Land Use Demands for the CLUE-S Spatiotemporal Model in an Agroforestry Perspective

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Abstract: Rural landscape evolution models are used as tools for the analysis of the causes and impact of land use changes on landscapes. The CLUE-S (the Conversion of Land Use and its Effects at Small regional extent) model was developed to simulate the changes in current land use, by using quantitative relationships between land uses and driving factors combined with a dynamic modeling of land use competition. One of the modules that build the “CLUE-S” is the non-spatial subset of the model that calculates the temporal evolution of the land use/cover under several socio-economic scenarios. The purpose of this research was to estimate the demands of land use in the area of Mouzaki, Thessaly plain, Greece with the ultimate goal of using them in the non-spatial module of the CLUE-S to predict the evolution of land uses in year 2040. These estimations are the quantitative prediction of the spatial change for all land use types at the aggregate level. Three models of forecasting the future land cover in the area were simulated, in order to obtain a clear view of the different land uses in the future. We distinguished three model-scenarios for calculating the demand-forecasts: (a) business as usual (BAU) scenario, that deals with a linear projection of the current land use demands, (b) rapid economic development (RED) scenario, and (c) ecological land protection (ELP) scenario. In the BAU scenario the land use demands for the year 2040 were calculated using linear interpolation utilizing historical data from 1960 to 2020. In the RED scenario, the demands were calculated by maximizing the economic benefit of land uses, and in the ELP scenario the demands were calculated by maximizing the environmental benefit of land uses. Furthermore, a multi-criteria analysis was performed to find the trade-offs between economic benefit maximization and environmental benefit optimization. It was found that the agricultural lands reach their maximum area under the RED scenario, while reaching their lower bound for the ELP scenario. The same goes for agroforestry systems. The grasslands reach their lower bound under the ELP scenario, while they achieve a higher value under the RED scenario. Concerning the silvopastoral woodlands, although an increase is foreseen under the BAU scenario, it appears that they reach their lower bound in the other two scenarios, RED and ELP. Forests receive intermediate values and cover a larger area under the ELP scenario compared with the RED scenario. The expected forest cover under the BAU scenario is higher. Moreover, sparse and dense shrublands receive their lower bound for both optimization scenarios, while the settlements reach the upper bound for the RED scenario and the lower one under the ELP scenario.

Keywords: agroforestry; non-spatial module of CLUE-S; scenario building; land use change; demand forecasts

1. Introduction

It is well documented that Mediterranean landscapes are undergoing significant changes in land uses (Ambarli et al. [1], Guarino et al. [2]). These changes begin from a
socio-economic basis, such as the movement of rural populations to urban centers with the consequent abandonment of the (traditional) use of rural and forest land (Chouvardas [3], Papanastasis [4], Chouvardas et al. [5], Perpiña et al. [6]). The result of these changes in land use is the formation of new landscapes, as they evolve with the succession of natural vegetation. In order to control the succession of natural vegetation and to support rural income, state and regional rural policies promote agroforestry practices. In the European Union for example, agroforestry is frequently reported in the draft Strategic Plan Regulation of the new Common Agriculture Policy (2021–2027), and in the Farm to Fork and Biodiversity Strategies, which are all developed within the general framework of the EU’s Green Deal.

Agroforestry systems can have significant advantages over conventional agriculture, livestock farming or forest tree cultivation, such as increased productivity, economic benefits and greater variety in goods produced and services offered (Vrahnakis et al. [7]). However, agroforestry adoption by farmers seems to be low. Many different factors can influence the decision-making for agroforestry adoption. Aspects related to social capital, economic constraints, labor and land are recorded to play important role in such a decision (Mwase et al. [8], Adesina and Chianu [9], Fischer and Vasseur [10], Neupane et al. [11], Bannister and Nair [12]), while increased land-use flexibility (Djalilov et al. [13]) and awareness of the connection between agroforestry and land quality improvement could lead to increased adoption of the technology (Mwase et al. [8]). Risk and uncertainty also play an important role in the adoption of new agricultural technologies (Marra et al. [14]).

Rural landscape evolution models are used as tools for the analysis of the causes and impact of land use changes on landscapes. Additionally, they are used towards better understanding of the landscape functions and the development of policies and planning of management (Verburg et al. [15]). The scenario-based forecasts of the evolution of landscapes can be used as early warning systems for the (possible) negative effects of management policies that will result in the development of landscapes (Xiang and Clarke [16], Shearer [17]). The land use/cover evolution models should be able to answer critical diachronic questions, such as what the variables (biophysical and socioeconomic) affecting the evolution of land use/cover units are, where future landscape changes are identified, and at what rate/intensity the land use/cover units are changed (Veldkamp and Lambin [18]).

The CLUE-S (the Conversion of Land Use and its Effects at Small regional extent) model was developed to simulate the changes in current land use, by using quantitative relationships between land uses and driving factors combined with a dynamic modeling of land use competition (Verburg et al. [19]). The “CLUE-S” model consists of two totally distinct modules (Verburg et al. [15]). The first is the non-spatial subset of the model which calculates the temporal evolution of the land use/cover under several socio-economic scenarios. The second is the spatial subset which converts/transforms into sections the landscape spatial changes that are numerically calculated from the non-spatial subset, using a geographic, grid-oriented file system (raster). The predictive power, robustness and suitability of CLUE-S have already been proved in several cases (indicatively, Chouvardas and Vrahnakis [20], Zhang et al. [21], Han et al. [22]). However, it is the first time that CLUE-S is used to project spatiotemporal land use changes in an agroforestry perspective.

