# EFFICIENCY ANALYSIS OF POLICIES AGAINST DESERTIFICATION BY APPLYING DEA: A CASE STUDY IN THE RIVER GUADALENTIN CATCHMENT (ALMERIA, SPAIN)

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## ABSTRACT

*This paper deals about an attempt to evaluate the different policies against desertification carried out during a twenty five year period (1978-2003) in the eight municipalities which compound the river Guadalentín catchment (Murcia, Spain). The approach is based on DEA and the European Environmental Agency indicator studies, the former to measure the efficiency and the second to select the best environmental indicators. The analysis has been reiterated with three different sets of outputs related to the different levels and aspects of the desertification process- from the merely soil losses to the overall desertification process in which population losses are considered. As a result a set of efficiency indexes has been obtained for each municipality, which show clearly the contribution of each action against desertification. These results are very valuable to establish future long term desertification policies in similar territories.*

## THE APPROACH TO ANALYSING THE POLICIES

Numerous environmental measures have been taken by the different authorities to alleviate the problem of desertification in south-eastern Spain [1,2]. In the past national strategy was aimed at repopulating large areas, but in recent years policies have shifted towards changing crop types, generally financed by European Union schemes [3,4]. Doubts arise when the question is raised of whether this is the best policies and which activity is the most efficient way of achieving the objectives [5].

Desertification is a slow and complex process; a variety of actions have been taken and their effects have been diluted over time. It must also be admitted that this is a multidimensional or multi-attribute process: there is a physical component, a biological component and a social component, and therefore studying it involves seeking indicators to reflect the process as a whole [6].

It must be remembered that the slowness of the process means that the results can only be assessed after decades. Moreover, the complexity of the process means that measures which are theoretically unconnected with it have a substantial influence on the degree of desertification. However, it is internationally accepted [7,8] that the factors contributing to desertification include erosion, deforestation, loss of landscape diversity and human depopulation. Monitoring the system and the factors involved requires a system of indicators which reflect its development [9,10].

This study takes policy against desertification to mean the management and implementation of plans and projects in a region with the aim of mitigating desertification. Such management would include economic and fiscal tools such as subsidies for giving up farming activities, subsidies for improving agro-forestry infrastructure, soil conservation practices, environmental assistance, training aid and so on [11].

With regard to the information used, it was impossible to gain access to some data due to statistical confidentiality clause protecting the personal details of each landowner. Moreover, it is hard to date the information which exists concerning the reforestation measures carried out, because several years can pass between an application for a subsidy and the actual measure, which makes estimates of running-down and capitalization rather imprecise.

For the above reasons, it was decided that the policies would be analyzed in terms of physical variables such as the area reforested, the area subject to water planning and soil conservation practices, the reduction in the dryland farming area, the increase in irrigated farmland or the land declared a protected natural area. Thus, "policies" are characterised here through a set of indicators associated with the municipality, which is the chosen working unit of territory [12].

It seems reasonable to believe that all the measures have a positive effect on desertification, but it is also reasonable to argue that not all of them contribute to the goal in the same way. The question posed here is which policy implemented in the area has proved the best way of countering desertification.
The approach to the problem is firmly based on a variety of criteria, as both the indicators of responses (reforestation, water planning, abandonment of crop growing, construction of dykes and so on) and the indicators of the situation (soil losses, reduction in cover, deterioration of vegetation) involve multiple components. For this study data were handled using a vector-based geographical information system (GIS), but many measures could only be assigned at municipal level. Consequently, for each municipality there is a multi-criterion vector of indicators of the current situation (y) and of indicators of taken actions (x), and there must be an assessment of which of these vectors achieves the best combination of measures to optimise the indicators of the desertification situation.

## LOCATION AND GEOGRAPHY

The study took in the agricultural area around the river Guadalentín, one of six which make up the region of Murcia, covering an area of 3,096.4km$^2$ which is divided into eight municipalities: Aguilas, Aledo, Alhama de Murcia, Librilla, Lorca, Mazarrón, Puerto Lumbreras and Totana. Except for the Guadalentín, there are no permanent watercourses, though there are two reservoirs: Valdeinfierno and Puentes. The aquifers in the region are extensive, holding large reserves. However, generalised over-exploitation and the resulting deterioration, basically in the form of increased salinity, has led to a critical situation in many areas such as the Guadalentín valley or Águilas-Mazarrón.[12,13]

