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Balancing Efficiency and Inequality in a Non-Linear Multi-Regional Water Allocation Optimization Model

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Abstract

Accounting for green and blue water resources, this study determines the optimal allocation of water between economic sectors under varying drought circumstances, applying non-linear optimization in a multi-regional input-output modeling framework. The results are compared to the regulated reallocation of water under existing regional drought warning and emergency plans. The analysis reveals that substantial economic gains can be achieved when considering efficiency in inter-sectoral water reallocation policies, mitigating value added losses. However, such optimal water allocation leads to greater inequality compared to the current drought policy measures. Extending the model and combining efficiency and equality concerns yields a production possibility frontier for second-best allocations that accounts for the distributional impacts of water reallocations under droughts. Notably, our findings demonstrate that there is potential for a more efficient distribution that is equal to the distributional impacts under the existing drought warning and emergency plans at lower total economic resource scarcity costs.

Keywords Non-linear Optimization · Multi-Regional Input-Output Model · Droughts · Efficiency · Inequality · Resource Scarcity Costs

1 Introduction

Climate change and rising water demands are expected to aggravate pressure on water allocations between the agricultural, industrial and domestic sectors (UNESCO & UN-Water 2020). In addition to the increase in water scarcity, climate change also increases the frequency and severity of extreme events like droughts (IPCC 2018), further exacerbating

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intersectoral trade-offs. As drought events cannot be accurately anticipated (Gil et al. 2011), much work has been done in recent years to assess the risks and socio-economic impacts of this natural hazard. In the hydro-economic modeling literature (e.g. Brouwer and Hofkes 2008; Harou et al. 2009), various studies using either input-output (IO) models or computable general equilibrium (CGE) models, have assessed the implications of different water policies tackling the inter-sectoral distribution of water in the face of water shortages. The economic consequences of water availability reductions and proposed adaptation measures are typically estimated and evaluated with the help of these models in terms of economic damages measured through the (reduced) loss of Gross Domestic Product (GDP) (Freire-González 2011; Freire-González et al. 2018; Garcia-Hernandez and Brouwer 2020; López-Morales and Duchin 2011, 2015; Roson and Damania 2017). The economic effects of an unexpected drought episode directly depend on how available water is distributed among different economic sectors (Eamen et al. 2020; Koopman et al. 2015; Ortuzar et al. 2023; Teotónio et al. 2020), which has increased policymaker demand for integrated models of the entire water-dependent economic system and calls for the implementation of efficient water allocation strategies (OECD 2015a; UNECE 2021).

Since there are large differences between economic sectors in terms of water use and productivity (Eamen et al. 2020), the social planner is confronted with trade-offs between efficiency and equality when designing optimal water distribution policies under drought conditions. In order to minimize overall economic losses in terms of GDP, it has been argued that water should be reallocated away from sectors that consume a lot of water but generate relatively low value added (VA) towards sectors that have a higher VA in relation to the amount of water they use (Roson and Damania 2017). This redistribution might lead to a significant reduction of production levels in certain sectors, some of which deliver essential public water services (e.g. utilities), that should be accounted for when designing and implementing water reallocation policies (Pérez-Blanco 2022).

The main objective and new contribution of this study to the existing hydro-economic modeling literature on drought events is the development of a hybrid, non-linear optimization model that simultaneously integrates efficiency and equality concerns. The model replicates the short-term behavior of the economy in the face of a supply-side shock in agriculture and other economic sectors that use water as an input. It considers that during the disruptive event, economic agents such as households, firms and governments will try to preserve current production and consumption behavior and pre-established trade patterns (Oosterhaven and Bouwmeester 2016). This approach has already been used to assess the economy-wide impacts of different disruptions, such as earthquakes (Bonfiglio et al. 2021), COVID-19 lockdowns (Bonfiglio et al. 2022), supply of natural gas flows obstructions (Bouwmeester and Oosterhaven 2017), floods (Oosterhaven and Többen 2017) and water restrictions (Ortuzar et al. 2023). Our paper adds to this strand of literature in two respects. First, the modeling approach extends previous work on water shortages and provides a methodological contribution by identifying efficient (optimal) water allocations whilst also addressing their distributional impacts across sectors, measured by the Gini coefficient. The pursuit of equality in the distribution of VA losses among sectors may be driven by several factors, many of which are often political (e.g. fairness, equal access to water). From an economic point of view, we are primarily interested to examine the distribution of the resource scarcity costs under drought events across different sectors and how unequal or disproportionate impacts can be mitigated at the lowest costs possible for the economy as a whole.

Second, our results also provide an empirical contribution as the modeling approach allows to accurately characterize real drought conditions and assess policy choices by modeling available green and blue water resources separately. The insights drawn from the analysis thus provide real-world evidence to support policymakers in designing water allocation schemes that balance both efficiency and equality during droughts. Further, the results also underscore the need to increase the uptake of integrated water accounting practices and multisectoral models in water management to tap into these benefits.

Spain is used as a case study due to its vulnerability to droughts. According to Eurostat (2023), Spain is the largest water user in the European Union and highly specialized in the supply of agri-food products (Serrano et al. 2015). Climate models predict a sharp reduction in Spanish water endowments, as well as an increase in the frequency of droughts (Rodríguez and Gutiérrez 2018). These impacts will be greatest in the southern regions of the country. Most studies so far analyzed the impacts of water shortages and adaptive water policies on agriculture (e.g. Berbel and Esteban 2019; Espinosa-Tasón et al. 2022; Graveline et al. 2014; Kahil et al. 2015; Martínez-Dalmau et al. 2023), whereas only a few studies (e.g. Almazán-Gómez et al. 2019; Borrego-Marín et al. 2015; Pérez y Pérez and Barreiro-Hurlé 2009) consider the impacts on other sectors as well.

We define three sets of water-related disruption scenarios and analyze them with the help of a multi-sectoral, multi-regional IO database for Spain developed by Cazcarro et al. (2013). The first scenario simulates the economic impacts of water use restrictions as imposed by existing drought management plans (DMP) for Spanish river basins. The second scenario determines the economic efficient allocation of water resources under the same water constraints as the first scenario. Finally, the third scenario accounts for the distributional impacts of the scenarios and calculates the economically optimal allocation of water that minimizes both VA losses and their unequal distribution across different economic sectors. In doing so, we evaluate, for the first time at regional and national scale, the economic impacts of existing drought warning and emergency policies, identify the economically optimal allocation of the available water resources under drought conditions, and we discuss the trade-off between efficiency and equality when reallocating the water resources. The model developed in this study can be tailored to other countries and economic regions, since the non-linear optimization procedure can be applied to any IO modeling framework. Similarly, it can be adapted to address the efficiency-equality trade-off of other resource allocation challenges within multisectoral models.

The remainder of the paper proceeds as follows: Sect. 2 presents the structure of the developed model, and Sect. 3 describes the data used for the analysis as well as the case study and the scenarios considered. Section 4 presents the results of the optimal water allocation between economic sectors during different drought conditions, with and without implementation of existing warning and emergency plans, in the southern part of Spain and the country as a whole, and also examines second-best policies that incorporate equality considerations, comparing them in terms of GDP losses. Section 5 discusses the findings, and Sect. 6 concludes the paper.

