and Python. Results demonstrated variations of indicator values for different scenarios like in the examples illustrated below.

Figure 5 shows that encroachment in protected areas is most pronounced in Scenario 1 and least in Scenario 3 (Brennan et al, 2009).

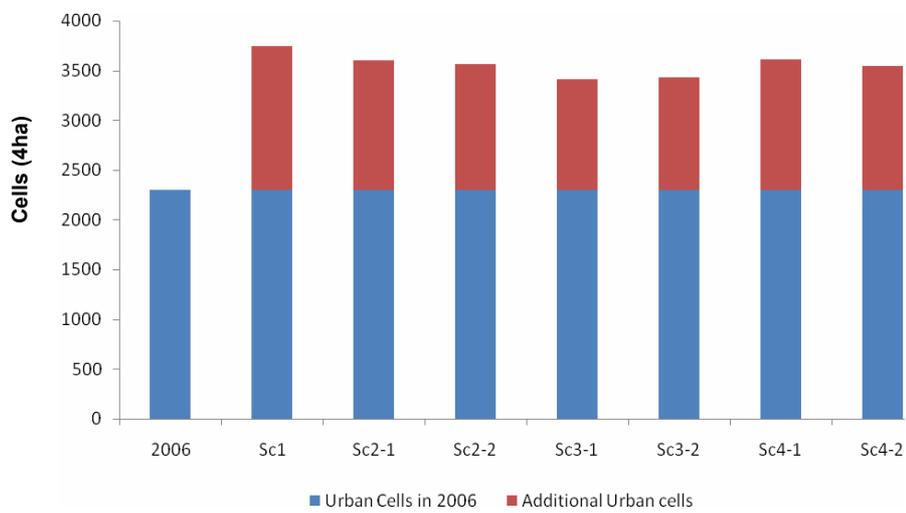


Figure 5: Encroachment of development within 1km of protected areas in 2026.

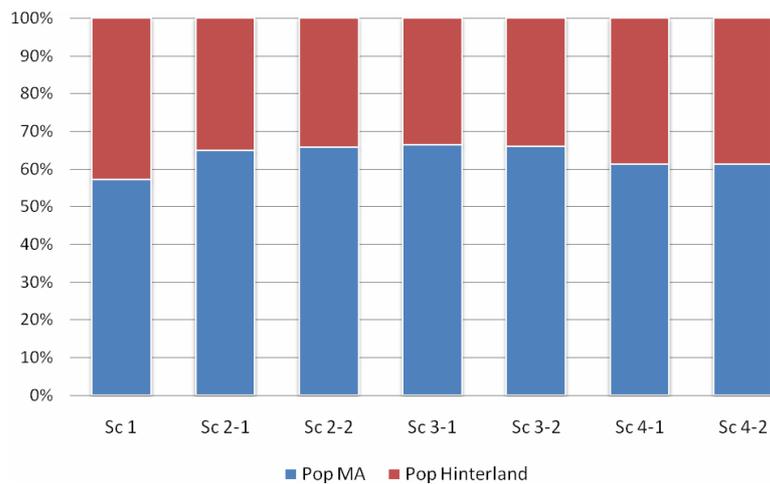


Figure 6: Population distribution between MF and the Hinterland in 2026

Population in the MF is highest in case of Scenarios 2 and 3 and lowest in case of Scenario 1 (Figure 6). Though the mean distance between residential and service areas is lowest in Dublin for all scenarios, in Scenario 2.1 it is about 1km longer than in other scenarios (Figure 7).

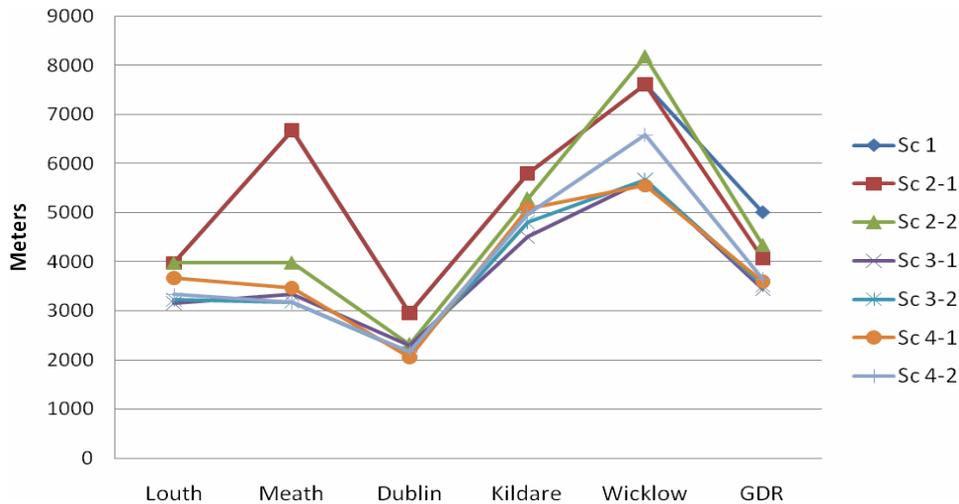


Figure 7: Mean minimum distance between Residential and Service areas in 2026 (McInerney et al, 2010).