The soils are little evolved, with few horizons, and are difficult to differentiate. Their depth and physical and chemical features are determined by the type of geological strata; deeper soils lie over soft substrates and in flat areas, while shallower ones lie over hard, rocky substrates and on slopes.
The vegetation in the region consists of non-deteriorated scrub, retreating scrub, pinewoods with juniper. In highland and foothill areas hills with holm oaks and Mediterranean scrub may be found. Lorca and Puerto Lumbreras have extensive areas with dryland farming, scrub and fields of esparto grass, with some pinewoods in the hills. There is irrigated farmland on the Guadalentín plain. To the east (Mazarrón), aquatic ecosystems predominate, with wetlands, salt lagoons, salt marshes and salt flats. In the hills of the Sierra de Carrascoy, the wet Mediterranean holm oak woods of Murcia make their appearance. Around Totana cabbage palm is plentiful. In the Sierra Espuña stands of gall oak, tetraclinis, maple and strawberry tree can be seen [12,13,15].

## SOURCES OF DATA AND INDICATORS

A system of indicators must be based on variables which are easy to measure and interpret. The sources of information used to produce the indicators were the following:

**Vegetation**: Digitized maps were obtained from the maps of crops and exploitation of 1978 and 2003[14,15]. Vegetation was also an essential component in mapping laminar erosion, salinity and structural diversity.

**Erosion**: Use was made of the information contained in the map of erosive states and in the national soil erosion inventory and the data were extrapolated to make up two consistent laminar erosion maps consistent with the MUSLE: one for the year 1978 and the other for 2003 [16,17].

**Diversity:** The Shannon-Wiener index was taken as an indicator of structural diversity of plant life in the region because it is one of the simplest and most widely-used [18]. Taking structural diversity as a sustainability indicator was quickly accepted by the scientific and technical community, and these indices are currently being used for the Spanish National

Statistics Institute (INE) for each municipality in the 3rd national forestry inventory [19].

**Population:** The information collected by the years 1978 and 2003 was obtained [20].

**Reforestation:** The information about corrective forest and water management measures was obtained from the staff of the regional and central governments and the documentation concerning their proposals [21]. The reforested areas and those covered by corrective forest and water management projects were inspected, and the number of projects carried out was reviewed.
When the study was planned it was expected that access to information about the measures taken and the economic resources and funds used (Euros invested in reforestation by hectares, Euros invested in corrective forest and water management, European Union aid to give up agricultural activities, European Union aid to improve agricultural infrastructure, agro-forestry aid in protected areas) would be easy to obtain. However, in most cases these administrative data could not be obtained; on other occasions, when they were obtained, it was impossible to determine which years they were received in and therefore the costs, investments and subsidies could not be deducted or capitalised. Thus, the only indicators were physical ones rather than economic ones.

The indicators used to measure the state of desertification were the following:

$y_1$: Erosion: Decrease in laminar erosion (ΔTn/Ha)
$y_2$: Landscape diversity: Increase in Shannon index (ΔIndex/Ha)
$y_3$: Populations: Increase in human density (Δperson x 100/Ha)

The indicators of measures taken were the following:

$x_1$: Repopulated forested area (% of forested area)
$x_2$: Land area under corrective soil practices and water management projects not reforested (% of area managed)
$x_3$: Abandonment of dryland farming (% of dryland crops)
$x_4$: Establishment of irrigated farming (% of irrigated crops)
$x_5$: Land area protected as natural areas (% of area protected).

## DESCRIPTION OF TAKEN MEASURES TO PREVENT DESERTIFICATION: PERIOD 1978-2003

The measures which have been taken in the different municipal areas are described and summarized below:

**Aguilas (DMU-1):** Considerable planning but little execution of forestry work and the abandonment of farmland has ceased; in addition irrigated land has been extended. Erosion level has slowed down a lot and diversity and population have arisen.

**Aledo (DMU-2):** Considerable reforesting but little soil practice conservation and the abandonment of farmland has ceased; erosion has slowed down, diversity has improved and the population has increased.

**Alhama (DMU-3)**: Little reforesting activity, average soil practice conservation, abandonment of dryland cultivation and increase in protected areas.

**Librilla (DMU-4)**: No reforesting, but no abandonment of crops or irrigation, or establishment of natural areas; erosion slowed down a little, diversity decreased.

**Lorca (DMU-5):** Average reforestation, a lot of abandonment of dryland crops and little irrigation; diversity and the population all increased.

**Mazarron (DMU-6):** Little reforestation, a lot of abandonment of dryland farming and changeover to irrigation, without an increase in natural areas; erosion improved and diversity and population increased as well.