2 Modeling Framework

For the assessment of the economy-wide impacts of different water management policies related to the distribution of water between economic sectors, we use a non-linear programming model (NLP) based on a MRIO table (Oosterhaven and Bouwmeester 2016). This approach allows accounting for both demand and supply effects, including spatial substitution of imports and exports of both intermediates and final products, as opposed to standard IO analysis (see Appendix A for a detailed description of the baseline model). In the following subsections, we describe how water is incorporated and how the different water-constrained scenarios are modeled.

2.1 Modeling Water Shortage and Allocation Policies

To assess the economic impacts of drought episodes an analytical framework is needed that is capable of encompassing the main characteristics of droughts (Freire-González et al. 2017). In particular, the available sources of water in a region, and the policy decisions and operational choices before and during the drought are crucial determinants of the short-term economic impacts. The total amount of available water in a region is primarily determined by two factors: climate conditions (precipitation, temperature, dryness/humidity conditions) and the capacity of the region to use water resources stored in surface and groundwater reservoirs. Here it is necessary to distinguish between "green water" resources, which is the amount of water stored in or that stays in the top of the soil and is available for plants, and "blue water", which is fresh surface and groundwater (including human-made reservoirs) (Hoekstra et al. 2011). In the short term, climate conditions will directly impact the availability of green water resources through soil moisture deficiency, impacting crop yields and other green-water related activities. In this case, having sufficient reserves of available blue water can help mitigate the economic impacts induced by the green water deficit. However, if drought conditions persist (low rainfall, high temperatures, aridity) blue water reserves may start to diminish too. At this point, water authorities and regulators will need to rationalize blue water consumption by restricting water to different users. Hence, whereas climate aspects will affect both green and blue water, policy decisions will be a key determinant for the availability of stored (blue) water resources, and the short-term economic impacts of water deficits.

We follow this framework and incorporate these hydrological and policy elements into the modeling by adding the following constraints to the baseline equations (A.3-A.7) (see Appendix A). First, we define the total amount of water consumed (w) as the total sum of green (g) and blue (b) water resources used by sector i in the affected region k:

$$w_i^k = g_i^k + b_i^k, \qquad \forall\ i,\ k \tag{1}$$

Second, since during a drought episode the level of green water resources in a region will be directly determined by exogenous climate conditions, the following equation establishes the amount of this source of water that will be available for use:

$$g_i^k = (1 - \gamma_{\,g}) g_i^{k,\ ex}, \qquad \forall\ i,\ k \tag{2}$$

where γ_g is the green water scarcity parameter (i.e., the percentage by which the quantity of available green water is reduced) and $g_i^{k,\ ex}$ the total amount of green water resources consumed by sector i in the affected region k, and is obtained from the water accounts underlying the baseline MRIO table (Cazcarro et al. 2013). Third, since water authorities and regulators may restrict water to the different users according to the measures foreseen in the existing drought warning and emergency plans of the specific region or river basin under the different water scarcity scenarios, the following constraint establishes the amount of blue water resources available for the different sectors i in region k:

$$b_i^k = (1 - m_i^k d_i^k) b_i^{k,\ ex}, \qquad \forall\ i,\ k \tag{3}$$

where $b_i^{k,\ ex}$ is the total amount of blue water resources consumed by sector i in the affected region k from Cazcarro et al.'s (2013) base year MRIO table, m_i^k are the measures (water restrictions) defined in the drought contingency mitigation plan (see Table 4 in Appendix B) to be applied to sector i in region k and d_i^k is the proportion of water demanded by industry i in region k that is affected by the measures.[1] Finally, we link changes in total water availability to changes in production by including industry-specific output-water elasticities (δ_i^k), which quantify how changes in water translate into changes in output:

$$\left(\frac{x_i^k - x_i^{k,\ ex}}{x_i^{k,\ ex}} \right) = \delta_i^k \left(\frac{w_i^k - w_i^{k,\ ex}}{w_i^{k,ex}} \right), \qquad \forall\ i, k \tag{4}$$

where $x_i^{k,\ ex}$ and $w_i^{k,ex}$are, respectively, the total output and amount of water consumed by sector i in the affected region k as obtained from the baseline MRIO table.

Solving equation (A.2) subject to (A.3–A.7) and (1)–(4) provides the post-MRIO tables that most resemble the initial economic situation in the face of a water shortage induced both by climate conditions and the specific water allocation policy.

2.2 Modeling Optimal and Second-best Water Allocations

One important aspect of the measures defined in the drought warning and emergency plans is that, although they acknowledge the specific characteristics of agriculture and establish more tailored measures for this sector, this is not usually the case for the other economic activities. Instead, the measures are defined by categories of sectors (industry, services and/or urban users), and all industries belonging to each category are to face the same water restriction regardless of their specific characteristics. Moreover, the measures are also not based on any economic assessment taking into account the economic structure of the region nor the interdependencies between different economic sectors. Consequently, existing drought warning and emergency policies may not be the least-cost way to address the water shortages. It may therefore very well be, and this is our a priori expectation, that there exists another water allocation policy that complies with the same water reduction target as

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[1] MRIO tables depict a country's economic structure for a specific year, whereas water reduction measures may extend over part or the entire year. To achieve more precise calculations of the water shortage effects, monthly water demand in agriculture has been extracted from the Hydrological Plan of the river basin district, whereas for industrial and service sectors it has been estimated based on industrial production and turnover indices, respectively. These monthly water demands have been correlated with the months in which the measures defined in the DMP are more likely to be applied.

defined in the drought contingency plan, but that minimizes the overall economic losses. This scenario aims to assess how accounting for the water efficiency of the different sectors in a region when designing the water allocation measures, as well as the inter-industry and interregional economic linkages based on the MRIO framework, can help mitigate the economic impacts of water use restrictions. This economically efficient water allocation is defined by replacing Eq. (3) with the following constraints:

$$b_i^k = \left(1 - \alpha_i^k d_i^k\right) b_i^{k,\ ex}, \quad \forall\ i,\ k \tag{5}$$

$$\sum_{i=1}^{n} \alpha_i^k d_i^k b_i^{k,\ ex} \le \sum_{i=1}^{n} m_i^k d_i^k b_i^{k,\ ex}, \qquad \forall\ k \tag{6}$$

where $\alpha_i^k \in [0,1]$ is the optimal water restriction to be applied on sector i and is now estimated by the model, and n is the number of sectors. Equation (5) identifies the amount of blue water that is available for sector i in affected region k, while Eq. (6) ensures that the total water reduction in blue water resources achieved by this allocation policy is at least equal to the one that would be attained by the drought warning and emergency measures.

However, as some economic sectors are more efficient in terms of water usage than others, an optimal water allocation solution inevitably results in a deterioration of an equal distribution of sectoral VA losses, i.e., water is mostly withdrawn from the less productive sectors. This is a key element of political discussion in the design of water allocation policies, since greater efficiency is achieved at the expense of more unequal outcomes.