Considering that all indicators are barely satisfactory for a scenario and that no single indicator is enough to describe differences in the region at an aggregated level it is essential to evaluate scenarios based on more sophisticated multi-criteria evaluation approach. The GeoChoicePerspectivesTM SDSS described below was used for that purpose.

GEO CHOICE PERSPECTIVES

GeoChoicePerspectivesTM software supports single user and/or group-based decision making in a GIS context. Decision participants use GeoChoicePerspectivesTM to explore, evaluate and prioritise preferences on all aspects of a decision-making process involving multiple criteria and location-based decision option (Jankowski, 2000). The package is composed of three components:

- The GeoVisual component is used by decision participants for exploring geographic data on maps, and presenting the results of site option's rankings for single user or group contexts. GeoVisual is implemented as an extension of the ArcView GIS 3.x platform.
- The ChoiceExplorer component is used by decision participants to perform criteria selection, prioritisation and options evaluation.
- ChoicePerspectives collates rankings from ChoiceExplorer that are subsequently displayed as consensus maps in GeoVisual.

GeoChoicePerspectivesTM was used in the GDR case study. Particularly, with the help of GeoVisual extension the scenarios were examined in terms of their indicator values, which subsequently served as the scenario evaluation criteria. Then, ChoiceExplorer was used to examine criteria and set priorities for scenario selection. Lastly, ChoicePerspectives was applied for

synthesising multiple decision files generated by a group of scenario evaluators each containing a set of rank ordered scenarios.

CASE STUDY

In the GDR case study a two stage approach for multi-criteria analysis was used: in the first stage the best scenario for the whole Region was selected based on the indicator (criterion) values and their relative importance. In the second stage the scenarios were analysed based on their performance for each county. A group of seven evaluators including a spatial planner, a forester, a GIS specialist and PHD students from Dublin City Council, University College Dublin and Trinity College Dublin took part in the evaluation process conducted at the Urban Institute Ireland (UII) in January, 2010.

One of the initial steps in multiple criteria evaluation process, following the selection of evaluation criteria, is determining whether one desires to maximize or minimize a given criterion values. We call this step *criteria valuation*. An example set of the criteria valuation used in this study is presented in the table below.

Table 1: An example of the main indicators' valuation used in the study.

Indicators	Abbreviation	Value preference
Ratio of Green Areas vs Built Areas	GAVB	Higher
Ratio of Green Areas vs Activity Areas	GAVA	Higher
Encroachment of development within 1km of protected areas	EPA 1km	Lower
Urban areas within 1km of transport nodes	UTN 1km	Higher
Residential areas within 100/200m distance from major roads	RM 100/200	Lower
Population allocated to Sparse/Other residential areas in the MF	RSMA/ROMA	Lower/Higher
Population allocated to Sparse/Other residential areas in the Hinterland.	RSH/ROH	Higher/Lower
Population in MF	PopMA	Higher
Population in Hinterland	PopH	Lower
Mean distance between residential and green urban areas	RTG	Lower
water objects	RTW	Lower
industrial areas	RTI	Higher
commercial areas	RTC	Lower
service areas	RTS	Lower

In the GDR scenario evaluation process ChoiceExplorer was used to assign criterion value preferences, weights and to evaluate scenarios based on the criterion valuations and weights. Choice Explorer provides users with the selection of three common criterion weighting functions: ranking, rating, and pairwise comparison, and three criterion score and weight aggregation functions: weighted summation, ideal point, and ordinal ranking (Jankowski et al. 1997). In the case study the users were free to use a criterion weighting function of their choice and asked to use weighted summation for aggregating criterion scores with weights. Figure 8 presents the weights and corresponding ranking of the Scenarios based on the criteria valuation of one of the evaluators. Note that in this example Scenario 3.1 ranked the highest and Scenario 1 ranked the lowest.

The ChoiceExplorer module has a Sensitivity Analysis function enabling a user to dynamically evaluate how sensitive option ranks are to shifts in individual criterion weights. If the ranks appear sensitive to small changes in weights, a user may want to re-examine their weighting preferences.