The purpose of this research was to find the demands of land use in the area of Mouzaki, Thessaly plain, Greece with the ultimate goal of using them in the non-spatial module of the CLUE-S model to predict the evolution of land uses in year 2040. We distinguished three model-scenarios for calculating the demands-forecasts: (a) business as usual (BAU) scenario, that deals with a linear projection of the current land use demands, (b) rapid economic development (RED) scenario, and (c) ecological land protection (ELP) scenario. In the BAU scenario the land use demands for year 2040 were calculated using linear interpolation utilizing historical data from 1960 to 2020. In the RED scenario the
demands were calculated by maximizing the economic benefit of land uses and in the ELP scenario the demands were calculated by maximizing the environmental benefit of land uses. Furthermore, a multi-criteria analysis was performed to find the trade-offs between economic benefit maximization and environmental benefit optimization.

2. Scenarios on Land Use Demands

Various models have been proposed to deal with the demands of each land use, from simple trend projections to complex economic models (Reginster and Rounsevell [23], Hoymann [24]). Linear extrapolation of recent land use changing trends in the near future is the most common practice for finding the demands for each land use. For the CLUE-S spatiotemporal model, the results of the unit of demands (non-spatial unit) determine, on an annual basis, the area to be covered by each land use. This information constitutes direct input data for the spatial unit of the CLUE-S. Therefore, we focused on finding the land use requirements that will frame the linear projection of trends in recent land use change in the near future. Recent literature directs to models and methods of operations research for the prediction of land uses demands (Wang et al. [25]).

The most recently used scenarios for the CLUE-S model were proposed by Wang et al. [25]; apart from the typical linear business as usual (BAU) scenario, they proposed the rapid economic development (RED), and ecological land protection (ELP) scenarios. The BAU scenario, which is widely used in such studies, is derived from the historical trends of land use change and serves as the basis of the research, since it does not require the mediation of policies, other than those that already exist. The other two scenarios are based on constrained optimization models, based on different needs for green space and urban development. In particular, the aim of the RED scenario is to optimize the economic benefits generated by the land system (in this case the research area), while the ELP scenario considers the protection of ecosystems or otherwise maximizes the benefits of the ecosystem services produced by the land system. The proposed scenarios elaborate many degrees of freedom. Various parameters need to be defined, which are site-specific. The details of the scenarios, as well as how they were applied in the research area are presented below. Finally, a multi-criteria analysis was performed to calculate trade-offs between the two scenarios (RED and ELP), which facilitates the formulation of a common policy for optimal economic growth and environmental balance as well.

3. Study Area and Forecast Period

The research area is the administrative territory of the Municipality of Mouzaki, central Greece (31,326.97 Ha, Figure 1). The municipality includes 27 village communities populated by more than 13,000 inhabitants. Agricultural lands occupy 11,144.03 Ha (35.57%), silvoarable 556.38 Ha (1.78%), grasslands 2405 Ha (7.68%), silvopastoral woodlands (10–40% tree cover) 3815.39 Ha (12.18%), forests (40–100% tree cover) 10,573.64 Ha (33.75%), sparse shrublands (10–40% shrub cover) 503.74 Ha (1.61%), dense shrublands (>40% shrub cover) 784.99 Ha (2.51%), urban 1457.79 Ha (4.65%) and barren land 86.01 Ha (0.27%) (Figure 1, Nasiakou et al. [26]).
4. Materials and Methods

For predicting land use demands, that will then be utilized by CLUE-S software to simulate the future land use changes, we rely on a recent study of Wang et al. [25]). In this study a model for projecting land use demand is proposed based on operations research optimization models. This study concerns the implementation of these models in the area of Mouzaki, Karditsa.

Usually, when CLUE-S is applied for a real case three scenarios are developing by researchers. The most recently used scenarios for the CLUE-S model were proposed by Wang et al. [25]; apart from the typical linear business as usual (BAU) scenario, they proposed the rapid economic development (RED), and ecological land protection (ELP) scenarios.

A period of twenty years (2020–2040) was chosen as the most appropriate forecast period for the study. This choice is a compromise between the time it takes to see the results of the forecast (the shorter the forecast time, the smaller the change in land use) and the uncertainty that arises if a large time horizon is chosen. Specifically, we came up with a scenario model that uses optimization theory to (a) maximize financial profit, and (b) maximizes the benefit of ecosystem services. For this purpose, a thorough study of the most suitable method of economic evaluation of ecosystem services was carried out for the area of Mouzaki, Karditsa.

4.1. Business as Usual (BAU) Scenario

In the BAU scenario the land use demands for year 2040 were calculated by using linear interpolation of historical data from 1960 to 2020. Specifically, the historical trend of land use changes was used to find the land use demands for the BAU scenario. Table 1 presents the land uses for years 1960 and 2020, as well as their percentage change (Nasiakou et al. [26]).
Table 1. Historical, current and predicted area (Ha) in 2040 for the BAU scenario (Municipality of Mouzaki, Greece).

