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Land use structure optimization in Los Angeles County based on grey linear programming

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Abstract. In the rapidly developing modern world, population growth and urbanization have driven the prioritization of industrial settlements over the natural environment in land use. Besides losing ecological services, many inherent problems emerge in cities due to inefficient planning. This study presents an application of a grey linear program to maximize the socio-economic and environmental benefits of the land use structure in Los Angeles County. A technique in operations research, linear programming fits the purpose of this study since it optimizes a function concerning constraints. For each of the fourteen land types in this research, a monetary value is assigned to its economic output and environmental services, and the scalar sum is the goal to be maximized. The constraints consist of inequalities built from historical trends, developmental needs, and targets. On the other hand, based on past data, the grey model employs differential equations to predict the value of several parameters for the linear program, such as GDP output. The results are calculated by the Scipy library in a Python program and improve the quantified benefit by 8.26%, with an increase in residential, commercial, and industrial land and a slower decrease in natural landscape. Environmental initiatives and improvements in LA County's livability are necessary to fulfill long-term values.

Keywords: Linear programming, land use optimization, scipy.

1. Introduction

The land is a basic necessity for all forms of development. From growing crops to accommodating business activities, humans rely on this physical asset to carry out daily tasks. However, as human development continues to grow, problems with land use also occur. Primarily, most commercial and industrial land use conflict with the natural landscape. Water, air, and soil pollution further diminish nature's ecological values. With the pattern of population increase, urbanization has been a prevalent phenomenon. While occupying only 2% of the Earth's surface, urban areas consume 78% of global energy and produce more than 60% of greenhouse gas emissions. Due to the potential of further urban sprawl, the ecological services of land are an even scarcer, more precious resource. Uncontrolled development will only hinder efficiency and exacerbate the already jeopardized environment.

It is, therefore, most favorable to plan the land areas to balance various interests. This study implements grey linear programming to optimize the land use structure in Los Angeles (LA) County. Specifically, optimizing land use structure, based on compatibility and existing features in LA County, aims to maximize ecological and socio-economic benefits for sustainable development. The linear

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program outputs the optimized area for each land type after considering its economic and environmental benefits and imposing appropriate constraints to satisfy different social needs. In constructing the model, current land use, historical trends, and developmental goals are considered. Analyzing existing data, changes and problems in land use in LA County are discovered and addressed in the solution. The grey model is an add-on to the traditional method that determines a probable value among a range, yielding predicted values to include in constraints. The optimized result could serve as a quantitative guideline for land allocations.

The rest of the paper is organized as follows: Section 2 outlines the related work and current situation of LA County; Section 3 details the methods and model that the linear program is built upon; Section 4 presents the result of optimization alongside the status quo; Section 5 examines the result and identifies areas of improvement of the model; Section 6, finally, concludes all the observations.

2. Theoretical framework

2.1. Related work

Grey linear programming is a relatively well-established method for land use structure optimization. In Zhang's case study in Yun County, the grey prediction model GM (1,1), which relies on differential equations, is employed to project population and GDP output at the target year [1]. Both values come in handy since population and local population density serve as a limit for areas of residence, and GDP output helps scale experts' ratings to form the coefficient of each land type in the objective function. Even though the economic constraints are rather cursory, the predictions allow the model to befit the local situation.

Furthermore, linear programming is a systematic guideline that yields quantitative makeup for spatial optimization. Wu et al. set up two objective functions concerning carbon emission and maximizing economic gain on six land types in Chengdu [2]. Calculated from constraints of developmental standards, the predicted land use allocation (a.k.a. expanding all land types except farmland) is the demand for the future land use simulation (FLUS) model — a spatial layout optimization model trained on data ranging from topography to land use convertibility, that calculates probability-of-occurrence and emulates land use changes. While the constraints appear arbitrary and the classification of urban land is generic, the outputs are deductive and reliable.

In terms of expectation of future land use in LA County, Sleeter et al. have predicted an increase in urban land use at the expense of natural lands across virtually all regions of California [3]. This conclusion is arrived at with a business-as-usual (BAU) scenario and three population growth scenarios, all built with the Land Use and Carbon Scenario Simulator (LUCAS) model using state variables. Specifically in coastal Southern California, urban area increase is among the highest. As much as the study holds empirical grounds, it overlooks specific developments' prospective influence on urbanization, and some finding mismatches the general trend, such as agricultural expansion outpacing agricultural contraction.