Criteria	Weight	Options	Score
Gava	04	3.1	84
Guva	04	3.2	83
Epa_1km	09	2.2	65
Utn_1km	08	2.1	56
Rm_100m	04	4.1	53
Rm_200m	04	4.2	50
Roma	05	1	28
Roh	05		
Rsma	04		
Rsh	04		
Popma	03		
Poph	03		
Rtg	07		
Rtw	00		
Rti	04		
Rtc	08		
Rts	08		

Weighting: USER (EQL) Aggregation: WSUM

Figure 8: The weights of criteria and the corresponding ranking of scenarios based on one user’s valuation. Scenario (option) names are represented by their numerical codes.

The ChoicePerspectives module supports the users in conducting scenario evaluation as a group process. To this effect the ChoicePerspectives module can collate inputs from several decision participants, submitted in the form of electronic votes, to provide an overall depiction of options’ ranks. Votes can concern any aspect of the multiple criteria analysis process including evaluation criteria and decision options. The former involves a simply non-ordered list of criteria whereas the latter requires an ordered list of decision options. ChoicePerspectives together with ChoiceExplorer help decision participants select decision criteria, weights for criteria, and evaluate the effects of changing preferences on decision options.

During the GDR scenario evaluation process that took place in January 2010 the participants first developed their individual rankings of scenarios and then voted by submitting their rank-ordered lists of scenarios in the form of vote files. The results of voting processed in the ChoicePerspective module of GeoChoicePerspectives™ are presented below.

Decision Makers	Options	Score	Variance
brian	3.1	98	8
Bryan	3.2	88	8
ch	2.2	71	0
ecoin	2.1	57	0
Harut	4.1	39	14
Nuala	4.2	29	17
sheila	1	18	17

Method: Ranked Vote View: Group Displaying the result of multiple voting

Figure 9: Ranking of scenarios based on the group voting.

Voting shows that Scenario 3.1 received the highest score and a relatively small variance of opinions (Figure 9). This may be an indication that Scenario 3.1 is the overall best option for the Region according to the views of the voters. It is worth mentioning also that the “business as usual” scenario (Scenario 1) received the lowest rank, making it the least desirable scenario. This gives potentially valuable information for the decision makers in their effort to select an appropriate regional development scenario.

After evaluation of the scenarios for the whole region it is important to ascertain how they perform for the individual counties. For example if the decision makers decide to promote Scenario 3.1, it is of interest to know which county will benefit or lose the most as a result of the corresponding growth strategy. To find out how would the selected Scenario 3.1 impacts each of five counties comprising GDR the same technique of multi-criteria evaluation was applied for counties instead of scenarios, using the indicator values of Scenario 3.1 for each county. Figure 10 presents the results obtained by one of the participants showing that in case of Scenario 3.1 the Dublin County benefits the most, while Counties Meath and Wicklow lose out considerably.

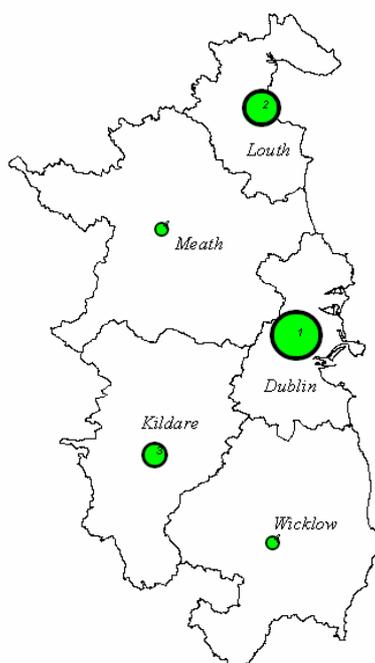


Figure 10: Ranking of the counties for Scenario 3.1 based on one user’s valuation.

This evaluation is based on all indicators, which means that for any single indicator the result may be different. For example, Figure 11 shows the encroachment within the 1km buffer of protected areas; and it is clear that the Dublin County experiences the most encroachment in spite of its good ranking in the overall evaluation.

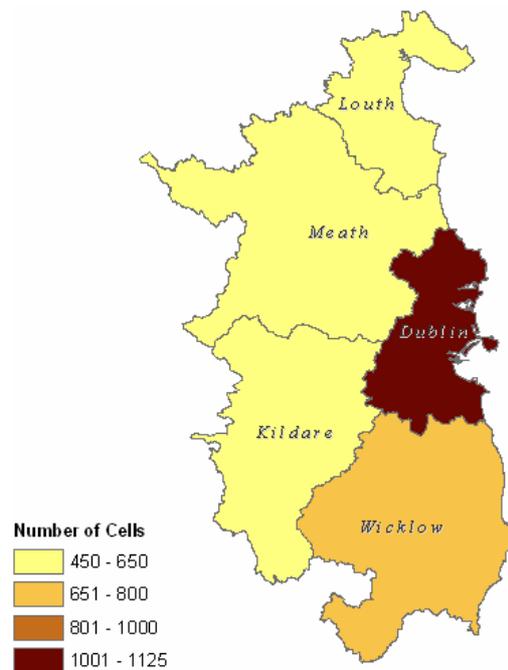


Figure 11: Encroachment of the 1km buffer of protected areas.