| Variable | Land Use Type                        | Area in 1960 (Ha) | Area in 2020 (Ha) | Difference (%) | Predicted Area in 2040 (Ha) |
|----------|--------------------------------------|------------------|------------------|---------------|---------------------------|
| x1       | Agricultural land                    | 14,206.52        | 11,144.03        | −21.56        | 10,343.15                |
| x2       | Silvoarable land                     | 200.51           | 556.38           | 177.48        | 650.26                   |
| x3       | Grassland                            | 5009.69          | 2405             | −51.99        | 1988.21                  |
| x4       | Silvopastoral woodland (10–40% tree cover) | 2525.42        | 3815.39          | 51.08         | 4000.68                  |
| x5       | Forest (40–100% tree cover)          | 5175.8           | 10,573.64        | 104.29        | 11,622.04                |
| x6       | Sparse shrubland (10–40% cover)      | 394.88           | 503.74           | 27.57         | 516.94                   |
| x7       | Dense shrubland (40–100% cover)      | 2398.44          | 784.99           | −67.27        | 608.97                   |
| x8       | Urban land                           | 939.72           | 1457.79          | 55.13         | 1534.20                  |
| x9       | Barren land                          | 475.99           | 86.01            | −81.93        | 62.52                    |
| **TOTAL:**|                                      | 31,326.97        | 31,326.97        | −             | 31,326.97                |

4.2. Rapid Economic Development (RED) Scenario

The rapid economic development (RED) scenario is the first of the two optimization models used in this study to calculate the demands. The objective of the RED scenario is to maximize the economic benefits provided by different land use types. An optimization function was constructed for the scenario of maximizing the total economic benefit of land uses (RED), where the areas of each land use (x1−x9) serve as variables. Parameters in the optimization function were the economic benefit that results from each land use. The objective function that maximizes the economic benefits provided by different land use types has as follows.

\[
\text{Maximize } f_1(x, \text{RED}) = 3146.10x_1 + 3914.55x_2 + 306.74x_3 + 278.64x_4 + 340.08x_5 + 511.68x_6 + 188.3x_7 + 45,038.35x_8 + 0x_9,
\]

4.2.1. Parameters Estimation

A thorough analysis was performed to find the parameters, which represent the economic benefit per unit of land (Ha) for each land use.

The economic benefit for agricultural land (x1) was calculated using official state data (HSA [27]). Specifically, the total value of the crop production in Greece amounted to 10,941,730,000 EUR which comes from an area of 3,477,900 Ha. Therefore, the total benefit per unit of Agricultural land is 3146.10 EUR/Ha (first parameter in the RED objective function.

The economic benefit for silvoarable land (parameter of x2) was divided into two terms. The first represents 50% of the economic benefit produced by Agricultural land. To this amount, the economic benefit that results from the forest trees was added. For the latter, an amount of 75,000 EUR was considered in the rotating year (Mantzanas [28]). The rotating time was set equal to 25 years. Then the following formula was used to find the economic benefit:

\[
PMT = \frac{FV \times i}{(1 + i)^n - 1},
\]

where \( FV \) is the economic benefit of the trees in rotating time \( (n) \), \( i \) represents the discount rate and PMT the equivalent annual benefit. The discount rate was set at 2%, which was considered a conservative choice as the interest rate on Greece’s 10-year bond is currently around 1%. Thus, the economic benefit of the specific use of the trees is equal to \( 2341.5 \) EUR/Ha and the total annual benefit for the silvoarable land is equal to \( 2341.5 \) EUR/Ha + 50% × value of Agricultural land \( (1573.05 \) EUR/Ha) = 3914.55 EUR/Ha.

To find the economic benefit of forest \( (x_5) \), grassland \( (x_3) \), silvopastoral woodland \( (x_4) \) and shrubland \( (x_6, x_7) \) the data obtained by the Institute of Mediterranean Forest
Ecosystems of Athens (Albanis et al. [29]) were adapted to the specific conditions of area of Mouzaki, Karditsa.

The total annual value for forest ($x_5$) is estimated at €760.85 EUR $\times 10^6$, which is produced by an area of 2,237,239 Ha (Table 2). Thus, the annual financial benefit from the forest is 340.08 EUR/Ha (Table 3).

Table 2. Value (EUR) of forest per service and forest species.

| Services and Externalities | Fir | Spruce | Pine | Beech | Oak | Total |
|---------------------------|-----|--------|------|-------|-----|-------|
| Total area (Ha)           | 548,070 | 2754 | 878,786 | 336,640 | 470,989 | 2,237,239 |
| Wood production ($\times 10^6$ €) | 29.06 | 0.72 | 27.96 | 15.22 | 12.67 | 85.63 |
| Non-Wood Forest Products ($\times 10^6$ €) | Mushroom 0.82 | 0.42 | 0.50 | 0.71 | 2.45 |
| | Honey 5.61 | 0.028 | 9.00 | 3.45 | 15.07 | 33.16 |
| | Christmas trees 0.62 | | | | 0.62 |
| | Resin | | 9.58 | | 9.58 |
| | Pine seeds | | 0.55 | | 0.55 |
| Total (NTFPs) | 7.05 | 0.03 | 19.55 | 3.95 | 15.78 | 46.36 |
| Livestock grazing ($\times 10^6$ €) | 16.63 | 0.08 | 26.89 | 10.30 | 0.00 | 53.90 |
| Hunting ($\times 10^6$ €) | 0.54 | 0.00 | 0.86 | 0.33 | 0.46 | 2.19 |
| Recreation ($\times 10^6$ €) | 51.68 | 0.26 | 82.87 | 31.75 | 44.41 | 210.97 |
| Soil protection ($\times 10^6$ €) | 57.55 | 0.29 | 92.270 | 35.35 | 103.03 | 288.49 |
| C sequestration ($\times 10^6$ €) | 2.86 | 0.017 | 5.69 | 2.19 | 3.01 | 13.77 |
| Biodiversity ($\times 10^6$ €) | 46.04 | 0.23 | 73.82 | 28.28 | 39.56 | 187.93 |
| Losses (wildfires) ($\times 10^6$ €) | 21.18 | 0.12 | 48.64 | 12.43 | 46.03 | 128.40 |
| Total annual value ($\times 10^6$ €) | 190.23 | 1.52 | 281.27 | 114.94 | 172.89 | 760.85 |