**Puerto Lumbreras (DMU-7):** No reforestation, a lot of abandonment of dryland farming and changeover to irrigation, without any increase in natural areas; small improvement in erosion but the diversity level increased.

**Totana (DMU-8):** Considerable reforesting but little abandonment of dryland farming and changeover to irrigation, little increase in natural areas; erosion worsened but diversity increased and population rose slightly.

## DEA APPLIED TO THE ASSESSMENT OF MEASURES TO PREVENT DESERTIFICATION.

DEA (Data Envelopment Analysis) is an application of multicriterion linear programming [22,23] which seeks to optimise the ratio between results and resources. First applications of DEA were focused to identify efficient points in cases where the objective function consists of goals of a "more the better" nature in combination with resources of a "less the better" nature, however step by step the methods was extending its applications from cost-benefit assessment [24] to efficiency assessment in not-for-profit organizations [25,26,27]. Nowadays DEA is a technical paradigm applied in many sectors and aims [28]. In our case the aim was to obtain a preference ranking of the desertification policies carried out in different municipalities, therefore we based on preference ranking approach started by Sexton, Green, Doyle and Cook [29,30,31,32].

Our aim was to maximize the variation over time in the desertification indicators ($y_1$, $y_2$, $y_3$) brought about by implementing the policies or measures ($x_1$, $x_2$, $x_3$, $x_4$, $x_5$). All the indicators were obtained by measuring the difference in them between the years 2003 and 1978. Some indexes obtained were shifted in order to be positive values [33,34].

The basic mathematical formulation of DEA can be expressed as:

$$\max \quad \theta_i = \frac{\sum_{j=1}^{m} u_{ji} \cdot y_{ji}}{\sum_{k=1}^{r} v_{ki} \cdot x_{ki}} \qquad \forall\, i = 1,2,\dots,n$$

$$\textit{subject to} \quad \frac{\sum_{j=1}^{m} u_{ji} \cdot y_{ji}}{\sum_{k=1}^{r} v_{ki} \cdot x_{ki}} \le 1$$

$$\textit{and} \quad u_{ji}, v_{ki} \ge 0 \quad (j = 1,2,\dots,m; k = 1,2,\dots,r)$$

Where $m$ is the number of goal indicators, $r$ is the number of input resources and $n$ the number of DMU. The weights or contributions of the different indicators of goals achieved are denoted by $u_{ji}$ and the weight of the inputs or resources are denoted by $v_{ki}$, both can be considered as "virtual prices" of goals and inputs, respectively.

The solution from the system provides the maximum efficiency value, the optimal values for the weighting of goals and resources, the cost reductions, the dummy variables, which will give the distance between a given policy and the optimum, and the dual prices. The main results are $\theta_i$ calculated for each DMU that summarize the degree of efficiency in each municipal area. The closer to 1 it is, the greater the efficiency. Municipal areas with an efficiency of 1 will be the ideal.

In addition, the product of the weighting of resources by the level of use also reveals which input resources are the ones that affect efficiency and which ones make no difference.

However the system has not a unique way of optimization, two approaches can be applied whether maximize goals or minimize inputs, we applied the second one that is called input oriented CCR [35]. The formulation applied in each DMU was:

$$\max \quad \sum_{j=1}^{m} u_{ji} \cdot y_{ji} = \theta_i \qquad \forall\, i = 1,2,\dots,n$$

$$\textit{subject to} \quad \sum_{k=1}^{r} v_{ki} \cdot x_{ki} = 1$$

$$-\sum_{k=1}^{r} v_{ki} \cdot x_{ki} + \sum_{j=1}^{m} u_{ji} \cdot y_{ji} \le 0$$

$$u_{ji}, v_{ki} \ge 0 \quad (j = 1,2,\dots,m; k = 1,2,\dots,r)$$

In DEA each decision-maker is left to choose what vector of weight they prefer, so many municipalities rate themselves at the maximum level of efficiency, nevertheless some ones can be qualified as inefficient due to $\theta_i < 1$. For these inefficient DMUs DEA provides the slacks variables for analyzing the inefficient causes and the range for improving. Other information provided by this method includes the contribution made by each resource to achieving a standard goal.

Based on the maximum efficiency $\theta_i$ obtained in each DMU, a preference ranking can be built to apply in planning actions against desertification.

However, when DMUs are few and decision variables are many, it is likely that most of the DMUs were efficient $\theta_i = 1$ and none ranking can be made among them due to a large number of ties. In these cases many approaches have been made for discriminating level of efficiency among DMUs. Cross-evaluation efficiency assessment [29,30,31,32,35,36] is one of these approaches being particularly appropriated to short number of DMUs and applied frequently in policy assessment [37,38,39]. In addition methodological variations can be interpreted as applications of different shared responsibility making decision process [40,41].