This examples show the results obtained by an individual user only. However, during a decision making process, the group voting results can be obtained, making the outputs more reliable (Figure 12).

ChoicePerspectives 1.2			
Decision Makers	Options	Score	Variance
brian	Wicklow	97	14
Bryan	Meath	73	50
ch	Kildare	57	47
Harut	Louth	47	39
Nuala	Dublin	27	28
sheila			

Method: Ranked Vote View: Group Displaying the result of multiple voting

Figure 12: Ranking of counties for Scenario 3.1 based on the group voting.

Based on the synthesis of individual rank-ordered lists of five counties, submitted by the members of the group, Wicklow County performs the best with the smallest variance of opinions between the voters. This means that in the opinion of the group and in light of the indicators used by the group as evaluation criteria, the overall impact of Scenario 3.1 is the most favourable for the Wicklow County and the least favourable for the Dublin County. It is worth noting that the variance of opinions in both cases is relatively small.

GeoVisual module can be used in conjunction with ChoicePerspectives to present the results of voting in a consensus map (Figure 13). Symbol size and colour are used in the consensus map to represent the option position in the ranking and a relative level of agreement/disagreement about the rank. The larger the circle's size the higher the rank. Green colouring indicates a relatively high agreement with the rank position, yellow indicates medium, and red indicates a relatively low agreement. In moving toward an agreement concerning highly ranked counties large green circles will be evident.

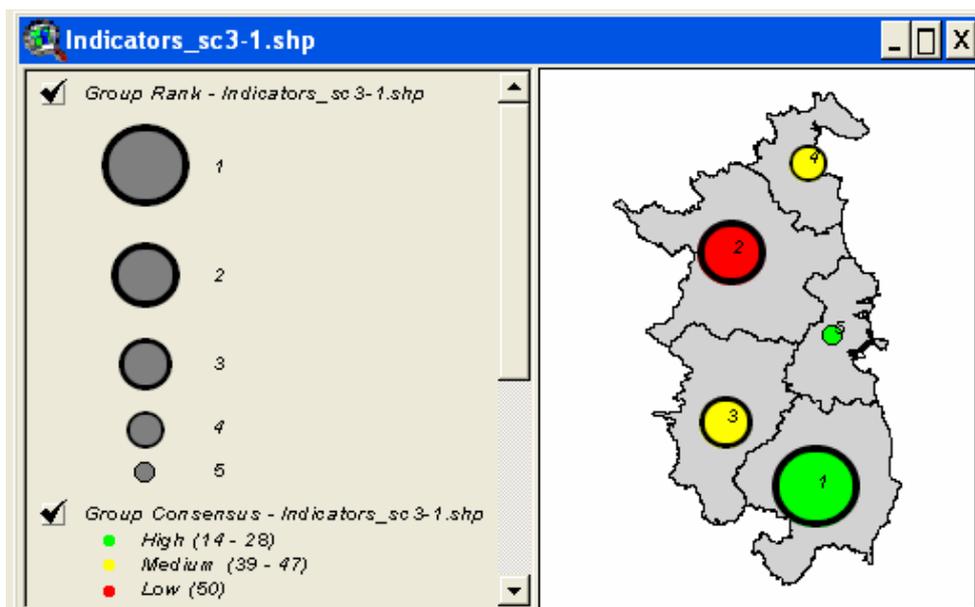


Figure 13: Ranking of the scenarios based on the group voting.

CONCLUSION

The Irish economy is facing challenging times with a deep recession and rising unemployment. In such situation it is hard to have a model which can give precise answers about future developments. However, scenarios, modelling and analysis are an effective way to assess effects of current actions on possible land use changes in future. The use of scenarios can assist in the selection of development strategy by relying on comprehensive indicators.

There are several land-use models providing rich functionalities for scenario simulation. But most of them lack the functions of multi-criteria analysis and tools for group decision making. Coupling the MOLAND model, GIS and GeoChoicePerspectivesTM aims to fill that gap. This study does not aim to provide operational development patterns of GDR, but rather to show that the combined system can be an effective framework for scenario simulation and evaluation, as well as for facilitating discussions between planners, policy makers and experts with different areas of specialisation. The study underscores also the importance of selecting good indicators which properly express the differences between available options.

As part of future work we plan to apply the presented approach working with the local decision maker of the Greater Dublin Region and report on the efficacy of the approach in a realistic decision making context.

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