Table 3. Value (EUR/Ha) of ecosystem services per land use category in the area of the Municipality of Mouzaki, adapted from Albanis et al. [29].

| Variable | Land Use Type | Annual Financial Benefit (€/Ha) |
|----------|---------------|--------------------------------|
| $x_1$    | Agricultural land | 3146.10                        |
| $x_2$    | Silvoarable land  | 3914.55                        |
| $x_3$    | Grassland       | 306.74                         |
| $x_4$    | Silvopastoral woodland (10–40% tree cover) | 278.64 |
| $x_5$    | Forest (40–100% tree cover) | 340.08 |
| $x_6$    | Sparse shrubland (10–40% cover) | 511.68 |
| $x_7$    | Dense shrubland (40–100% cover) | 188.3 |
| $x_8$    | Urban land | 45,038.35 |
| $x_9$    | Barren land | 0.0 |

The total economic benefit from the grassland ($x_3$) is 306.74 EUR $\times 10^6$, produced by an area of 1000 $\times 10^3$ Ha (Table 4). Thus, the total annual benefit from the grassland is 306.74 EUR/Ha (Table 3).
Table 4. Value (EUR) of grassland, silvopastoral woodland and sparse and dense shrubland per service and product.

| Services and Externalities | Grassland | Silvopastoral Woodland | Sparse Shrubland | Dense Shrubland |
|----------------------------|-----------|------------------------|------------------|-----------------|
| Total area (Ha)            | 1,000,000 | 1,000,850              | 1,309,992        | 1,964,987       |
| Wood production ($\times 10^6$ £) | 12.67     | 1.508                  | 2.262            | 2.262           |
| Mushrooms ($\times 10^6$ £) | 1.50      | 0.35                   | 0.015            | 0.015           |
| Honey ($\times 10^6$ £)     | 10.24     | 10.25                  | 0.004            | 0.004           |
| Heath (Erica) roots ($\times 10^6$) | 0.002   | 0.015                  | 0.004            | 0.004           |
| Livestock grazing ($\times 10^6$ £) | 125.00   | 45.04                  | 211.128          | 52.782          |
| Soil protection ($\times 10^6$ £) | 67.98     | 51.51                  | 275.100          | 49.840          |
| C sequestration ($\times 10^6$ £) | 0.98      | 0.98                   | 2.240            | 0.960           |
| Biodiversity ($\times 10^6$ £) | 48.00     | 84.07                  | 220.080          | 55.020          |
| Losses (wildfires) ($\times 10^6$ £) | 37.68     | 23.02                  | 54.112           | 81.170          |
| Total annual value ($\times 10^6$ £) | 306.74   | 278.88                 | 670.301          | 369.955         |

The total annual value of the silvopastoral (mostly oak) woodland ($x_4$) for Greece was estimated at 278.88 EUR $\times 10^6$. The total area that produces grazing values is equal to 1,000,850 Ha (Table 4). Thus, the total annual benefit for silvopastoral woodland is estimated to 278.64 EUR/Ha (Table 3).

The annual economic benefit for sparse shrubland ($x_5$) is € 670.301 $\times 10^6$ and the total area is 1,309,991.6 Ha (Table 4). Thus, the total annual economic benefit from sparse shrubland is 511.68 EUR/Ha (Table 3).

The annual economic benefit for dense shrubland is 369,955 EUR $\times 10^6$ and the total area is 1,964,987.4 Ha (Table 4). Thus, the total annual economic benefit for dense shrubland is 188.3 EUR/Ha (Table 3).

To find the economic benefit resulting from the urban land ($x_6$) the total production of the secondary and tertiary sector of Greece was used, proposed by Wang et al. [25], and adapted for the area of Mouzaki, Karditsa. Accordingly, the total turnover of the secondary and tertiary sector in Greece was 54,119,766,393.00 EUR (HSA [27]). The total population of the country according to the 2011 census was 10,816,286 inhabitants. Thus, the turnover per capita amounted to 5003.54 EUR. The turnover for the urban area of Municipality of Mouzaki (13,122 inhabitants), which expresses the economic benefit of the urban land, of the secondary and tertiary sector is 5003.54 EUR $\times 13,122 = 65,656,451.88$ EUR, and the turnover is equal to 65,656,451.88 EUR/1457.79 Ha = 45,038.35 EUR/Ha.

Finally, the annual financial benefit (EUR) is presented in Table 2.