In order to incorporate this equality dimension into the framework and explore second-best optimal allocations, we consider the use of the Gini coefficient (Gini 1921), which was originally proposed as a measure of income distribution within a society. However, it has also been applied in environmental studies as an effective measure of inequality in resource allocation problems (Druckman and Jackson 2008; Münnich Vass et al. 2013), including water (e.g. Dai et al. 2018; Hu et al. 2016; Wu et al. 2022). Since different sectors have different water productivities, an equal allocation of water may not guarantee an equal distribution of the economic impacts. So, here we consider equality in terms of economic losses and propose to measure and evaluate the Gini coefficient based on the relative VA losses of different sectors. To the best of our knowledge, this measure has not been used before to assess the distributional impacts of water restrictions in the economy.

The Gini coefficient is usually measured based on the Lorenz curve, calculated as the ratio of the area lying between the line of equality and the Lorenz curve over the total area under the line of equality. This is mathematically equivalent to defining the Gini as half of the relative mean absolute difference of all possible pairs of individuals (Litchfield 1999). Thus, we define our Gini coefficient as:

$$G_k = \frac{1}{2n^2 \bar{V}_k} \sum_{i}^{n} \sum_{j}^{n} \left| V_i^k - V_j^k \right| \tag{7}$$

where $V_i^k = \left(\frac{v_i^k}{v_i^{k,\ ex}} - 1 \right)$ is the relative change of VA losses for sector i and $\bar{V}_k$ the mean of the relative VA changes of all sectors, calculated as $\bar{V}_k = \frac{1}{n} \sum_{i}^{n} V_i^k$. A value of Gini of 0 (perfect equality) would therefore imply that all economic sectors experience exactly the same relative losses in value added, whereas a value of (or close to) 1 would represent a situation where economic losses are mostly borne by only one (or few) economic sector(s). Hence, to include this equality dimension into the optimization problem and explore optimal water allocations conditioned on the prerogative of a more equal distribution of the economic impacts, we add the following constraint to Eqs. (5) and (6):

$$G_k \leq E_k \tag{8}$$

where $E_k \in [0,1]$ is the minimum equality threshold policymakers and regulators may want to achieve when estimating the optimal water allocation that minimizes the overall economic impact in the affected region k, and G_k is the Gini value measured based on the relative VA losses of the different economic sectors of the optimal solution of the model calculated as in Eq. (7).

3 Case Study Data and Scenarios

3.1 Case Study

We use an existing MRIO model for Spain for the year 2005 (Cazcarro et al. 2013). The model provides information on the economic linkages among 40 sectors[2] (see Table 6 in Appendix B for more details on the sectoral breakdown) in 19 regions, i.e. 17 so-called autonomous communities and two additional regions, namely the rest of the European Union and the Rest of the World. The economic data is matched with water satellite accounts distinguishing between blue and green sectoral water consumption for all Spanish regions (INE 2010). This is the only MRIO extended to the use of water resources ever built for Spain, and it has not been updated since 2005. The reason for this is that most Spanish regions have not updated their regional IO tables, the main data source for the construction of the MRIO framework, and there has not been any update on sectoral water use data either (Cazcarro et al. 2020). However, the model still represents Andalusia's economic structure sufficiently well for the purpose of this analysis, as it has not experienced significant sectoral changes between 2005 and the present when it comes to the main economic sectors relying on the available water resources (INE 2024).

The MRIO tables are used to calibrate the NLP's coefficients defined in Sect. 2 to reproduce the baseline year, and the water accounts to estimate the direct production losses induced by the water shortages and the imposed restrictions. For this, we use industry-specific water output elasticities, which quantify the percentage change in sectoral output due to a relative change in the water resources used by each industry. The elasticity for agriculture is taken from Berbel et al. (2011), whereas the values of the elasticities for manufacturing and services have been derived from Gracia-de-Rentería et al. (2019, 2021), respectively.[3] These elasticities can be found in Table 5 in Appendix B.

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[2] Sectors are classified according to the European Classification of Economic Activities (NACE). They include two primary sectors, the energy sector, the water sector, construction, 16 industrial sectors and 19 service sectors.

[3] Manufacturing and services elasticities have been calculated by taking the inverse of those presented in Gracia-de-Rentería et al. (2019, 2021), which measure the change in water due to a change in the output

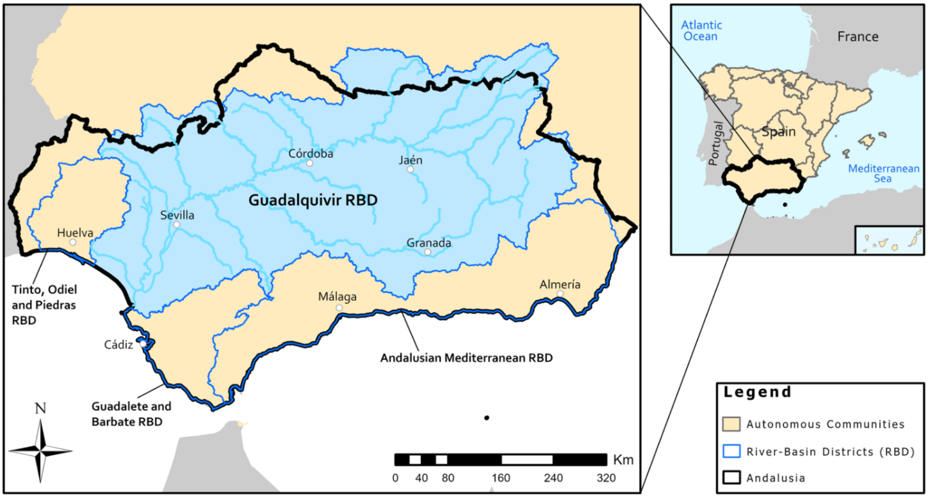

Fig. 1 Map of the study area in southern Spain

Spain suffers from recurrent droughts, which have worsened in recent years due to climate change. Some regions, particularly in the south, have experienced severe water deficits, with significant economic and environmental impacts (Espinosa-Tasón et al. 2022; Gomez-Gomez et al. 2022; Rodríguez and Gutiérrez 2018). According to Spanish legislation, specifically the Consolidated Text of the Water Law (BOE 2001), domestic and household uses are given the highest priority in the allocation of water resources. Agricultural and industrial activities may be subject to water restrictions during droughts, leading to economic losses. The latter include reduced crop yields, changes in production patterns, diminished industrial output, reduced hydropower generation, and negative impacts on tourism and local economies. The effects of the prioritization of water uses as set out in the law can also aggravate conflicts between different water users and regions. To address these challenges, drought management plans (DMPs) have been developed, and a system of monitoring water use and enforcement has been promoted. To examine the trade-off between efficiency and equality, we model the effects of a drought in the driest and most southern region, Andalusia, where more than 25% of the total irrigated land area in Spain is found (INE 2020).

