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Using a Hybrid Semi-Integrated Spatial Allocation Model to Model Future Housing Allocation

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Abstract. In this paper we present the semi-integrated land use model Land Use Scanner 2.0 (in Dutch: RuimteScanner 2.0) to model the future growth of housing in the Netherlands, by 2050. The modelling was done in the scope of four future scenarios which were developed for the Spatial Outlook 2023, a study carried out between the period of 2021 and 2023, by the Netherlands Environmental Assessment Agency (PBL). The scenarios in the Spatial Outlook 2023 present different futures of land use, based, among other things, on the Dutch ambition to develop sustainable land use and to reduce carbon footprint and natural resources depletion by 2050. At the same time, several socioeconomic challenges are central drivers in the Outlook, such as the housing shortage and the developing economy, as well as the progressive shift to renewable energy sources and sustainable farming, all placing claims on the future land use. The results discuss two of the four future scenarios and show both spatial and quantitative variations between the scenarios in the allocation of houses, indicating the importance of differences in living conditions and housing preferences. The possibilities of the Land Use Scanner 2.0 to serve as a tool for policy dialog and design, rather than prediction, is presented.

Keywords. land use model, housing, allocation

1 Introduction Land Use Scanner 2.0

The Land Used Scanner has a relative long history of application in policy related Dutch studies. Recently, it started to be used in international research and modelling context through the introduction of the LUISA land use modelling framework (Lavalle et al., 2020). The GIS-oriented modelling framework programmed in the Geo Data and Model Server (GeoDMS) open-source software, has been used in the Netherlands for more than 25 years to simulate and evaluate changes in land use (Hamers et al., 2023; Kuiper et al., 2023), and since recently, it has been extended to calculate/model a variety of spatial indicators (e.g. flood damage, accessibility of green space). The Land Use Scanner 2.0 (LUS2) can be characterized as a hybrid flexible semi-integrated spatial allocation model that allocates regional projections of actors, objects (e.g. houses) and land use (Koomen et al., 2024).

1.1 Modelling Framework

The original model, namely the Land Use Scanner 1.0 (LUS1), was based on logit regression (doubly constrained land use model) to model continuous (i.e. probabilistic) land use allocation (Hilferink and Rietveld, 1999; Schotten et al., 1997) at 500 meter resolution based on the bid-rent theory. In the earlier version, rural functions such as agriculture and nature were also integrally included.

The one-dimensional land use allocation module of the original model was advanced in LUS2 by adding two extra modules: actors (e.g. employees) and objects (homes, commercial buildings). Typical modelled time-horizons are in the order of 30 years with a spatial resolution of 25 meters. Allocation is done in pre-defined sequential order of the sectors: housing, labour, holiday homes, wind energy and solar energy, although this order can be changed in the model. The demand for space in each of the sectors is defined at regional level, while the suitability of each grid cell of available space is defined on local level. Suitability is determined empirically by logistic regressions and hedonic price analysis (Claassens & Koomen, 2017).

1.2 Objectives of the LUS2

To address the housing shortage in the Netherlands, the Dutch government aims to create approximately 900.000 new homes from 2023 based on the country's population projections for the year of 2030 (Geis, 2023), driven by changes in household composition and immigration (Groenemeijer et al., 2021). This is a major challenge since spatial planning is heavily regulated with long approval periods that last up to 10 years from plan to realisation of new construction projects. As such, a need has arisen from the necessity to be better equipped to answers future allocation issues in spatial planning in order to generate new insights, extend to more complex requirements and increase LUS's application possibilities with high detailed data. Therefore, the 2.0 version of the Land Use Scanner has been developed.

Thus, the main objective of the Land Use Scanner is not to predict future land use per se, but to integrate and allocate future land use demands coming from different sectors like housing, or labour, based on a demand-supply interaction among the sectors competing for land. It increases insight in processes that play a role in land use allocation, making the process of future land use planning more transparent, goal oriented and engaging at any decision-making level.

2 Model Structure

The core of the Land Use Scanner model consists of the allocation of regional space demand of the different sectors to specific locations based on their suitability determined on the basis of statistical analysis (regression), expert judgment or a combination of both. It models actors, objects and land use. The sectors modelled in LUS2 are housing, labour, holiday homes, wind energy and solar energy (fields).