4.2.2. Constraints on the Optimization Model

The following constraints (C) are used in the optimization model:

C1: The constraint considers the total research area, as shown by the sum of the areas of individual land uses for year 2020, i.e.,

$$C1: x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 = 31,326.97 \text{ Ha}$$

C2: At least 1% of the total area should be allocated to land uses such as pastures ($x_3, x_6, x_7$) and barren land ($x_9$), as these land types are most likely to be occupied by future urban sprawl, such as proposed by Wang et al. [25]. In this case,

$$C2: x_3 + x_6 + x_7 + x_9 \geq 1\% \times 31,326.97 \text{ Ha}$$
C3: It refers to forest cover that must be maintained for environmental purposes. The coefficients of the following equation were derived from Wang et al. [25] and retained in the model:

\[ C_3 : 0.73x_2 + 0.49x_3 + 0.75x_4 + x_5 + 0.49x_6 + 0.49x_7 \geq 50\% \times 31,326.97 \text{ Ha} \]

C4–C12: Finally, upper and lower bounds for each land use in the model area were introduced as follows: If BAU projections show that the trend for a land use is decreasing then its current area becomes upper bound and its forecast for 2040 according to the BAU scenario lower bound. If, on the other hand, the tendency for a land use is increasing then its current area becomes lower bound. A proportional increase for the year 2040 was received as the upper bound, e.g., if for the years 1960–2020 it was observed an increase for a land use by \( \alpha \) %, then the value of the area assuming an increase of \( (\alpha/3) \) % on its current area was received as upper bound. Like for BAU scenario, the ratio 60/20 = 3 calculated as the ratio between the number of past years (1960–2020, i.e., 60 years) and the number of years projected into the future (2020–2040, i.e., 20 years). For the barren land \((x_9)\) the lower bound was set equal to zero, similarly to Wang et al. [25]. As shown in Table 1, the trend is decreasing for Agricultural land \((x_1)\), grassland \((x_3)\), dense shrubland \((x_7)\) and barren land \((x_9)\). On the contrary the trend is increasing for silvoarable land \((x_2)\), silvopastoral woodland \((x_4)\), forest \((x_5)\), sparse shrubland \((x_6)\) and urban land \((x_8)\).

Accordingly, the formulated constraints were:

\[
\begin{align*}
C_4: & \quad 10,343.15 \leq x_1 \leq 11,144.03 \\
C_5: & \quad 556.38 \leq x_2 \leq 885.53 \\
C_6: & \quad 1988.21 \leq x_3 \leq 2405.00 \\
C_7: & \quad 3815.39 \leq x_4 \leq 4465.02 \\
C_8: & \quad 10,573.64 \leq x_5 \leq 14,249.39 \\
C_9: & \quad 503.74 \leq x_6 \leq 550.03 \\
C_{10}: & \quad 608.97 \leq x_7 \leq 784.99 \\
C_{11}: & \quad 1457.79 \leq x_8 \leq 1725.68 \\
C_{12}: & \quad 0 \leq x_9 \leq 86.01
\end{align*}
\]

4.3. Ecological Land Protection (ELP) Scenario

The third scenario of ecological land protection (ELP) concerns finding the distribution–forecast for each land use using the total value of ecosystem services as an objective function. The coefficients of the objective function, i.e., the ecosystem value produced by each land use, were consistent with Costanza et al. [30], but adapted to the Greek condition in year 2020 (Table 5). The values taken from the study of Costanza et al. [30] were translated into Euros, divided by the ratio of the USA’s GDP to Greece’s GDP and compounded till year 2020 with the rate of inflation of Greece from 1997 to 2020. The ecological value for the silvoarable land is not mentioned in the paper of Costanza et al. [30]. As an approximation, to estimate its value we added to the ecological value of agricultural land the 50% of the ecological value of forest.

The objective function is:

\[
\text{Maximize } f_2(x) = 67.75x_1 + 178.94x_2 + 170.84x_3 + 196.61x_4 + 222.38x_5 + 170.84x_6 + 170.84x_7
\]

The rest constraints in this scenario are the same as for the RED scenario.
Table 5. Value (EUR/Ha) of ecosystem services by land use category in the area of the Municipality of Mouzaki, adapted from Constanza et al. [30].

| Variable | Land Use Type | Annual Financial Benefit (€/Ha) |
|----------|---------------|---------------------------------|
| x1       | Agricultural land | 67.75                          |
| x2       | Silvoarable land  | 178.94                         |
| x3       | Grassland       | 170.84                         |
| x4       | Silvopastoral woodland (10–40% tree cover) | 196.61                          |
| x5       | Forest (40–100% tree cover)    | 222.38                         |
| x6       | Sparse shrubland (10–40% cover) | 170.84                          |
| x7       | Dense shrubland (40–100% cover) | 170.84                          |
| x8       | Urban land       | 0.0                            |
| x9       | Barren land      | 0.0                            |

4.4. Multiobjective Optimization

Multiobjective optimization consists of finding good solutions from a set of alternatives with respect to multiple objective functions. Usually, these objective functions are in conflict, i.e., when one objective function is improved the other is deteriorated. In the particular study at hand, we have two optimization models and two objective functions. The one derived from the RED scenario (objective function 1, $f_1(x)$) and the other derived from the ELP scenario (objective function 2, $f_2(x)$). For most multiobjective optimization problems, no single solution (in this study, allocation of the entire area into different land uses) exists that simultaneously optimizes each objective function. As it will be evident in the Results section, the land use allocation that gives the maximum economic benefit has the minimum ecological benefit and vice versa). Thus, the notion of optimality changes with respect to single objective (with only one objective function optimized) optimization. Usually, in multiobjective optimization we are interested in the so-called Pareto optimal or nondominated solutions. A solution is called nondominated or Pareto optimal, if none of the objective functions can be improved in value without deteriorating some of the other objective values. Nondominated or Pareto optimal solutions expresses the different trade-offs among the objective functions.