Andalusia consists of 6 river basin districts, with four of them having their primary territory within this autonomous community: Guadalquivir; Tinto, Odiel and Piedras; Guadalete and Barbate; and the Andalusian Mediterranean River basin district (see Fig. 1). The Guadalquivir River Basin (GRB) falls almost entirely within the region (90% of the GRB is located in Andalusia) and provides over 63% of Andalusia's freshwater supply (CESUR 2021). The basin has a Mediterranean climate with warm temperatures and low rainfall, especially in the interior where most irrigated agriculture is located (Salmoral et al. 2011). Agriculture is the largest consumer of water in the area, accounting for 65% of the consumptive use of green water and 80% of blue water (Salmoral et al. 2011). According to

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level, so that we can obtain values that relate water changes to output changes. However, note that this adjustment does not influence the results, as it is mathematically equivalent to use either sets of elasticities in the constraint specified in Eq. [4]. That is, elasticities from Gracia-de-Rentería et al. (2019, 2021) could be applied directly on the left-hand side of the equation leading to the same outcome.

Table 1 Hydrological status and risk of water restrictions related to Spain's standardized national drought indicator

Drought indicator	Hydrological status	Risk of water restrictions
1–0.50	Normal	Very low - low
0.50−0.30	Pre-warning	Medium
0.30−0.15	Warning	High
0.15–0	Emergency	Very high

Martínez-Dalmau et al. (2023), the analysis of the impacts of different water management strategies is particularly interesting in this region given its structural drought conditions (Espinosa-Tasón et al. 2022), the periodicity and intensity of drought episodes, the importance of irrigated agriculture and the scarce opportunities to increase the water endowment.

3.2 Scenarios

The history of droughts in Spain has led to the development and implementation of DMPs in so-called River Basin Organizations, together with the establishment of a common drought indicator for the whole country. The drought indicator is based on water availability data collected at different points, such as the volume of water stored in surface water reservoirs, groundwater in aquifers, river flow discharges, inflows to reservoirs and rainfall. These data are aggregated and compared with water demand to produce a standardized index, ranging from 0 to 1, representing the status of each water resource system (Estrela and Sancho 2016), where values close to 1 represent a good hydrological status of the system and values close to 0 an extremely poor situation with very little water resources. The purpose of this index is twofold. First, it allows anticipating drought situations and assess their seriousness, and second it is a crucial instrument supporting the management of scarce water resources during drought events. Moreover, it facilitates an objective characterization of the drought status by defining threshold values (see Table 1) and corresponding predefined action plans to gradually and cumulatively implement policy measures depending on the specific drought phase.

Figure 2 shows the evolution of this drought indicator for the GRB. It illustrates the phases of pre-warning (yellow) corresponding to a drought index between 0.3 and 0.5; warning (orange) with a drought index between 0.15 and 0.3; and emergency (red) when the index falls below 0.15. As can be seen in Fig. 2, the most severe drought periods occurred in the years between 1991 and 1996, 1999 and 2001, 2005 and 2009, and between 2017 and 2019.

For the analysis presented here, we simulate a drought equivalent to the situation between 2005 and 2009, when the index was mostly in the warning phase. In both the warning and emergency phases, the restrictions proposed in the DMP apply to all economic sectors (CHG 2018). Among these two phases, we are specifically interested in the warning phase because it is more frequently observed than the emergency phase in the GRB based on historical data.[4] As a result, there is also more historical data available for this phase, i.e. more observations to estimate the green water scarcity parameters. Moreover, changes in water availability in the warning phase are not as extreme as in an emergency situation. Consequently, the expected impacts on water shortages and output price levels, as well as potential technological changes induced by increased prices, are more limited. The measures to be

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[4] The complete historical data for the drought indicator over the past 30 years were obtained from the State Secretariat for the Environment, Ministry for Ecological Transition and Demographic Challenge.

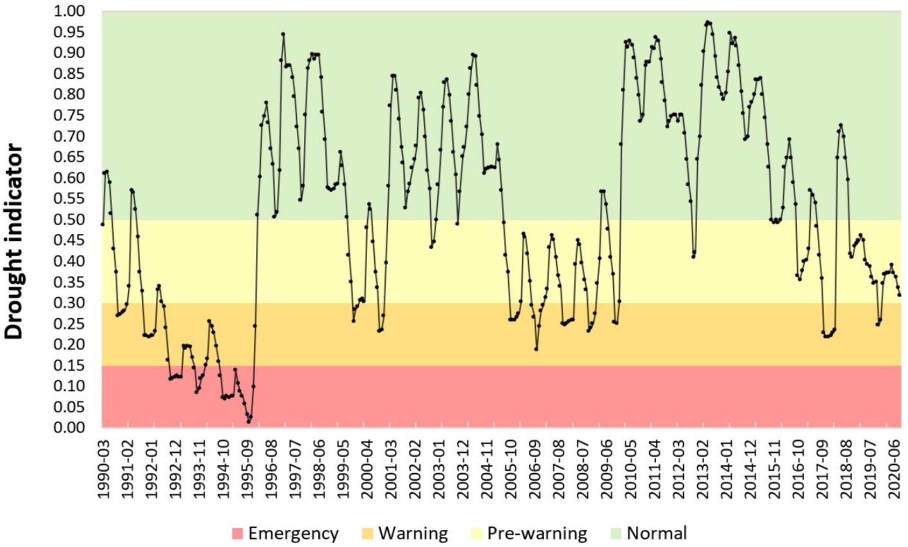

Fig. 2 Evolution of the drought indicator for the Guadalquivir river basin

applied during the warning phase are defined in the DMP for the GRB and are presented in Table 4 in Appendix B. This drought status involves the progressive implementation of water restrictions on all sectors of the economy, with water constraints on industrial and urban users of up to 5%. For irrigated agriculture the DMP proposes a decreasing volume of water discharge based on the total amount of water reserves in the system for each of the drought phases (CHG 2018). From these proposed water discharges, it is possible to estimate how much water is reduced compared to what would be available in a normal situation. These estimated reductions range from 17.4% (right after entering the warning phase) to 30.5% (the midpoint value during the warning phase) and 61.4% (right before entering the emergency phase). Correspondingly, we categorize the warning phase into three levels of severity (warning 1 to warning 3) that vary based on the degree of water stress. They are differentiated by the warning level, i.e. at the beginning of the warning when the drought index is between 0.30 and 0.25, in the middle of the warning phase (0.25 − 0.20), and when the economy is about to enter an emergency phase (0.20 − 0.15), with progressive blue water restrictions being imposed on the different sectors in each of these phases (see Table 2).[5] In addition, the reduction in green water availability for each scenario has been estimated by relying on soil moisture data from the Ministry for Ecological Transition and Demographic

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[5] Note that the water satellite accounts of the MRIO table account for the total water consumption of the different economic sectors, and not total domestic water use. For the Guadalquivir basin, urban water demand amounts to approximately 10% of the total water consumption in the region (CHG 2015), and the DMPs also envisage specific water saving measures for domestic users during the different drought phases. Hence, the scenarios modeled reallocate blue water resources that are used for economic purposes among the different economic sectors and assume that, in parallel, specific measures will be applied to domestic users. However, prioritizing more water for domestic water uses can be modeled by assuming further constraints on the amount of blue water resources that would be available for economic purposes during a drought situation.