2.1 Future Projections

Projections of sector demands (i.e. claims) usually come from regional models but can also be based on expert judgment or policy goals. The regional development of housing and jobs is taken from the Land Use Transport Interaction (LUTI) model Tigris XL (Zondag et al., 2015; Zondag and Geurs, 2011), a model owned by the Rijkswaterstaat and the PBL. Future national population growth in Tigris XL is delivered by PEARL (de Jong, 2013), a model developed by the PBL and the Central Bureau for Statistics (CBS). The regional level at which the housing claims are defined and assigned in the LUS2 is determined by the Association of Dutch Real Estate Agents NVM (Nederlandse Vereniging van Makelaars), which divides the country in 66 housing market regions. In the event of space shortage, any spill over, is allocated at the COROP level (40 regions) and, if that is not possible, at the provincial level (12 regions).

2.2 Restrictions – Availability

The non-availability of locations in the form of grid cells for development for each (sub)sector is partly based on a large number of restriction maps. At the highest level these restrictions are imposed by EU-policy, followed by national and the regional policy. Examples of these maps are: Natura 2000 (nature protection areas), Netherlands Nature Network (NatuurNetwerk Nederland) and the safety contours around airports. Potentially, a large number of areas, depending on the scenario, are excluded in the allocation step for each of the sectors due to their current land use like infrastructure, inland water and cemeteries. This is based on the fact that the likelihood that new developments will take place in these areas is extremely low. Although, in the case of infrastructure, this is a limitation in the current model, since it is very likely that the allocation of new land uses will demand expansion of current infrastructure capacity. If there are already known building projects that will certainly be realized, the restrictions in the model are overruled.

In addition to the claims, the model takes as input a large number of suitability maps with extra factors, which are as well scenario-depended. These factors exclude land, such as houses with recent year of construction (e.g. onwards 2000), private ownership and unfavourable local physical conditions, from potential allocation. Distances to for example roads and amenities are also considered. In addition to the suitability maps, only a limited number of policy maps are used to stimulate certain developments of sectors.

2.3 Modelling the Housing Subsectors

Housing is divided into four categories (living subsectors): single-family houses owner-occupied, single-family houses rental, multi-family houses owner-occupied and multi-family houses rental. The modelled variable is *number of houses per grid cell*. The number of employees is used to model claims for new jobs (i.e. labour) in six categories: industry, logistics, retail, business services, other consumer services and government knowledge-based services. Accommodation for recreation (i.e. holiday homes) is represented by the modelled number of objects. Solar and wind energy demands are modelled in Gigawatt units.

Spatial competition for land claims is simulated only between 'subsectors' within each sector. Spatial competition between sectors is not considered. An iterative allocation procedure is implemented in which the regional developments within the subsectors are allocated to the available locations based on their suitability.

2.4 Suitability - Development Packages for Housing

The criteria for the housing claims within the living subsectors are defined by 17 'development packages'. These packages are residential environments with a size of one hectare, designed based on key figures and expert opinions with regard to plausible (urban) architectural compositions. It is important to mention that the model does not allocate public services like schools, sports facilities and hospitals within these packages. The building characteristics within the living subsectors, defined separately by each development package, are: Surface area per home, Number of rooms, Number of bathrooms, Private parking possibility, Floor Space Index (FSI) of the neighbourhood, Ground Space Index (GSI) of the neighbourhood, Residential building type, some accessibility indicators and green-index indicators. For each living subsector, only a certain selection of development packages is available. For example, multi-family houses owner-occupied are only found in the development packages: Super Urban, High Urban, Urban and Low Urban. In addition, not every development package is possible at every location. The possibility for a certain package to be developed is determined by overlay mapping.

The empirical component of suitability is interpreted in euro/m^2 per development package, in terms of the hypothetical balance of the local real estate developments. These balances are expressed in euros and determined on the basis of an empirically valuable reconstruction of the most relevant costs and benefits. These cost benefits analysis includes:

Acquisition costs of any existing real estate. These costs are based on a hedonic price analysis in which observed transaction prices are explained by the (location) characteristics of the relevant real estate (Claassens and Koomen, 2017).

Demolition costs of this property, based on key figures from Bouwkompas (2020).

Construction and residential preparation costs, regional costs, and planning process costs. These costs are based on a statistical analysis in which the land development is priced based on the location characteristics, such as the size of the planning area, plot density and soil type (Fakton, 2021).

Construction costs depends on the development package based on key figures (Bouwkompas, 2020).