2.2. Status quo

LA County is located in the Pacific coastal region of Southern California. It is comprised of 88 incorporated cities as well as many unincorporated areas, spanning a total land area of almost 10600 km2 and a coastline of 110km. It has a Mediterranean climate, with a mean annual temperature and precipitation of roughly 17.6°C and 35.7cm, respectively, and a mean of 9 hours of daily sunlight. It encompasses many land types, including mountain ranges, forests, and islands. The county is enriched with mineral resources, including oil, rock deposits, and sand. The county has a high level of urban development centering around the city of LA and more open space through the mountain range. Figure 1 and Appendix 1 summarize the areas and distribution of significant land categories, which serve as the starting point of this study [4].

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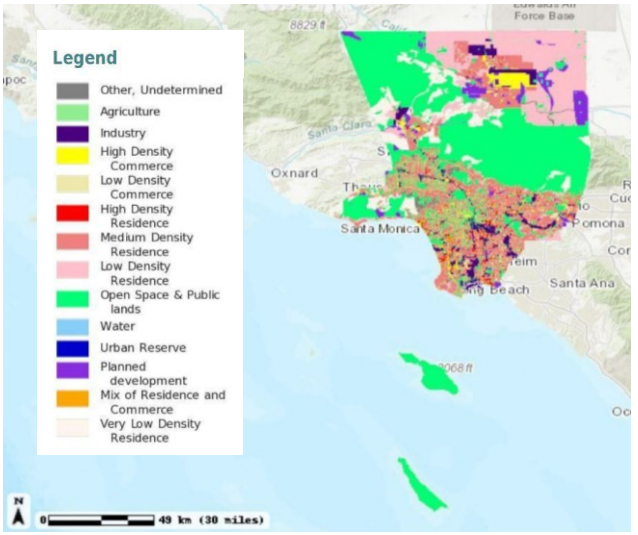

Figure 1. Land use in LA county.

LA County is also the most populous county in the United States, with a population just over 10.2 million and 39.8 in median age in 2023 [5]. According to most recent economic statistics, LA County has a real GDP of 2012$711.87 billion in 2021, which ranked first among all counties [6]. Its top industries include entertainment, aerospace, and finance.

Table 1. LA County 2017-2019 & 2021 GDP (thousands chained 2012$) by Economic Activity

Economic Activity		2017	2018	2019	2021
Primary Sector of Economy		6700555	6433821	6253602	6245288
	Agriculture & Forestry	235192	252461	190582	201203
	Natural Resource Extraction	1785546	1455097	1428985	1498930
	Utilities	4679817	4726263	4634035	4545155
Secondary Sector of Economy		149263395	158803251	160257130	155406764
	Construction	16026646	16452373	16707409	15632412
	Manufacturing	69572284	75842045	75488126	72782314
	Wholesale Trade	41841551	42857454	43632245	45106790
	Transportation and warehousing	21822914	23651379	24429350	21885248
Tertiary Sector of Economy		441872508	518836418	535620901	556333303
	Retail Trade	35993793	36569645	37053384	36770565
	Information	103134099	104463976	110570017	125565002
	Finance, insurance, real estate, rental, and leasing	118115648	120711713	121897107	120923386
	Professional and business services	81348467	85500184	90452775	100209363
	Educational services, health care, and social assistance	53,054,603	55,096,064	56,873,621	59333027
	Arts, entertainment, recreation,	36951552	38407244	39985793	36556606

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Table 1. (continued).

	accommodation, and food services				
	Other services (except government and government enterprises)	13274346	12848144	12988909	11949377
Public Sector (Government and its Enterprises)		63998700	65239448	65799295	65025977
Total		661835158	749312938	767930928	783011332

However, several issues exist along the current land use. Like many other metropolises, LA County has sacrificed much of its ecosystem for economic development. In only two years, from 2016 to 2018, the county has lost almost 16km2 of its important farmland, grazing land, and open space for urban development. The decrease in agricultural potential reduces local natural capital and worsens food insecurity in the region. Besides, traffic in LA is one of the most notorious. Despite having 77000 lane miles, congestion cost the L.A. metropolitan region $13.3 billion in lost productivity in 2014. Contributing to this are almost 80% of workers commuting by driving and vehicle miles traveled (VMT) per capita of 21.5 miles [7]. There is also a lack of alternatives as the 1670km2 High Quality Transit Area (HQTA), defined as an area within one-half mile of a transit stop with 15-minute or less peak hour service frequency, covers merely 22% of the population [8]. Based on previous research in section 1.2, it is hypothesized that residential, commercial, and industrial land use will grow while the natural landscape diminishes in LA County. However, the change may not be drastic due to the relatively small demographic changes and increased environmental efforts.