In cross-evaluation efficiency all DMU are evaluated with the technical coefficient considered optimum by all other. Consequently, each DMU present a vector $\Theta_i(\theta_{1i}, \theta_{2i}, ..., \theta_{ii}, ..., \theta_{ni})$ of efficiency which assesses the shared efficiency. In order to obtain an overall efficiency index and make a preference ranking different methods have been proposed [29,39], however in the context of not-for-profit entities with long-term policies the above benevolent approach it seems more appropriated than o aggressive approach [30]. So the benevolent DEA applied can be formulated as:

$$\max \quad \sum_{j=1}^{m} u_{ji} \cdot \left( \sum_{i=1, j \neq k}^{n} y_{ki} \right)$$

$$\text{subject to} \quad \sum_{k=1}^{r} v_{ki} \cdot \left( \sum_{i=1, j \neq k}^{n} x_{ji} \right) = 1$$

$$-\theta_{ii}^{*} \cdot \sum_{k=1}^{r} v_{ki} \cdot x_{ki} + \sum_{j=1}^{m} u_{ji} \cdot y_{ji} \leq 0$$

$$-\sum_{k=1}^{r} v_{ki} \cdot x_{ki} + \sum_{j=1}^{m} u_{ji} \cdot y_{ji} \leq 0, \quad i = 1,...,n; \quad j \neq k$$

$$u_{ji}, v_{ki} \geq 0 \quad (j = 1,2,...,m; k = 1,2,...,r)$$

Finally, in order to analysis the goodness and stability of preference rankings, some correlation has been made between the obtained index and other naïve indexes as the number of $\theta_i = 1$ and products of $\theta_i$ efficiency index.

## ESTABLISHING SCENARIOS

Three scenarios or combinations of different results and resources were established.

Scenario 1 is considered a multi-criterion goal with the objectives of (y1) mitigating soil erosion, (y2) diversity and (y3) increasing population, through the use of the resources of (x1) reforestation, (x2) soil conservation practices, (x3) abandonment of dryland farming, (x4) irrigation crops and (x5) increases in protected land or natural areas.

In scenario 2 the objective of increasing population (y3) has been eliminated; this is a factor in desertification in other regions around the Mediterranean but in Spain it is more conditional upon the development of tourism and the service sector.

In the last scenario, number 3, the intention was so analyse only the objective of erosion (y1), which has historically been the main reason for reforesting in this part of Spain.

## RESULTS

### General results.

The application of CCR DEA discriminated only two municipalities as inefficient (Alhama $\theta_3^E = 0.44$ and Totana $\theta_8^E = 0.55$) in the one output scenario. Alhama (DMU-3) and Totana (DMU-8) presented abandon crops (x3) and irrigation crops (x4) as causes of inefficiency and Aledo (DMU-2) and Librilla (DMU-4) as efficient preference units.

When other outputs were included their efficiency were improved, so in two output scenario all of three improved ($\theta_3^{E,D} = 0.60$, $\theta_5^{E,D} = 1$ and $\theta_8^{E,D} = 1$) and, as well, in three outputs scenario ($\theta_3^{E,D,P} = 0.62$, $\theta_5^{E,D,P} = 1$ and $\theta_8^{E,D,P} = 1$), therefore making a preference order was getting more difficult.

When applying cross-efficiency methods as benevolent analysis, the weighted average and the weighted-cross evaluation showed a good performance as maker of preference rankings.

### Scenario 1: (y1) Erosion, (y2) Diversity, (y3) Population

In principle, all the policies were optimal except those of Alhama (0.62). The order of the best policies according to the average benevolent cross-weighted evaluation is: Aledo (1), P. Lumbreras (0.99), Lorca (0.70), Mazarron (0.64) and Librilla (0.53), and the worst policies would be those of Aguilas (0.47), Totana (0.38) and Alhama (0.29).
Aledo's efficiency rating is due to a high weight of the decrement of erosion while the most useful resource is the amount of reforestation lands. On the other hand P. Lumbreras is efficient thanks to increment of diversity and human population, soil conservation practices are the main input. Lorca outcome improved due to less erosion

and increased in human populations, the best inputs were reforestation surfaces and soil practices conservation. The worst DMU presents a output vector based on erosion and diversity with a strong effort in irrigation and land abandons.