Table 2 Summary of the green and blue water restrictions applied in this study

		Severity (drought indicator)			
	Origin of water constraint	Sectoral domain	Warning phase 1	Warning phase 2	Warning phase 3
			(0.30 − 0.25)	(0.25 − 0.20)	(0.20 − 0.15)
Green water restriction	Estimated soil moisture deficit	Rainfed agriculture	8.0%	25.5%	33.3%
Blue water restriction policies	DMP	Irrigated agriculture	17.4%	30.5%	61.4%
		Industry and urban	1.0%	3.0%	5.0%
	Optimal	Irrigated agriculture	Endogenously determined by the model, Eqs. (A.2–A.7), (1)–(2) and (4–6)		
		Industry and urban			
	Equality	Irrigated agriculture	Endogenously determined by the model, Eqs. (A.2–A.7), (1)–(2) and (4–8)		
		Industry and urban			

Challenge (MITECO) for the GRB.[6] Based on the drought index, we identified the specific months in which each type of warning (1 to 3) was in place and calculated the reduction in soil moisture in these months compared to each monthly average.

For each of the warning levels, we assess the economic impact resulting from three different policies. The first policy that we analyzed is used as a baseline here, and builds on the policy interventions defined in the Guadalquivir DMP (see the percentage sectoral reductions in Table 2). The second policy refers to the economic optimal allocation of blue water between different economic sectors that minimizes the total economic impact, i.e. the allocation of available blue water that brings the economy as close as possible to the pre-drought situation. For comparison reasons, the optimal allocation is constrained by exactly the same aggregate water reduction as under the DMP. In other words, the total amount of available blue water is equal to the available amount under the DMP in each of the warning levels. Aiming for an economic optimal allocation of water means in this case minimizing any deviations from the initial situation. However, such an economically optimal allocation of water is expected to introduce distortions between economic sectors, which might invoke policymakers to consider alternative water allocation solutions. Hence, we propose a last set of scenarios where we explore second-best allocations by imposing a constraint on the inequality of the economic impacts, as measured by the Gini index. Figure 3 presents a detailed diagram of the modeling framework used in the study.

4 Results

4.1 Efficiency Improvements When Optimizing Water Allocation under Drought Conditions

At the national level, VA losses (and hence loss of GDP) would vary between 0.16% and 0.75% depending on the drought warning in the case of applying the restrictions proposed in the drought contingency plan, and are reduced to 0.05–0.21% if we aim for an economically optimal redistribution that minimizes overall losses (see Table 3). As expected, the

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[6] https://www.miteco.gob.es/es/agua/temas/evaluacion-de-los-recursos-hidricos/evaluacion-recursos-hidricos-regimen-natural/. Accessed on 21 September, 2023.

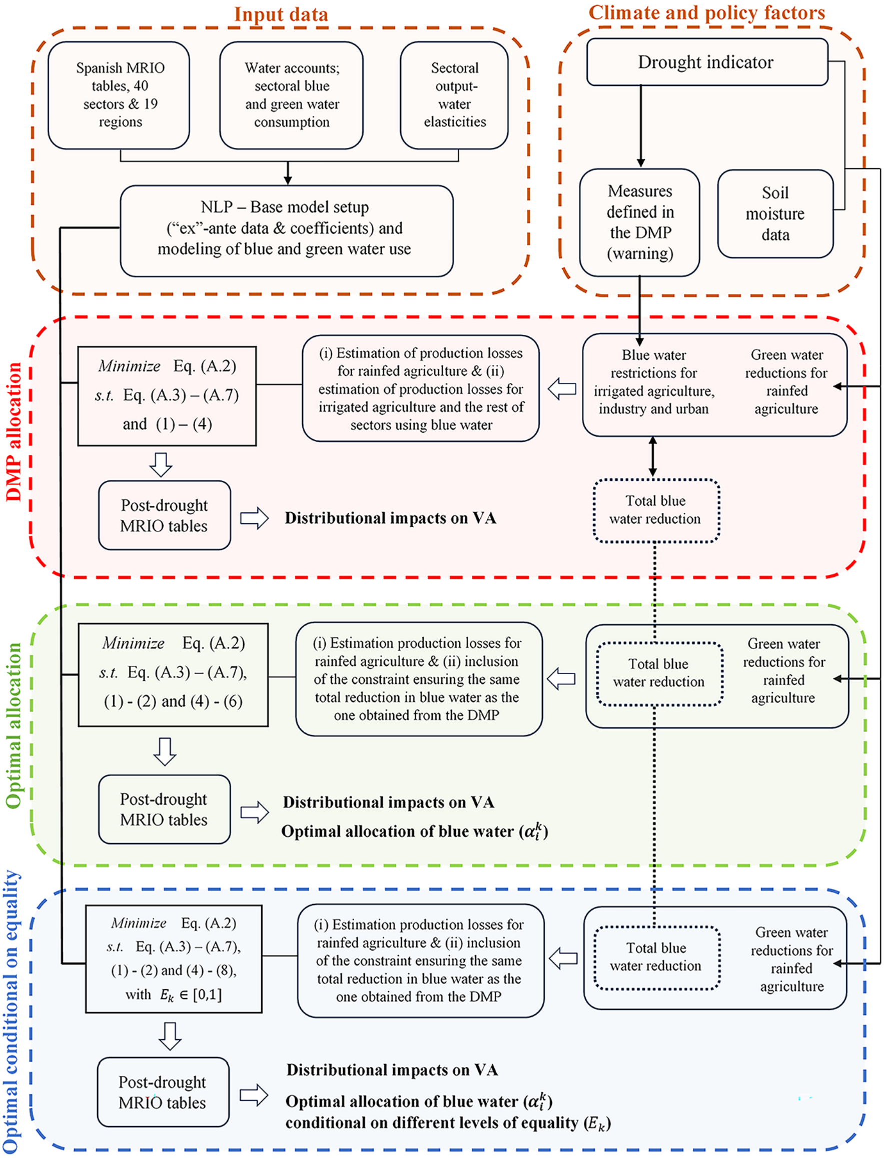

Fig. 3 Modeling framework

largest economic damage occurs in the region directly affected by the drought, i.e. Andalusia. Andalusia's VA would fall between 1.11% and 5.30% when applying the restrictions specified in the drought management plan, depending on the warning phase, and by around 0.36% and 1.50% if water allocations under the drought conditions is managed by minimizing the negative impacts of the water restrictions on the region's income (Table 3).

Hence, we obtain an interesting first result both at national and regional scale. There clearly exist possibilities of managing water resources in the face of a drought that help

Table 3 Water restrictions under different water allocation scenarios and their impacts on VA of the country as a whole and the region of Andalusia

	Existing Drought Management Plan			Economic Optimal Distribution		
Change in Value Added (%)	Warning 1	Warning 2	Warning 3	Warning 1	Warning 2	Warning 3
Spain as a whole	–0.16	–0.47	–0.75	–0.05	–0.15	–0.21
Region of Andalusia	–1.11	–3.35	–5.30	–0.36	–1.11	–1.50
Total blue water restriction (%)	–4.56	–8.19	–16.33	–4.56	–8.19	–16.33
Total green water restriction (%)	–7.99	–25.50	–33.27	–7.99	–25.50	–33.27

minimize both the overall national economic losses and the economic impacts in the area directly affected by the water restriction (Andalusia in our case). Table 3 shows that for each of the three levels of water stress, it is possible to find an allocation of the limited water resources that improves the efficiency of the economic system compared to the economic outcome when implementing the existing drought management policies. Specifically, if water is distributed optimally, losses would be more than three times lower compared to the ones obtained from existing drought warning measures, depending on the specific water stress. Further, if we compare the different severity levels under each policy, we also observe that reducing the water endowments from the first to the third warning phase increases the negative impact on income significantly. Concretely, the reduction in VA would be more than four times larger if we compare the most optimistic (warning phase 1) and pessimistic (warning phase 3) scenario.