3. Method

3.1. Grey Multi-Objective linear programming

Grey multi-objective linear programming is incorporated to maximize the socio-economic and ecological benefits of land use in LA County. Linear programming is a widespread technique in operations research that optimizes the objective and strategies within existing constraints. All parts of the program are linear, and since land use areas are discrete variables, linear programming guarantees an exact optimal solution [9]. Graphically, the optimal solution is an extreme point of the feasible region formed by constraints. The grey framework enhances the program by predicting uncertainties in the future. It discerns the feasible range of a parameter based on its past data and calculates a probable value using differential equations. As introduced in section 1.2, grey linear programming works for diverse variables. The exact program for GM (1,1) is in Appendix 2 [10].

3.2. Data collection and processing

The setup of the linear program involves determining land types of interest and their economic values and various limits. Consistent with the status quo of the region, the distribution, areas, and economic outputs of land types are found in open databases and government agencies, including Data Basin, California Department of Conservation, and the U.S. Bureau of Economic Analysis [4, 6, 11]. Further details, such as developmental goals and historical trends, are derived from government reports, documents, news, and scholarly studies.

3.3. Mathematical formulation

3.3.1. Decision variables. The following table specifies the definition of each land type, according to Title 22 of the Ordinances of Los Angeles County, that the research premises on, which establishes the setting and guides the purpose of the optimization, and assigns each with an indexed variable x_i, representing the area of a land type [12].

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Table 2. Definition of each land type

Land Type		Definition
Agriculture, Open Space, and Water		Agricultural use, buffer zone, recreation, natural resource industry and protection
x_1	Agriculture	Production of plants in- and extensively, of timbers, and of animals in grazing lands
x_2	Open Space & Public Lands	Preservation, maintenance, and enhancement of the recreational, natural, and environmental resources (e.g. groundwater recharge, minerals, wildlife survival, etc.)
x_3	Water	Conservation of water and protection against wild hazards
Commerce		Meeting the needs of communities and strengthening the tax base
x_4	High Density Commerce	Higher-end goods and services (e.g. office, civic centers, downtown)
x_5	Low Density Commerce	Lower-end goods and services (e.g. neighborhood, community, school, public facility)
Residence		Human habitation
x_6	High Density Residence	Dwelling with density greater than 1977 units/km^2
x_7	Medium Density Residence	Dwelling with density between 124 and 1977 units/km^2
x_8	Low Density Residence	Dwelling with density between 12 and 124 units/km^2
x_9	Very Low Density Residence	Dwelling with density between 1 and 12 units/km^2
x_{10}	Industry	Manufacturing and employment center
Other		Miscellaneous
x_{11}	Urban Reserve	Undeveloped area reserved for future urban use
x_{12}	Mix of Residence and Commerce	67% medium-density residence and 33% commerce
x_{13}	Planned Development	Developments that do not fit within a single use
x_{14}	Undetermined	Unknown

3.3.2. Objective function. The objective function follows the weighted sum method, in which each decision variables x_i is given a coefficient and combined to form a scalar value for optimization. In this study, each coefficient is the sum of the economic benefit (\$/km^2) and ecological benefit (\$/km^2) per unit area of land in target year 2025, and so the combined scalar value represents the benefit, which is to be maximized. The result indicates the optimal land use area allocation.

The economic benefit of each land type is derived from its industry's GDP output in thousands chained \$2012, classified in Table X. For example, commercial land corresponds to the vast majority of the tertiary sector of the economy, while industrial land corresponds to the vast majority of the secondary sector of the economy. For a land type with complete historical economic and area statistics, its GDP outputs per unit area in 2010, 2012, 2014, and 2016 are fed into the grey model GM(1,1) to predict its

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one in 2025. Otherwise, the GDP output per unit area in 2014 is adopted since that is when the area data is based. Regarding the distinction between subcategories of residential lands, higher-density residences are given higher values as they face a larger group of people and, thus, tend to generate more residential investment and consumption spending. The economic benefits of urban reserve, planned development, and undetermined lands are all set to 0 because the former brings latent impacts with no current value, and the latter is not applicable for use.