Revenue from the sale of the new construction per development package. In addition, the revenue per package is affected by four weighting parameters (0.5 - 1.0): proximity to public transport, proximity to green, urban attractiveness index (UAI) and distance to places with 100,000 inhabitants. This is important in the management of where certain development packages are more or less suitable. In this way, very dense high-rise development packages can easily be realized in the Randstad (highly urbanised part of in the west of The Netherlands), near stations, and near places with many clustered facilities. Ultimately, this determines, per subsector, per grid cell, which relevant development package has the highest operating balance (Fig. 1).

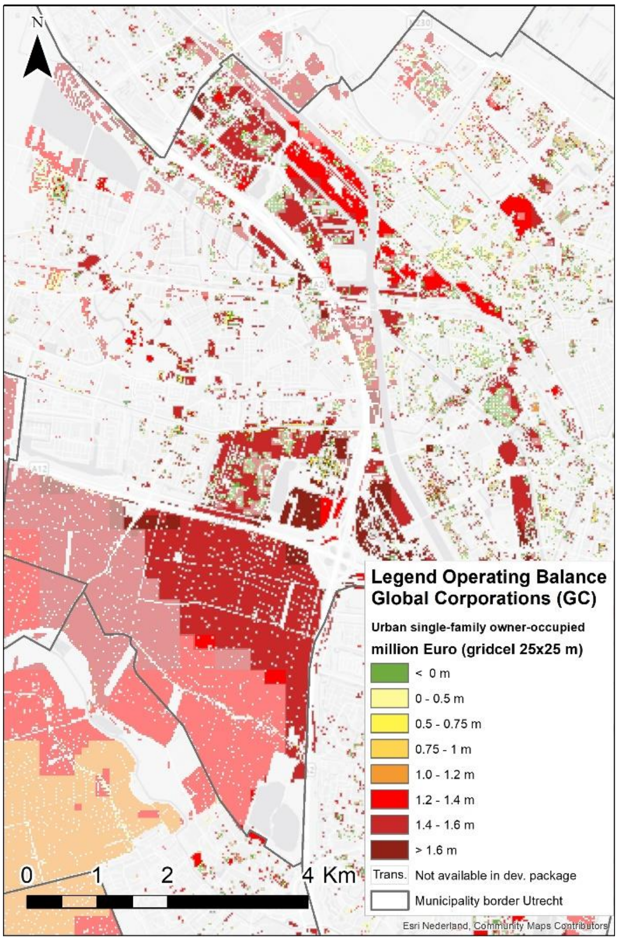

Figure 1. Example of operating balance for scenario Global Corporations for developing package 'Urban single family owner-occupied'.

In general, inner-city locations will have higher revenues but will also show higher development costs, as expected for these locations. The potential operating balance for a certain location per scenario is the same, differences can only appear according to where a developing package is possible.

Per subsector, the suitability per package is represented by the operating balance. In turn, the availability of the package is spatially limited by areas with a negative operating balance, a maximum allowed housing density in beautiful landscapes (CBS, 2024) and a minimum housing density increase. The package with the highest suitability at a location will ‘win’ the allocation.

2.5 Allocation

The implementation of a sequential order in the land allocation for the five sectors, instead of allowing this to be determined by competition between sectors, was justified by the fact that the defined prioritization of the sectors better aligns with the current practice of land use changes in the Netherlands, which is characterized by a rather segmented land market. In addition, this allowed for the model to be applied more exploratively and iteratively, in order to arrive at an outcome inferred from 'drawing and calculating'. The final allocation of the package with the highest suitability at a location is achieved by a great number of predefined spatial steps in order to provide enough room for 'drawing and calculating', such as land ownership situation, planned housing capacity and presence of construction sites/vacant lots. The number of steps is scenario-depended and lies in the range of 24 to 144 potential steps.

The allocation in LUS2 is done in one simulation run for the year of 2050. However, the simulation can also run incrementally, with a 10-year timestep. The allocation process, based on the highest suitability, determines where a development package is allowed, which development package will go where and what housing density will be achieved. The allocation is done in three sequences and up to ten iterations to enable allocation at a higher spatial level in case of a shortage of space, to prevent displacement and to achieve balance.