In the particular problem at hand the Pareto optimal solutions reflect the trade-offs between economic and ecological benefits. A solution (an allocation of the entire area into different land uses) that optimizes economic benefits has the worst ecological value and vice versa (i.e., a solution with optimal ecological benefits has the worst economic value). Between the two extremes there are compromised solutions.

Thus, in this study we face the following multiobjective optimization problem:

Maximize $[f_1(x), f_2(x)]$ subject to the same set of constraints C1:C12. Our goal now is to simultaneously optimize the two objective functions. However, a single solution that simultaneously maximizes objective 1 ($f_1(x)$) and objective 2 ($f_2(x)$) does not exist. In contrast there are “optimal” solutions that trade-off between the two objectives.

For computing the nondominated, Pareto optimal solutions that trade-off between the two objectives, the $\varepsilon$-constraint method is applied. In the $\varepsilon$-constraint method, one objective is optimized and the other is fixed as a constraint in the set of constraints. It does not matter which objective to optimize and which to use as a constraint in the constraint set. Thus, in the particular problem at hand, objective 1 is optimized and objective 2 is used as a constraint as follows. Maximize $f_1(x)$ subject to $f_2(x) = \varepsilon_i, i = 1, \ldots, p$ C1:C12, where $p$ is the number of Pareto optimal solutions desired to compute and C1:C12 is the set of constraints defined in Section 4. By parametrical variation of the constraint values $\varepsilon_i$, an appropriate number of Pareto-optimal solutions are obtained. Thus, in order to properly apply the $\varepsilon$-constraint method, the range of the second objective used as constraint must be computed. One point, that is also Pareto optimal, is the optimal value of objective 2 under constraints C1:C12. This is the biggest point in the range of values. The smallest point is the optimal solution obtained by optimizing the first objective function, evaluated however using the second objective function. In this way, we have the worst value (nadir value) of
the second objective function. Setting appropriate right-hand values $e_i$ between the nadir value and the maximum value for the second objective function in the constraints set, a number of Pareto optimal solutions are obtained. One Pareto optimal solution for each $e_i$ value. For the purposes of this study, nine equidistant values were fixed in the range of possible values of the second objective function.

5. Results

In this section, the experimental results of the optimization models (rapid economic development (RED), ecological land protection (ELP) and the business as usual (BAU)) are presented and analyzed, as well as a trade-off analysis between the two optimized scenarios RED and ELP.

5.1. Results for the Three Scenarios BAU, RED, ELP

In order to find the land use demands for year 2040 (20 years prediction trend), the expected percentage change of each land use was chosen by calculating the 1/3 of the total change trend between the years 1960 and 2020 (60 year trend).

The ratio 1/3 is used because we have a 20 years prediction period and 60 year of historical results; thus, it is expected, under the BAU scenario, that the 20 year period will give a third of the historical trend (60 years/20 years = 1/3).

Finally, an adjustment has been made by applying a proportional reduction of the total predicted area for all land use types that were expected to increase, during the specific period. This reduction was necessary in order for the total sum of the predicted land use areas to equal the total area in the region. The estimated area for each land use for year 2040 under the BAU scenario is presented in Tables 1 and 6.

### Table 6. Estimated area in 2040 (Ha) under the three scenarios (BAU, RED, ELP).

| Variable | Land Use Type                                      | Estimated Area in 2040 (Ha) |
|----------|---------------------------------------------------|-----------------------------|
| x_1      | Agricultural land                                 | 10,343.15                   |
| x_2      | Silvoarable land                                  | 650.26                      |
| x_3      | Grassland                                         | 1988.21                     |
| x_4      | Silvopastoral woodland (10–40% tree cover)       | 0.68                        |
| x_5      | Forest (40–100% tree cover)                       | 11,622.04                   |
| x_6      | Sparse shrubland (10–40% cover)                   | 516.94                      |
| x_7      | Dense shrubland (40–100% cover)                   | 608.97                      |
| x_8      | Urban land                                        | 1534.2                      |
| x_9      | Barren land                                       | 62.52                       |
| **TOTAL**|                                                   | 31,326.97                   |

As it is seen from Tables 1 and 6, the biggest increase, under the BAU scenario is predicted for silvoarable land (16.87%), while the biggest decrease is projected for the barren land (27.31%). However, the largest share (37.10% of the total land area of the area Mouzaki, Karditsa) is accounted for the forest land type followed by agricultural land (33.02%). Forest land is expected to increase by 9.92% under the BAU scenario. However, while agricultural land is in the second place considering the share of the total area is expected to decrease by 7.19% under the BAU scenario. From the same tables it is observed that silvoarable land is expected to have the biggest percentage increase (16.87%) under this scenario, while barren land the biggest percentage decrease (27.31%).

The results of the three scenarios (BAU, RED, ELP) are presented in Table 6. For the RED scenario, the biggest increase is predicted for silvoarable land (59.16%), while the biggest decrease is projected for the Barren land (100%). The biggest share (35.57%) of the total land area of the area Mouzaki, Karditsa) is accounted for the agricultural land followed by forest (33.89%). Under the RED scenario, agricultural land is expected to
remain the same while forest land is expected to increase by 0.41%. Finally, under the RED scenario, urban land is expected to increase by 18.38% (second biggest percentage increase after silvoarable land).