The ecological benefit of each land type is extracted from the ecosystem service values (ESV) estimated in a study by Costanza et al. [13], converted to thousands chained $2012. The ESV quantifies the ecological value of lands based on their contributions to humans' quality of life, specifically the provisioning, regulating, supporting, and cultural services. According to the nature of a land type, its value may be a mix of various ESVs. Despite lacking the exact amount of each biome in a land type, the proportion for mixing is estimated based on existing geology. For instance, the ecological benefit of agricultural land is a mix of the ESVs of 15% estuary (fishery), 10% temperate forest (timber), 40% cropland (crops), and 35% grassland (animal husbandry).

Thus, the objective function, in thousands chained 2012$, is obtained as follows:

$$\begin{aligned} Max\ Z\ =\ & (90.37+925.3)x_1 + (1579.88+516.27)x_2 + (104130.11+6348.5)x_3 + \\ & (977678.27+739.37)x_4 + (440288.39+739.37)x_5 + (50064.05+739.37)x_6 + \\ & (25032.03+683.6)x_7 + (2503.2+627.82)x_8 + (250.32+605.51)x_9 + \\ & (270205.4+739.37)x_{10} + (0+516.27)x_{11} + (242586.3+702)x_{12} + \\ & (0+709.69)x_{13} + (0+0)x_{14} \end{aligned} \quad . (1)$$

$$\Downarrow$$

$$\begin{aligned} Max\ Z\ =\ & 1015.67x_1 + 2096.15x_2 + 110478.61x_3 + 978417.64x_4 + 441027.76x_5 + \\ & 50803.42x_6 + 25715.63x_7 + 3131.02x_8 + 855.83x_9 + 270944.77x_{10} + \\ & 516.27x_{11} + 243288.3x_{12} + 709.69x_{13} + 0x_{14} \end{aligned}$$

3.3.3. Constraints. Constraint of total land area: The area of all land types added together need to be equal to the land area of LA County.

$$\sum_{i=1}^{14} xi = 10584.11. \quad (2)$$

Constraint of natural resources: The non-water natural capital in LA County should be preserved as much as possible in accordance with the General Plan from LA County Department of Regional Planning.

Forest cover, an open environment of 2636.61km^2 with a 2.01% annual deforestation rate, and agricultural land, which GM(1,1) predicted to be 1473.03km^2 in 2025, should decrease slower than they currently do, thus setting a target of 1.5%. Particularly, timberland, occupying about 51.58% of forests in California, counts as agricultural land [14]. In addition, noting a National Renewable Energy Laboratory study, an open space of 28.75km^2 must be reserved to achieve LA County's goal of 900-1500 MW of wind and solar capacity by 2025. The predicted areas are the lower limits [15].

$$\begin{aligned} & x_1 \geq 1473.03 + 0.5158 \cdot 2636.61(1-0.015)^2 \Rightarrow x_1 \geq 2792.5 \\ & x_2 \geq (1-0.5158) \cdot 2636.61(1-0.015)^2 + 28.75 \Rightarrow x_2 \geq 1267.38 \end{aligned} \quad . \quad (3)$$

Constraint of water resources: The water natural capital in LA County undergoes restoration measures. As outlined in Alternative 20, habitats within 2.91km^2 of the study area should be restored, in addition to stormwater retentions. While pursuing this goal, water area should at least maintain the status quo.

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$$37.08 + 2.91 \geq x_3 \geq 37.08 \Rightarrow 39.99 \geq x_3 \geq 37.08 . \quad (4)$$

Constraint of urbanization: Commercial and industrial land use expands due to various developments.