**Scenario 2: (y1) Erosion, (y2) Diversity**

In principle, all the policies were optimal except in Alhama (0.60) which presented a strong input in irrigation and reforestation to obtain a short result in erosion.
When analyzing the cross-evaluation the ranking of policies are Aledo (1), P.Lumbreras(1), Mazarrón (0.85), Lorca (0.78) and Librilla (0.68). The worst policies would be those of Alhama (0.31), Totana (0.36) and Aguila (0.44).
Aledo's efficiency rating is due to improvements in erosion and the most important resource is reforestation. Otherwise, P. Lumbreras improved its diversity with soil conservation practices and a little reforestation.

The resources with the most weighting were the abandonment of dryland farming and the declaration of protected areas. In Aguilas extensive water planning has managed to reduce erosion. The resources mobilized are: 13% reforestation, 17% planning, 39% abandonment of farmland and 31% protection of natural areas. The reforestation resource has poor ratings in Librilla and Puerto Lumbreras, which have to be compensated for by achievements in the area of salinisation.

**Scenario 3: (y1) Erosion**

In principle, all the policies were optimal except Alhama (0.44) and Totana (0.55). In principle the best policies were those of Aledo (1) and Librilla (1). Efficiency in Aledo and Librilla is based on reforestation and soil conservationpractices. The worst-rated policies are those of Alhama and Totana; the former is based on expanding protected areas, while the second is based on extensive soil conservation but with not stopping erosion.
The average contribution of the different resources is: 11% reforestation, 22% planning, 28% abandonment of crops and 39% protected areas. In certain municipalities a need arises to repeat reforestation which has been burnt down or failed, and the abandonment of farmland is moderated by reforestation, planning and the expansion of protected areas.

## CONCLUSIONS

The DEA method makes it easy to interpret policies and their results. The DEA is highly expressive when it shows a poor contribution by a resource, revealing the weakness in that area and the need to make up for it in another in order to reach a given efficiency rating.
If erosion, landscape diversity and population are analyzed together, the best policy is that implemented in Lorca, with a high level of abandonment of dryland farming and an expansion of protected areas, generally situated in areas with steep slopes.
If efficiency in desertification processes is assessed using two outputs, erosion and landscape, the best policy is that of Aledo, characterised by a high percentage of reforestation.
If only erosion is taken into account to rate the best policy, the highest level of efficiency was reached in Aledo, but the preference ranking depends on the used index.
In all the scenarios the greatest contribution to efficiency was made by reforestation and soil conservation practices. Consequently, future policies implemented to combat desertification in the area should prioritize the reforestation and soil conservation. In addition, abandonment of unproductive farmland and the expansion of protected areas rather than the classic corrective water-forestry strategy by means of reforestation.


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(Table 1) POLICIES COMPONENT ARRAY: 1978-2003.
Obtained as a difference of indicators from 2003 and 1978.

| DMU | Y1: Erosion (ΔTn/Ha) | Y2: Diversity (ΔIndex/Ha) | Y3: Human population (Δperson x 100/Ha) | X1: Reforestation (% of forested area) | X2: Soil conservation planning (% of area managed) | X3: Land abandonment (% of dryland crops) | X4: Irrigation (Glasshouses) (% of irrigated crops) | X5: Protected Wild Land (% of area protected) |
|---|---|---|---|---|---|---|---|---|
| DMU 1: Aguilas | 0.24 | 19.45 | 69.62 | 0,80 | 84,10 | 0,01 | 19,50 | 7,50 |
| DMU 2: Aledo | 0.16 | 5.48 | 0.01 | 9,02 | 0,01 | 0,30 | 0,30 | 0,00 |
| DMU 3: Alhama | 0.01 | -13.91 | 31.84 | 0,12 | 21,69 | 6,70 | 4,40 | 28,40 |
| DMU 4: Librilla | 0.07 | -30.13 | 4.09 | 0.01 | 1,16 | 2,10 | 4,10 | 14,80 |
| DMU 5: Lorca | 0.13 | 3.48 | 155.98 | 4,67 | 2,05 | 8,60 | 3,10 | 0,70 |
| DMU 6: Mazarron | 0.24 | 11.92 | 105.71 | 0,50 | 18,50 | 8,10 | 10,50 | 5,30 |
| DMU 7: P.Lumbreras | 0.07 | 15.03 | 27.71 | 0,01 | 4,51 | 12,20 | 6,90 | 0,00 |
| DMU 8: Totana | 0.01 | 2.84 | 61.20 | 5,98 | 41,90 | 1,00 | 0,90 | 1,90 |