3 Application

The main application where The Land Use Scanner 2.0 already has been used is the Spatial Outlook 2023-study by the PBL. Other applications are Plan Monitor NOVI 2023 (Kuiper et al., 2023) and the forthcoming study Prosperity and Living Environment (WLO) 2024, a similar study was also done in 2015 (van Eck et al., 2015).

3.1 Spatial Outlook 2023

In the Spatial Outlook 2023-study (Hamers et al., 2023), the PBL has developed scenarios for the design of the Netherlands in 2050. Four possible spatial futures are presented. These are:

- Global Corporations (GC): big corporations govern the country and individualistic, hedonistic behaviour places importance on prosperity over people and planet;
- Green State (GS): the government takes the lead in developing policies which steer society toward sustainability;
- Regional Roots (RR): communities take the lead, and the wellbeing of people comes before economic prosperity and the planet;
- Volatile World (VW): digitalization governs the development of the country and the society is characterized by digitally connected groups.

The study combines these four policy scenarios with two context scenarios (i.e. high vs. low socio-economic growth), resulting in eight scenarios in total. For each scenario, detailed maps of the Netherlands in 2050 have been created based on spatial modelling in LUS2 and design research. These scenario maps illustrate the outcomes of the different choices.

All four normative scenarios assume the same number of inhabitants in 2050. The number of houses needed to house the population by 2050 is not predetermined, nor is the space needed to build the projected homes. The number of houses range between 0.5 and 2.2 million, depending on the set of parameters used for the scenarios. The scenarios illustrate that the differences in living conditions and housing preferences have a strong influence on the number of households, for example due to differences in household formation, the tendency to share homes by multiple households and wishes regarding the type and size of homes. In this paper only the GC and the GS scenarios, with high socio-economic growth, are further explained.

3.2 Results

The results in Fig. 2, Tab. 1 and Tab. 2 show great spatial variety between the Global Corporations (GC) and the Green State (GS). Compared to GC, certain restrictions in the GS scenario are blocking new developments in quiet, important Bird and Biodiversity and geographically valuable areas. Also areas sensitive to subsidence, e.g. too weak and too wet soils are not available for allocation. The number of predefined spatial steps in GC is 24 and in GS 144. The total number of houses in 2050 for the GS scenario is approximately 0.75 million houses less compared to the GC scenario. Since the number of inhabitants in both scenarios is equal, that means the number of people per household is larger in the GS scenario. Houses in GC are more often build on former agricultural land compared to GS. This is true for both the number of houses and the percentage of houses build. The results of the packages (Fig. 3, Tab. 3 and Tab. 4) show significant difference between GC and GS concerning the occupied space in relation to the number of homes especially for the (Low) Urban packages.

Table 1. Global Corporations Subsector living 2050

Subsector living	Ha new dev.	Former agri.(%)	Density-change (houses/ ha)	Nr of houses in 2050
Single Family (o)	29483	46	+29.8	877590
Single Family (r)	7362	69	+25.6	188755
Multi Family (o)	8996	23	+41.0	369105
Multi Family (r)	8374	51	+52.4	438666
Sum	54215			1874116

o = owner-occupied
r = rental

Table 2. Green State Subsector living 2050

Subsector living	Ha new dev.	Former agri.(%)	Density-change (houses/ ha)	Nr of houses in 2050
Single Family (o)	20239	37	+19.1	387490
Single Family (r)	4664	66	+15.6	72661
Multi Family (o)	7975	19	+36.6	292026
Multi Family (r)	7333	33	+50.7	371913
Sum	40211			1124090

o = owner-occupied
r = rental

Table 3. Global Corporations development package 2050

Development package	ha	% SUM ha	Houses incl. current	% SUM houses
Super Urban (o)	68	0.1	16395	0.8
High Urban (o)	1122	2.5	154406	7.3
Urban mf (o)	2468	5.4	151996	7.2
Low Urban mf (o)	2788	6.1	103550	4.9
Urban sf (o)	9454	20.7	505800	23.8
Low Urban sf (o)	9956	21.8	340495	16.0
Rural (o)	4116	9.0	74296	3.5
Low Rural (o)	13	0.0	99	0.0
Super Urban (r)	73	0.2	20423	1.0
High Urban (r)	956	2.1	149107	7.0
Urban mf (r)	1878	4.1	129251	6.1
Low Urban mf (r)	5468	12.0	224460	10.6
Urban sf (r)	948	2.1	63419	3.0
Low Urban sf (r)	2430	5.3	101165	4.8
Rural (r)	3984	8.7	88501	4.2
SUM	45720		2123361	