For the ELP scenario the biggest increase is predicted for forest land (13.99%), while the biggest decrease is projected for the barren land (100%). The lion’s share (38.48%) of the total land area of the area Mouzaki, Karditsa, is accounted for the forest land followed by Agricultural land (33.02%). Silvoarable land is expected to remain the same under this scenario.

As shown in Table 6, under the RED scenario, the silvoarable land attains its upper bound as in the BAU scenario. Since in this study we approach land use modelling in agroforestry perspective, the question arises as to what grade this result can be improved? For this reason, we relax constraint C5 and eliminate the upper bound for the silvoarable land. The results are shown in Table 7.

| Variable | Land Use Type                                      | Estimated Area in 2040 (Ha) |
|----------|---------------------------------------------------|-----------------------------|
| $x_1$    | Agricultural land                                 | 10,343.15                   |
| $x_2$    | Silvoarable land                                  | 1768.22                     |
| $x_3$    | Grassland                                         | 1988.21                     |
| $x_4$    | Silvopastoral woodland (10–40% tree cover)       | 3815.39                     |
| $x_5$    | Forest (40–100% tree cover)                       | 10,573.64                   |
| $x_6$    | Sparse shrubland (10–40% cover)                  | 503.74                      |
| $x_7$    | Dense shrubland (40–100% cover)                  | 608.97                      |
| $x_8$    | Urban land                                        | 1725.68                     |
| $x_9$    | Barren land                                       | 0                           |
| **TOTAL**|                                                   | 31,326.97                   |

It is shown that silvoarable land increases 99.7% at the expense, mainly, of agricultural land which approaches its lower bound. The improvement in objective function (economic value) is 901,200 EUR. Moreover, if we let the lower bound for the agricultural land to decrease further till zero, the remaining land is totally allocated to silvoarable land i.e., the silvoarable land obtains the value 12,333.37 Ha, while agricultural land that of zero. This is very important since silvoarable land is competing agricultural land. This way the improvement in economic value is 7,948,193.62 EUR.

Under the ELP scenario, silvoarable land obtains its lower bound, so a relaxation of its upper bound is not expected to increase the area allocated to this land.

### 5.2. Trade-Offs between Economic and Ecological Benefits

The Pareto diagram reflects the trade-offs between economic and ecological benefits (Figure 2). The Pareto optimal solutions are generated by solving nine optimization problems (in addition to the two problems RED and ELP described above), where the total economic benefit is maximized subject to a constraint on the second objective function value (which was fixed at nine equidistant values) from the maximum value achieved by solving the ELP model and the value of the $f_2(x)$ where $x$ is obtained by the solution of the RED scenario. Furthermore, the same constraints used in the RED and ELP scenarios were utilized here without upper bound for the silvoarable land. It is observed that point 6 offers a good alternative to points 1 and 11 which are the results of the RED and ELP scenarios, respectively (Table 8). It is observed that point 6 has an increase of 10.59% or 11,277,600.00 EUR in relation to the value that can be achieved of the expected profit when we only maximize the ecological benefit (point 11), but with a minor decrease of only 1.18%
or 56,107.50 EUR in the environmental profit in relation to the environmental value $f_2(x)$ of point 11. From point 6 onwards the expected economic benefit further increases without a significant decrease in the ecological benefit. That is, from point 6 to point 1 the economic benefit increases further by 4.27% or 5,028,200.00 EUR with a decrease of the ecological benefit of only 1.12% or 56,107.50 EUR.

![Figure 2](image)

**Figure 2.** The Pareto front as formed for objectives 1 and 2 (functions $f_1(x)$ and $f_2(x)$, respectively).

These points are important for policy makers as they present the trade-off between economic values $f_1(x)$ (Objective 1) and ecological benefit $f_2(x)$ (Objective 2). Knowing these values, policy makers are better informed as they can find a compromise solution between the two criteria and not just apply either the maximization of one criterion (point 1) or the maximization of the ecological one (point 11). They may, for example, choose point 6 which has an increase of 10.54% or 11,277,600.00 EUR in relation to the value that can be achieved of the expected profit when we only maximize the ecological benefit (point 11), but with a decrease of only 1.18% or 56,107.50 EUR in the environmental profit in relation to the environmental value $f_2(x)$ of point 11. The policy maker can observe the optimal areas for different points and choose his/her optimal policy in favor of one or the other area.
Table 8. Results of the Pareto front, optimal areas for economic and ecological benefits (F1 and F2, respectively).