If we look at the sectoral changes in value added in Andalusia, we also find interesting patterns (see Fig. 4). First, agriculture suffers most in terms of income loss, i.e. –4.83%, –14.76% and – 19.81% under the warning scenarios 1, 2 and 3, respectively.[7] In the case of agriculture in the region of Andalusia, the losses would be similar for both the water allocation policy contemplated in the drought contingency plan and the optimal distribution estimated by the model. This highlights the strong dependence of Andalusian agriculture on the available water resources and the limited possibilities of avoiding the economic impacts due to a drought. Although agriculture only contributes 5.87% to Andalusian GDP, it accounts for approximately 70% of total water consumption (Table 6 in Appendix B).

The other economic sectors are much more able to absorb the economic effects of the drought scenarios and look for ways to minimize the impact on the economy by improving water allocation efficiency. The largest increases in efficiency, as measured by the reduction in VA losses, occur in sectors notably impacted by the measures envisaged in the drought warning mitigation plan, such as construction which accounts for 13.4% of total GDP and wholesale and retail trade which account for 9.3% of total GDP in Andalusia (see Table 6). In addition, activities closely linked to leisure and tourism, such as hotels, restaurants, real estate, rental and recreational activities, also show considerable opportunities for efficiency improvements. Together, these activities account for more than 15% of Andalusia’s GDP, although their share in direct water consumption is relatively small (3.25%) (see Table 6).

In the case of the industrial sectors, it is possible to find industries where losses are minimized considerably when optimizing water allocation economically, such as non-metallic minerals and manufacturing of metal products. Both sectors contribute significantly, both in terms of VA (1.2% and 1.1%, respectively) and direct water consumption (1.1% and 1.6%,

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[7] To avoid overloading the figure, Fig. 4 depicts only the results for the warning 2 phase. However, the complete numerical results can be observed in Table 7 in Appendix B.

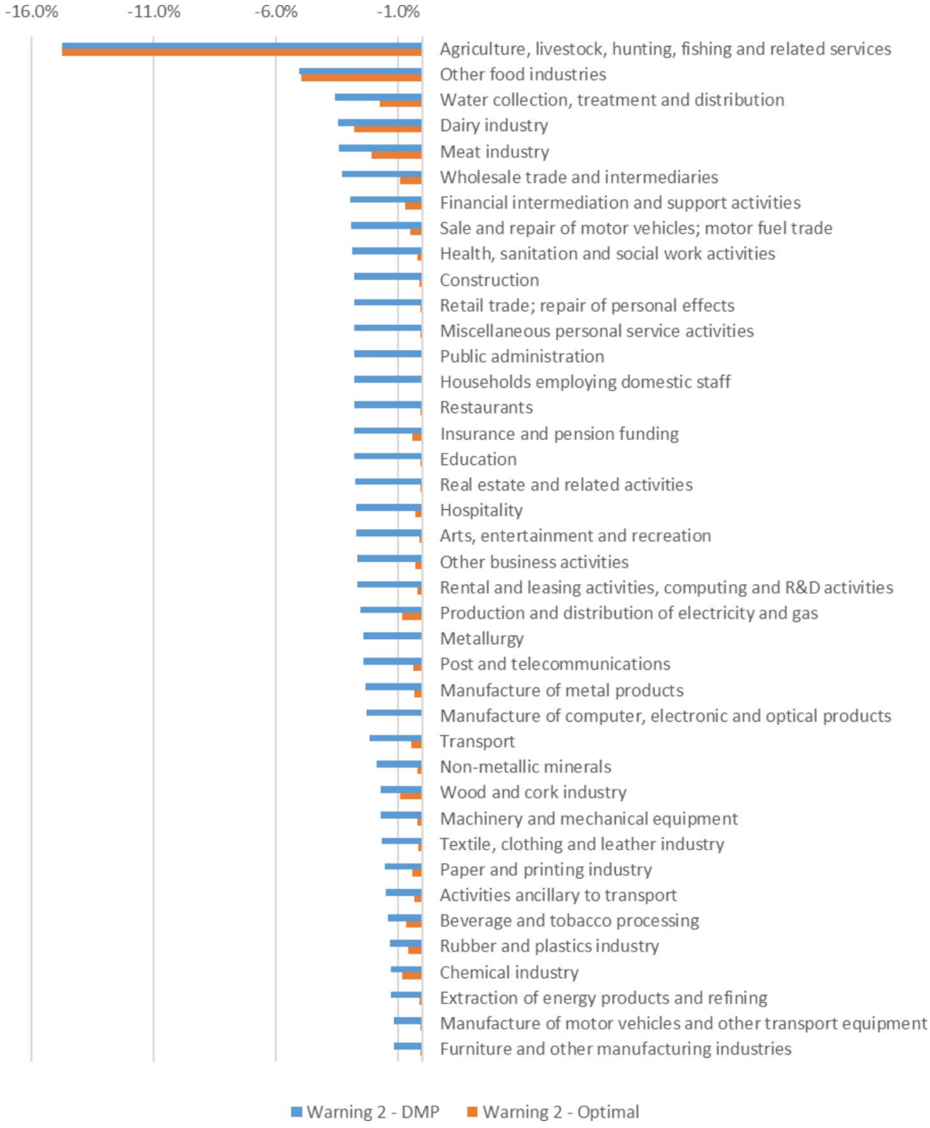

Fig. 4 Sectoral VA change (%) under warning 2 level

respectively) (see Table 6). The efficiency improvements are lower in the chemical industry, the most water-dependent industry in the region. The lowest efficiency improvement is found in the agri-food industry, as well as in the water collection, treatment and distribution sector. Figure 4 illustrates these efficiency improvements under the second warning phase.