The government of LA County has planned to increase HQTAs from 1670km2 in 2016 to 2396.88km2 in 2045 [16]. Without further progress detail, it is assumed to increase by the same rate each year, calculated to be 1.25%. Public transportation usually increases population density near stations, inducing business activities. Commercial and industrial land are therefore expected to grow. Education/healthcare services and hospitality have grown 6.9% and 2%, respectively, over the past year, and despite losing jobs, the manufacturing industry intends to counter the trend in the future [17]. Based on the GDP growth rate of LA County from 2014 to 2019 and GDP output in 2021 of $711.87 billion (chained 2012$), the growth rate until 2025 will hover around 3%. Prediction based on HQTA growth rate is the lower limits while that based on GDP growth rate is the upper limits.

$$\begin{aligned} &210.16(1+0.031)^2 \geq x_4 \geq 210.16(1+0.0125)^2 \Rightarrow 223.39 \geq x_4 \geq 215.45 \\ &252.73(1+0.031)^2 \geq x_5 \geq 252.73(1+0.0125)^2 \Rightarrow 268.64 \geq x_5 \geq 259.09 \\ &485.88(1+0.031)^2 \geq x_{10} \geq 485.88(1+0.0125)^2 \Rightarrow 516.47 \geq x_{10} \geq 498.1 \\ &0.33 \cdot 10.78 \cdot (1+0.031)^2 \geq 0.33x_{12} \geq 0.3310.78(1+0.0125)^2 \Rightarrow 11.46 \geq x_{12} \geq 11.05 \end{aligned} . \quad (5)$$

Constraint of total population: The residential areas should support the population of LA County at current population density. In addition, it is projected that LA County needs to build approximately 499,430 more affordable housing units to meet demands from lower-income households [18].

For the sake of calculation, high-, medium-, low-, and very low-density residences are assumed to be 2100, 1050, 70, and 5 units/km^2 respectively. Considering that affordable housing units are usually highly populated, high-density residences are designated to achieve the goal. According to California Department of Finance, the population of LA County in 2025 would be 10258572, and an average household size of 2.94 is found from the U.S. Census Bureau [5]. As LA County continues to grow during the studied time period, portions of low- and very low-density residences will most likely be turned into other land uses, presumably at a similar rate as HQTAs' development due to their overlapping areas. For low- and very low-density residences, predictions based on HQTA growth rate are the lower limits while the status quos are the upper limits.

$$\begin{aligned} &(2100 \cdot 2.94)x_6 + (1050 \cdot 2.94)x_7 + (70 \cdot 2.94)x_8 + (5 \cdot 2.94)x_9 + (1050 \cdot 2.94)0.67x_{12} \geq 10258572 \\ &\Downarrow \\ &6174x_6 + 3087x_7 + 205.8x_8 + 14.7x_9 + 2068.29x_{12} \geq 10258572 \\ &x_6 \leq 243.23 + \frac{499430}{2100} \Rightarrow x_6 \leq 481.05 \\ &1710.19 \geq x_8 \geq 1710.19(1-0.0125)^2 \Rightarrow 1710.19 \geq x_8 \geq 1667.7 \\ &697.49 \geq x_9 \geq 697.49(1-0.0125)^2 \Rightarrow 697.49 \geq x_9 \geq 680.16 \end{aligned} . \quad (6)$$

Constraint of potential development: Urban reserve should remain for the potential need for urban development.

According to official population projections, the population of LA County will grow in the near future. Thus, 0.5% to 1% of the total land area should be reserved for urban areas.

$$0.01 \cdot 10584.11 \geq x_{11} \geq 0.005 \cdot 10584.11 \Rightarrow 105.84 \geq x_{11} \geq 52.92 . \quad (7)$$

Constraint of governmental involvement: The land of planned use may evolve to serve a principal zone's purpose.

Based on the historical GDP growth rate of governmental services, this portion of GDP will decrease annually by 2.47% and 3.11% for the next two years. It is reasonable to conclude that land for planned

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development, often managed by governments, will decrease at a similar rate. The status quo is the upper limit while the predicted area is the lower limit.

$$385.24 \geq x_{13} \geq 385.24(1-0.0247)\cdot(1-0.0311) \Rightarrow 385.24 \geq x_{13} \geq 364.04 . \quad (8)$$

Constraint of undetermined land use: All lands serve a purpose, and therefore, no land should be undetermined in the optimal plan.

$$x_{14} = 0 . \quad (9)$$

Constraint of non-negativity: All land types' areas cannot be a negative number.

$$x_i \geq 0 (i = 1,2,\ldots\ldots,14) . \quad (10)$$

3.3.4. Python scipy program. The linear program above is transcribed into a Python computer script that implements the LinProg function from the library Scipy to return the optimal land use allocation. Utilized in the function, the method 'highs' automatically chooses a solver between the dual revised simplex implementation, which changes the basic set variables to traverse edges of the feasible region and find the optimal one, and the interior-point method, which approaches an optimal edge starting from inside the feasible region.