|     | Point 1  | Point 2  | Point 3  | Point 4  | Point 5  | Point 6  | Point 7  | Point 8  | Point 9  | Point 10 | Point 11 |
|-----|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| X1  | 10,343.15| 10,343.15| 10,343.15| 10,343.15| 10,343.15| 10,343.15| 10,343.15| 10,343.15| 10,343.15| 10,343.15| 10,343.15|
| X2  | 1768.19  | 1509.88  | 1251.56  | 993.23   | 734.91   | 556.38   | 556.38   | 556.38   | 556.38   | 556.38   | 556.38   |
| X3  | 1988.21  | 1988.21  | 1988.21  | 1988.21  | 1988.21  | 1988.21  | 1988.21  | 1988.21  | 1988.21  | 1988.21  | 1988.21  |
| X4  | 3815.39  | 3815.39  | 3815.39  | 3815.39  | 3815.39  | 3815.39  | 3815.39  | 3815.39  | 3815.39  | 3815.39  | 3815.39  |
| X5  | 10,573.64| 10,831.95| 11,090.27| 11,348.60| 11,606.92| 11,801.04| 11,901.96| 11,952.42| 12,002.88| 12,053.34|         |
| X6  | 503.74   | 503.74   | 503.74   | 503.74   | 503.74   | 503.74   | 503.74   | 503.74   | 503.74   | 503.74   | 503.74   |
| X7  | 608.97   | 608.97   | 608.97   | 608.97   | 608.97   | 608.97   | 608.97   | 608.97   | 608.97   | 608.97   | 608.97   |
| X8  | 1725.68  | 1725.68  | 1725.68  | 1725.68  | 1710.09  | 1659.63  | 1609.17  | 1558.71  | 1508.25  | 1457.79  |         |
| X9  | 0.00     | 0.00     | 0.00     | 0.00     | 0.00     | 0.00     | 0.00     | 0.00     | 0.00     | 0.00     | 0.00     |
| F1  | 122,825,300.00 | 121,902,000.00 | 120,978,600.00 | 120,055,300.00 | 119,131,900.00 | 117,797,100.00 | 115,541,500.00 | 113,286,000.00 | 111,030,500.00 | 108,775,000.00 | 106,519,500.00 |
| F2  | 4,648,419.00 | 4,659,640.50 | 4,670,862.00 | 4,682,083.50 | 4,693,305.00 | 4,704,526.50 | 4,715,748.00 | 4,726,969.50 | 4,738,191.00 | 4,749,412.50 | 4,760,634.00 |
6. Conclusions

In the present research, three scenarios/models for finding the land use requirements for Mouzaki area were developed: i business as usual (BAU), ii. rapid economic development (RED), and iii. ecological land protection (ELP).

This research’s purpose was to find the Demands for use of the CLUE-S model. For this reason, we used, beyond the classical BAU scenario, two operations research optimization models for predicting the required demands. In the BAU scenario the requirements are calculated by applying linear interpolation of historical data from 1960 to 2020. Specifically, the historical trend of land use change was used to find the land use requirements for the BAU scenario. For the RED scenario an objective maximization function was constructed, where the variables are the extent of each land use. Parameters in this function were the economic benefit for each land use. Finally, in the ELP scenario, which is also a maximization problem, the distribution–forecast for each land use has been taken into account using the total value of ecosystem services as an objective function. The coefficients of the objective function, i.e., the ecosystem value generated by each land use, were in line with the widely accepted work of Costanza et al. [30], adapted to the Greece for year 2020. The two optimization models was applied in the Area of Mouzaki, Karditsa. Several aspects of the models needed to be defined. For example, the input parameters used by the model. These parameters include the financial benefit and ecological benefit (in money terms) for the two distinct models (RED, ELP). A thorough analysis was performed to find the parameters, which represent the economic and ecological benefit per unit of land (Ha) for each land use.

Furthermore, a trade-off analysis was performed between economic and ecological benefits. As shown a solution obtained by the optimization models are in conflict. The solution that attains the maximum financial benefit has the worst ecological benefit and vice versa. Between these two extremes.

Furthermore, a multi-criteria analysis was performed to find intermediate values of the two scenarios RED and ELP. As shown, a solution obtained by the optimization models are in conflict. The solution that attains the maximum financial benefit has the worst ecological benefit and vice versa. It was observed that there are trade-offs for these two extreme scenarios. Optimizing function $f_1(x)$ produces the smallest value for the other function, and vice versa. The Pareto front gives significant advantages to policymakers. It appears that point 8 has a decrease of 2.66% in the expected profit, but an increase of 3.26% in the ecological profit compared to the RED scenario. On the other hand, point 6 has an increase of 10.59% or 11,277,600.00 EUR in relation to the value that can be achieved of the expected profit when we only maximize the ecological benefit (point 11), but with a minor decrease of only 1.18% or 56,107.50 EUR in the environmental profit in relation to the environmental value $f_2(x)$ of point 11. Policy makers need to know all the values of the Pareto front and not just the extremes (point 1 (RED scenario) and point 11 (ELP scenario)). The calculated demands will be used in future research by the CLUE-S model for their spatial distribution and validation.

The present study, as a part of the project entitled “Perspective of Agroforestry in Thessaly region: A research on social, environmental and economic aspects to enhance farmer participation”, provides useful input in terms of successful design of applying Agroforestry in the area. Results from the present study will be used to enrich the development of a Good Practice Guide resulting from the project, which will provide valuable instructions for proper implementation of Agroforestry in Thessaly region. Furthermore, methodology applied in this study could be fruitfully used in different areas of Greece. Results could be useful for policy makers, especially the trade-off analysis between economic and ecological benefits. Notably, Greece has still not adopted the Agroforestry Measure 8.2 provided by the updated EU’s Common Agriculture Policy, and this model-study may be proved as valuable to this adoption. The policy makers have the potential to enhance the utilization of one or another land use in order to achieve a balance between economic and ecological benefits, thus to assess potential effects of land management choices, and guide the design...
of more informed decisions. The trade-off analysis could rise their awareness about the potential trade-offs that arise from their decisions. The proposed models could be extended to other areas of Greece, by specifying the parameters of the optimization models. Especially for Greece, the models can directly be applied to other areas by only adjusting the parameters of the optimization models for urban land. The results of this study can be used as input to the CLUE-S model in order to predict the future change on different land uses in the area of Mouzaki. For future research, we plan to apply the models in other areas of Greece and compare the results.

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