The water restriction shock is disseminated through existing supply chains to regions that are not directly affected by the drought. As Fig. 5 shows, some regions would lose income whereas others would gain income as a result of the drought conditions in Andalusia. Among the regions facing losses are Madrid, Catalonia and the Basque Country three of

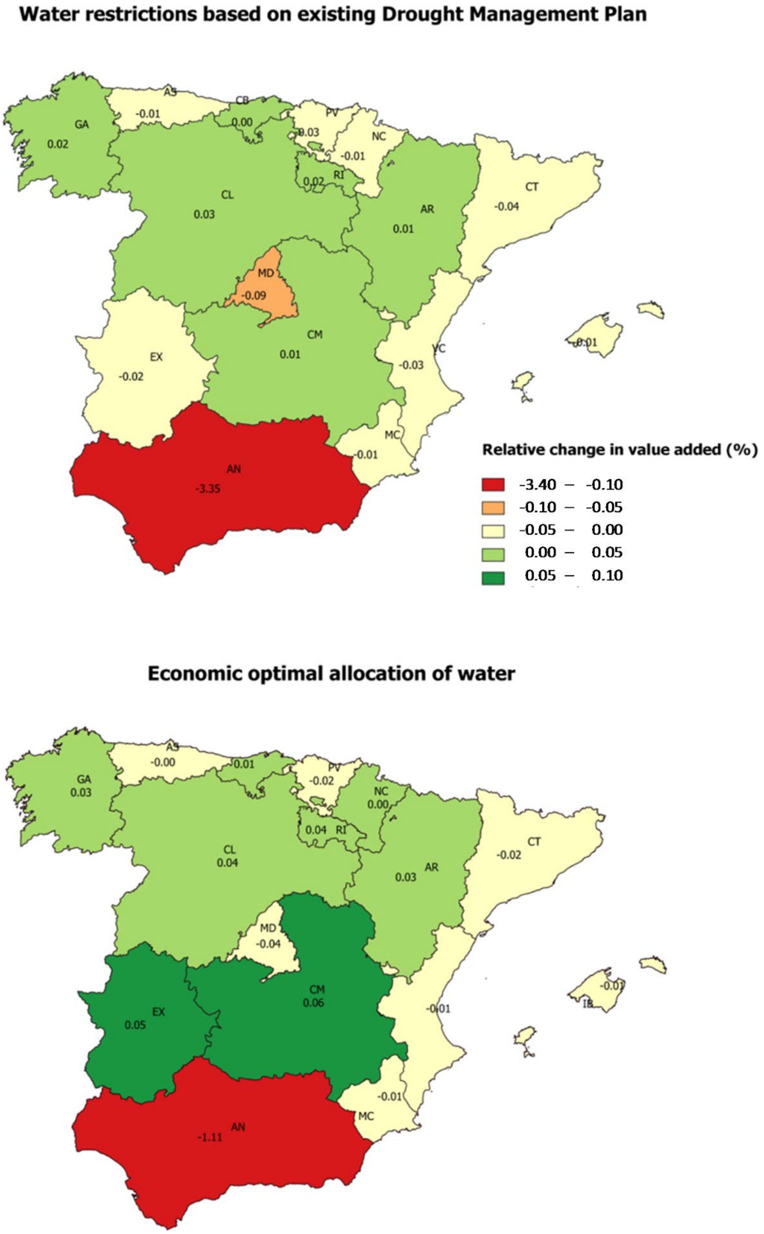

Fig. 5 Regional changes in value added (%) due to different policy responses under a drought warning 2 level. Note: Names of the regions and their acronyms are as follows: Aragon (AR); Asturias (AS); Balearic Islands (IB); Cantabria (CB); Catalonia (CT); Castilla-La Mancha (CM); Castile and Leon (CL); Extremadura (EX); Galicia (GA); La Rioja (RI); Madrid (MD); Murcia, Ceuta and Melilla (MC); Navarre (NC); Basque Country (PV); Valencia (VC)

the country's main urban and industrial centers. Losses are mainly associated with the agri-food, cork and timber industries. The application of the economically optimal drought management scenario in Andalusia would lead to significant economic improvements in these three regions. Traditional agricultural areas in the center of Spain, encompassing regions like Castile-La Mancha and Castile and Leon, as well as regions along the river Ebro valley, such as Aragon and La Rioja, would benefit from the water shock in Andalusia. This can be explained by substitution effects where part of the lost output from Andalusian agriculture is taken over in other, less water restricted regions. These regions would benefit from the implementation of a more optimal water allocation, which would increase their income as a result of the drought. Two regions with a strong agricultural base, Extremadura and Navarra, also stand out. Applying existing drought warning contingency policies would result in economic losses in both regions. However, if water allocation efficiency would increase, these regions would also increase their VA. In both cases the improvements would be associated with sectors such as beverage, tobacco, wood and cork manufacturing. Finally, the simulations show how the drought in Andalusia would have negative economic impacts on the rest of the European Union, with whom the affected region has strong trade ties, whereas it would have positive effects in other countries around the world.[8]

To provide empirical context to these substitution effects, we analyzed historical data on regional agricultural value added (de la Fuente and Ruiz 2024) as well as gross production and yields at the regional level for the entire country (MAPA 2024) between the period 2001–2004 which were normal or wet years and the subsequent 2005–2009 drought. By comparing changes in average physical production for different groups of crops in Andalusia between the two periods, we observe that the average production of all groups of crops decreased, except for citrus fruits. While the regions Castile and Leon, Aragon, Castile-La Mancha, Galicia, Cantabria, and La Rioja also experienced reductions in some crops during 2005–2009, they increased the production of others. For instance, average fodder crops production in Aragon increased by +6%, while it decreased in Andalusia (−13%). Castilla and Leon increased its production of cereals (+5%), fodder crop (+22%), olive groves (+11%), and vegetables (+15%), whereas these groups of crops declined in Andalusia by 23%, 13%, 7%, and 0.2%, respectively. Vegetable production also increased in Castilla-La Mancha (+18%) and Galicia (+52%), whereas Cantabria experienced significant increases in both cereals (+64%) and fodder crops (+45%), and La Rioja in the production of olives (+60%). These patterns can thus shed some light on which specific crops may drive the positive substitution effects in each of the regions.[9]

4.2 Efficiency-equality trade-offs

So far we have demonstrated how the total economic impact of drought events in southern Spain can be minimized through a more efficient sectoral water allocation than proposed

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[8] The results for the impact on other countries around the world are not included here to avoid overloading the presentation.

[9] The quantification of these substitution effects has to be interpreted with caution due to the presence of different confounding factors, such as the effect of policy interventions. For example, two significant events impacted the agricultural sector during the 2005–2009 drought in Spain. Firstly, implementation of the 2003 reform of the Common Agricultural Policy took effect in 2006, decoupling direct subsidies from crop production and leading to substantial and rapid shifts in production patterns. Secondly, the global food crisis in 2007–2008 potentially exerted significant influence on agricultural prices and production decisions.

policies in existing warning and emergency plans. In a next step, we add to this efficiency analysis an equality perspective by introducing different equality objectives into the economic modeling framework, as explained in the methodology section. The main results are shown in Fig. 6 for the drought warning 2 level, and the complete numerical results for all warning levels can be found in Table 7 in Appendix B.