4. Results

The following table compares current land use to optimized allocation.

Table 3. Current Land Use and Optimized Land Use

Land Type		Current Area (km^2)	Optimized Area (km^2)	Percentage Change
Agriculture, Open Space, and Water		4555.72	4096.96	-10.07%
	Agriculture	1.32	2792.5	N/A
	Open Space & Public Lands	4553.95	1267.38	N/A
	Water	0.45	37.08	N/A
Commerce		462.88	492.03	6.30%
	High Density Commerce	210.16	223.39	6.30%
	Low Density Commerce	252.73	268.64	6.30%
Residence		4574.37	5067.87	10.79%
	High Density Residence	243.23	481.05	97.78%
	Medium Density Residence	1923.46	2238.96	16.40%
	Low Density Residence	1710.19	1667.7	-2.48%
	Very Low Density Residence	697.49	680.16	-2.48%
Industry		485.88	498.83	2.67%

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Table 3. (continued).

Other		505.26	428.42	-15.21%
	Urban Reserve	0.08	52.92	66050.00%
	Mix of Residence and Commerce	10.78	11.46	6.31%
	Planned Development	385.24	364.04	-5.50%
	Undetermined	109.15	0	-100.00%
Total		10584.11	10584.11	0%
Objective Function Value (billions chained 2012$)		529	572.69	8.26%

5. Discussion

5.1. Analysis of change

The overall quantified benefit from optimized land use in LA County has a considerable improvement of 8.26%. The overarching trend is the compensation of natural landscapes and underdeveloped areas for economic and residential land use, which concurs with that in most other regions.

5.1.1. Agriculture, open space, and water. The optimal natural land area decreases from the status quo, slower than it did historically, by just over 10% for the excavation of farmland, grazeland, and forest. While they play an essential ecological role, they are overlooked for their lower economic yield. Over the past two decades, LA County has had drastic population growth that settled in sporadic locations, which had to be offset by agricultural land [19], and a substantial amount of timber is consumed for industrial purposes. Yet, the population growth has basically reached the projected maximum, and with conservation efforts in place, the natural landscape will thus likely retain most of its territory for the foreseeable future after 2025.

Particularly, LA County aims to reduce VMT per capita by at least 13% by 2025 [20]. This will reduce the need for developing agricultural land or open space to construct roadways, whose impermeable surfaces contribute to the urban heat island effect and hinder groundwater recharge. To achieve this, it has become imperative to enforce the County government's infrastructural plans. For example, expanding bike lanes by 20 lane miles per year starting in 2028 will encourage a larger portion of commuters to adopt green transportation [20]. Moreover, the reorganization of bus routes and expansion of HQTAs reinforce the conservation of natural land and its ecological services.

5.1.2. Commerce, industry, and residence. The optimal urban built-up land area increases by roughly 10% from current numbers. One reason is that the economy of LA County is still expanding. As outlined in the constraint section, various industries, including education and public service, have seen recent growth, not to mention that the County's real GDP has been steadily increasing despite the pandemic. Another pivotal driving force is regional demography. Besides the sheer need for more housing to accommodate the growing population, most houses need to be affordable to lower-income groups, thus dictating the development scheme of residence. In addition, extensions of the public transit system will stimulate economic activities. As more people live near a transit option, the increased connectivity ultimately leads to dense population zones, which induces residences and businesses. As estimated by the Southern California Association of Government, new households will grow by 6%, along with new

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jobs growing by 15% [21]. Meanwhile, another critical advantage of HQTAs is alleviating the environmental damage to cities. As a convenient commuting option that requires only a tiny portion of land area, public transportation decreases congestion and emissions. As a result, improvements in public transportation are necessary for cities to become more eco-friendly, and all things considered, the sizeably more significant economic gains justify the increased area.