o = owner-occupied
r = rental
sf = single-family
mf = multi-family

Table 4. Green State development package 2050

Development package	ha	% SUM ha	Houses incl. current	% SUM houses
Super Urban (o)	12	0.0	2821	0.1
High Urban (o)	736	2.3	101291	4.8
Urban mf (o)	2580	8.1	158854	7.5
Low Urban mf (o)	2098	6.6	77916	3.7
Urban sf (o)	6017	19.0	321947	15.2
Low Urban sf (o)	5478	17.3	187363	8.8
Rural (o)	2797	8.8	50479	2.4
Low Rural (o)	2	0.0	14	0.0
Super Urban (r)	0	0.0	0	0.0
High Urban (r)	732	2.3	114231	5.4
Urban mf (r)	1947	6.1	134012	6.3
Low Urban mf (r)	4654	14.7	191059	9.0
Urban sf (r)	768	2.4	51368	2.4
Low Urban sf (r)	964	3.0	40149	1.9
Rural (r)	2932	9.2	65129	3.1
SUM	31717		1496633	

o = owner-occupied
r = rental
sf = single-family
mf = multi-family

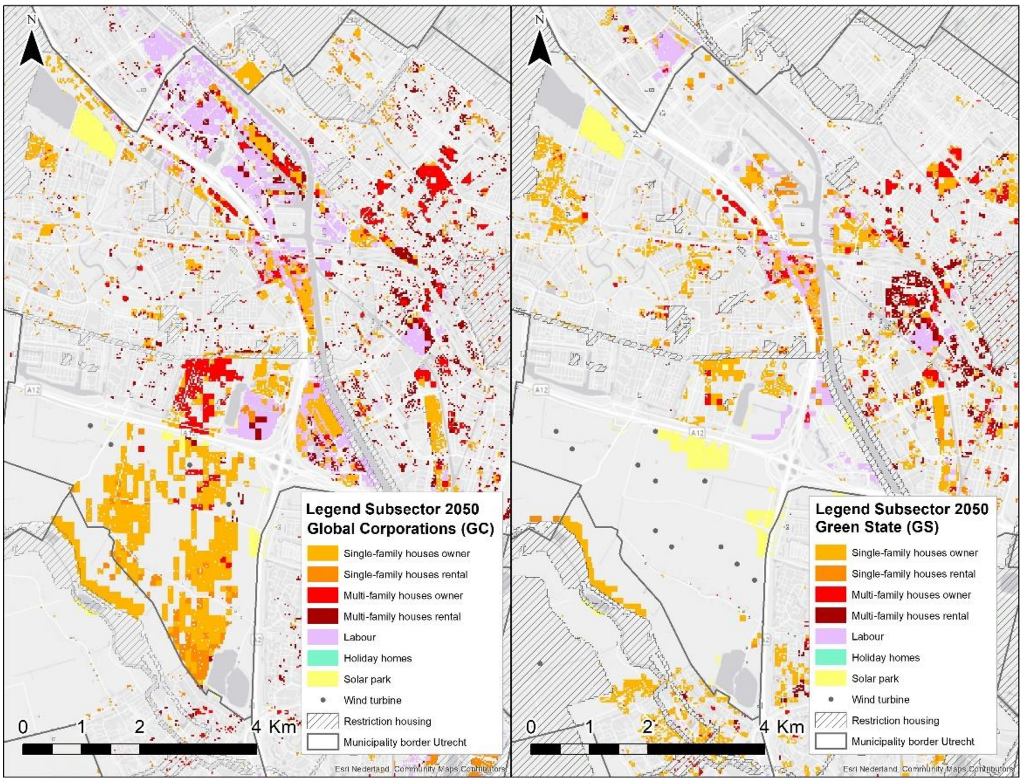

Figure 2. Example of modelled (sub)sectors in LUS2 for scenarios Global Corporations and (left) Green State (right) 2050 around the city of Utrecht The Netherlands.