5.2. Future work

5.2.1. Graphical organization of optimal land use. The linear programming model computes lump sums of land allocations, or numerical results that provide little insights into geographical distribution. It is also difficult to know which land type is changed into which. One prospective solution to narrow down the general pattern is applying the FLUS model with the linear programming results as a quantitative control, exemplified by Wu et al. [2]. By fitting the artificial neural network's geological data to LA County, such as including risk level of earthquake and forest fire, the value of each land type can be fully exploited. There would also be a greater emphasis on social benefits as the model ensures spatial compactness and access.

5.2.2. Multiple use of land. Due to the scarcity of land resources, buildings in many cities now allow diverse usages, such as adding a rooftop garden or mixing different economic activities. This study does not consider such flexible usage, affecting economic and ecological benefits estimation. In solving this problem, creating criteria for varied amenities and adopting the genetic algorithm in Haque et al.'s study take multi-use into account [22].

5.2.3. Applicability of objective function. The coefficient for each decision variable may not have been calculated with a fair weight between economic and ecological values, and the ESVs adopted from Costanza et al.'s study are general estimates for LA County and susceptible to change from developments above. The objective function could also expand its scope by involving other goals, such as spatial compactness and land use compatibility. Consultation with local experts and inspection of regional spatial data would cater the model to LA County and improve the result's significance.

6. Conclusion

In a metropolis like LA County, land resources are ever more invaluable as they need to support a large population for various activities efficiently. This research seeks to find the optimal land use structure that balances the natural capital and economic development in LA County by implementing a grey linear program on local demographic, economic, and geographical data, which reveals patterns that may continue influencing future land use changes. The mathematical model builds on fourteen land types, each put into relevant constraints, and the Scipy library applied through Python computes the results. The numerical outputs serve as a quantitative benchmark for future developments.

The optimal land use structure improves economic and environmental benefits by 8.26%. Agricultural land, open space, and water continue decreasing but at a slower rate as they progress toward conservation. Commercial, residential, and industrial land use, which compensate for moderate eco-services with significant economic productivity, increases by almost 10% to accommodate growing economic and infrastructural developments. Specifically, the boost in residences would support population growth, including affordable units.

The various environmental conservation efforts proposed by the County's government, such as constructing renewable energy facilities and establishing ecological areas, will alleviate further urban sprawl. However, it is equally essential to enforce infrastructural developments to neutralize cities' environmental degradation and maximize the value of land uses. Of particular interest are bike lanes and public transportation systems. While maintaining and creating economic opportunities, convenient public transit will address the significant congestion issue by lowering the personal need for a vehicle and reducing emissions in LA County.

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Appendix

Appendix 1. LA County Land Use Breakdown

Land Type		Total Area (km^2)	Percentage of Total
Agriculture, Open Space, and Water		4555.72	43.04%
	Agriculture	1.32	0.01%
	Open Space & Public Lands	4553.95	43.03%
	Water	0.45	0.00%

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Appendix 1. (continued).

Commerce		462.88	4.37%
	High Density Commerce	210.16	1.99%
	Low Density Commerce	252.73	2.39%
Residence		4574.37	43.22%
	High Density Residence	243.23	2.30%
	Medium Density Residence	1923.46	18.17%
	Low Density Residence	1710.19	16.16%
	Very Low Density Residence	697.49	6.59%
Industry		485.88	4.59%
Other		505.26	4.77%
	Urban Reserve	0.08	0.00%
	Mix of Residence and Commerce	10.78	0.10%
	Planned Development	385.24	3.64%
	Undetermined	109.15	1.03%
Total		10584.11	100.00%

Appendix 2. GM (1,1) Python Code

```
def greyModel(dataVec, predictLen):
    import numpy as np
    from scipy import io, integrate, linalg, signal
    from scipy.sparse.linalg import eigs
    from scipy.integrate import odeint

    x0 = np.array(dataVec, float)
    n = x0.shape[0]
    x1 = np.cumsum(x0)
    B = np.array([-0.5 * (x1[0:-1] + x1[1:]), np.ones(n-1)]).T
    Y = x0[1:]
    u = linalg.lstsq(B, Y)[0]

    def diffEqu(y, t, a, b):
        return np.array(-a * y + b)

    t = np.arange(n + predictLen)
    sol = odeint(diffEqu, x0[0], t, args=(u[0], u[1]))
    sol = sol.squeeze()
```

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```
    res = np.hstack((x0[0], np.diff(sol)))
    return res
```