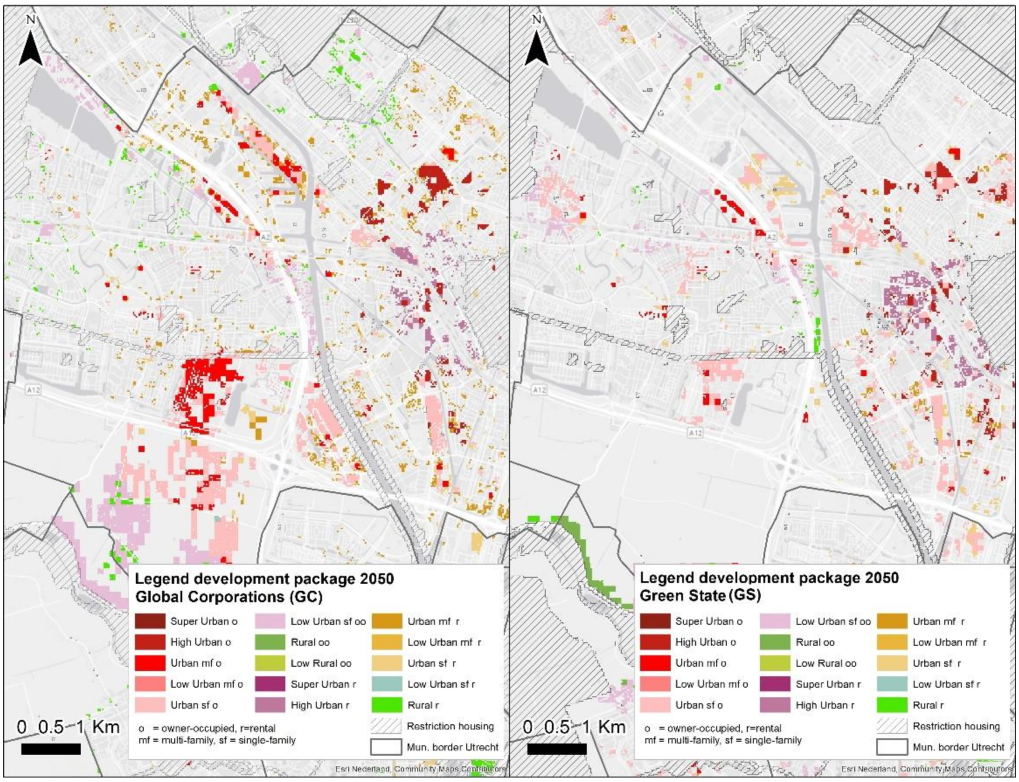

Figure 3. Example of modelled development packages in LUS 2 for scenarios Global Corporations (left) and Green State (right) 2050 around the city of Utrecht The Netherlands.

4 Conclusion

This study presented the improved version of the semi-integrated land use model Land Use Scanner 2.0, to help the Dutch government in finding the most suitable locations for 900.000 new homes across the country.

The housing allocation was modelled using four different scenarios imagining the future development of the Netherlands, based on five modelling components [1] future growth predictions, [2] restrictions, [3] suitability, [4] subsector competition and [5] availability constraints. The suitability and constraint factors are based on numerous national and regional goals, policies and restrictions.

The suitability of each grid cell is determined empirically by logistic regression and hedonic price analysis. The competition within the housing sector, the focus of this study, is defined by regional housing market claims – or higher aggregated administrative levels when the claim cannot be realised completely on this level – which were kept constant across all modelling scenarios. These components make the allocation modelling process more realistic, including legal and other policy directives, as well as current demand-supply market behaviour and national government targets. Although the spatial resolution in LUS2 has increased, the plausibility of the allocation patterns leave some room for debate and may fuel "Not in my back yard" (NIMBY) discussions.

Besides making the allocation modelling process more realistic, another strength in the LUS2 modelling approach is the semi-integration of the five sectors for available land in one model, which generates integrated results. While there is competition between subsectors in the sectors housing and labour, it could however be preferable to allocate land use between sectors in actual mutual competition. This requires suitability to be defined in an unambiguous comparable manner between the sectors. It is preferable to do this along the lines of the development packages for housing, with suitability in operating balances based on independent real estate prices. Currently the necessary data is either missing for the other sectors or is very complicated to acquire.

Finally, the LUS2 is used by stakeholders for policy support as a discussion platform offering spatially explicit scenario-oriented recommendations. This enables decision-makers to have more data-driven discussions and draw informed conclusions.

Software and Data Availability

The source code projects are on GitHub at https://github.com/ObjectVision/RSopen. The Open Source GeoDMS software to run the model can be found at https://github.com/ObjectVision/GeoDMS/releases.

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