Figure 6 shows, for the water restrictions under the second drought warning level, the relationship between total aggregate VA losses in Andalusia and the inequality in distributional losses across the economic sectors in the same region, as measured by the Gini index defined in Sect. 2.2. The red dot locates the economic loss (3.35%) and associated Gini coefficient (0.257) based on the measures foreseen in the DMP. The green dot at the end of the curve on the right-hand side reflects the optimum where the total economic impact in the region is minimized under the same water constraint. In this case, total VA would decrease by 1.11% but at the expense of a higher unequal distribution of the economic impacts across sectors with a Gini value of 0.746. If we estimate other economic optima conditional on increasingly lower Gini values, as shown by the blue line, we can observe a clear trade-off between efficiency and equality. If policymakers want to minimize the economic impact of drought events, they must accept growing inequality across sectors in the drought-affected

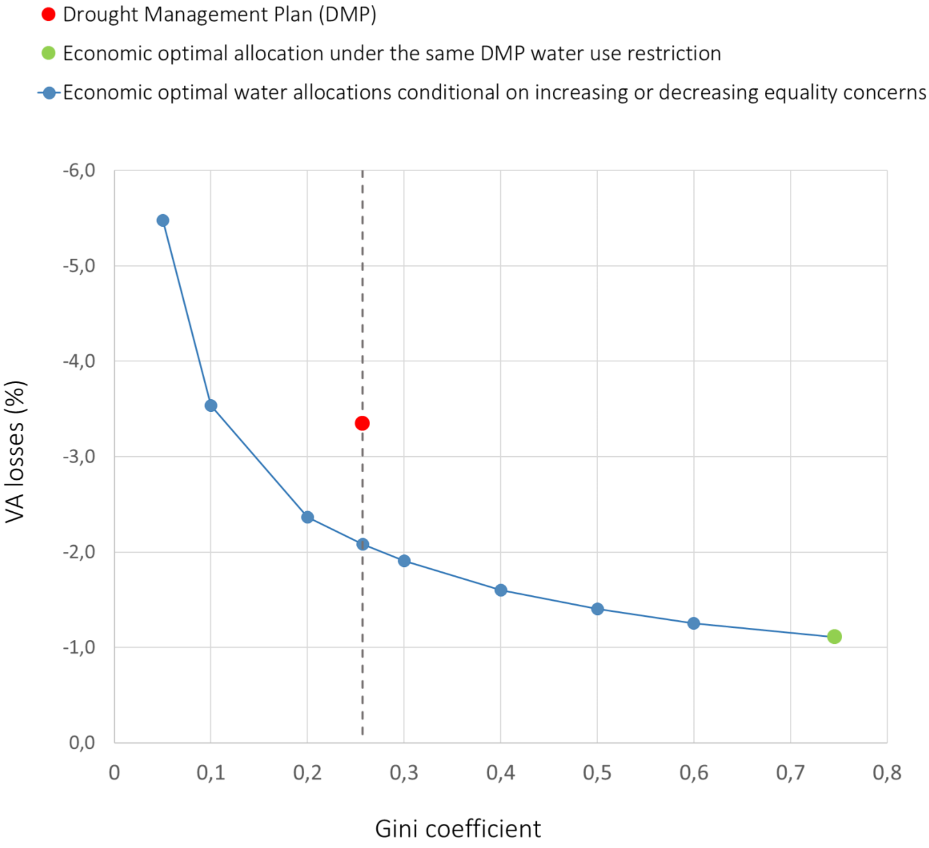

Fig. 6 Illustration of the trade-off between efficiency and equality in the region of Andalusia under the drought warning 2 level

region. Conversely, if the main objective is to distribute sectoral VA losses more equally, then economic losses will be higher. Interestingly, Fig. 6 also shows that it is possible to define a water allocation policy that is as equal as the one defined under the drought management plan, but that results in a much lower aggregate economic loss (–2.08%).

Figure 7 also depicts this equality-efficiency trade-off in Andalusia by means of Lorenz curves. The light green curve, which is the furthest away from the 45° equal distribution line, corresponds to the economic optimal scenario where the total costs on the Andalusian economy are minimized. The dashed blue lines represent the various economic optimal water allocations conditional on increasing equality of the cross-sectoral economic impacts, while the solid red curve is the Lorenz curve resulting from implementing the existing drought contingency plan-based water allocation rules. Thus, from both Figs. 6 and 7, it is clear that focusing on minimizing the economic losses of a drought event will increase cross-sectoral inequality. In this study, the Gini coefficient would be around three times higher for the economic optimal water allocation than for the one under the warning contingency plan. Conversely, although the distribution of the economic impacts of the water allocation rules as defined in the DMP across the various sectors would be more equal,

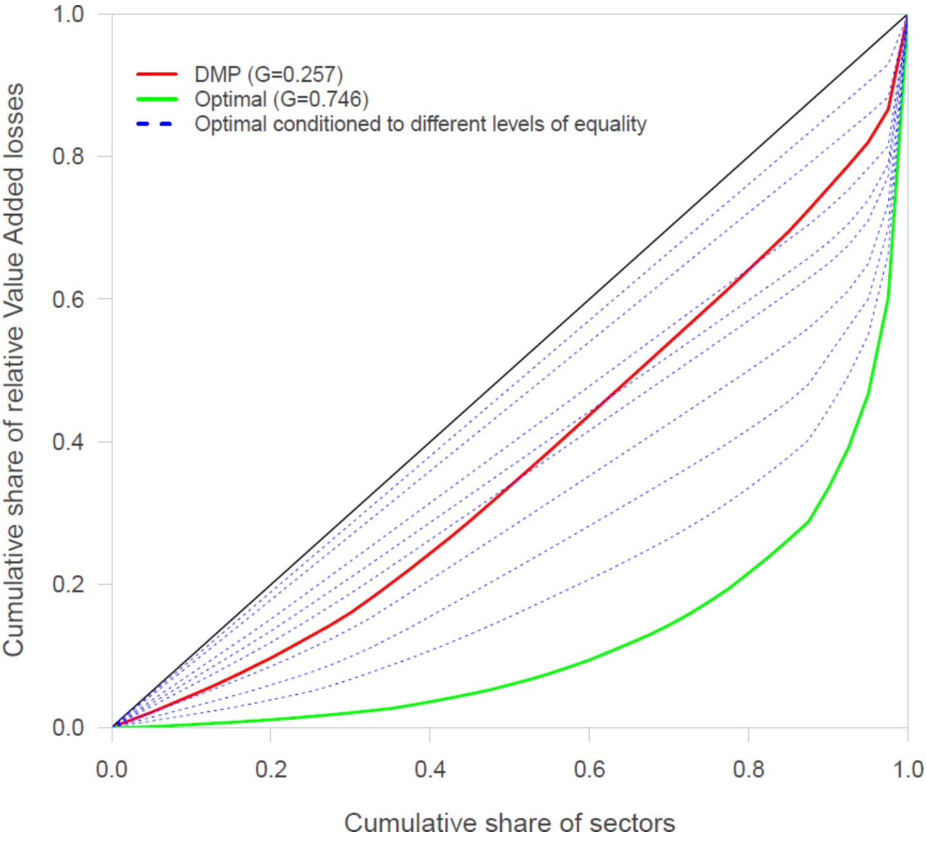

Fig. 7 Lorenz curves reflecting different efficiency-equality combinations under the second drought warning level

the aggregate economic loss on the Andalusian economy as a whole would be three times higher.

Zooming in on specific sectors (see Tables 7 and 8 in Appendix B), agricultural losses (sector i01) are stable regardless of the pursued objective (efficiency or equality). The impact on agricultural VA is always around − 14.7%, with losses decreasing slightly as the ambition to improve equality increases (Table 7 in Appendix B). Thus, equality concerns only marginally affect economic efficiency in the agricultural sector. As can be seen in Table 8 in Appendix B, as we take equality concerns into account, the amount of water withdrawn from agriculture does tend to decrease. On the contrary, most other sectors face increasingly negative economic impacts as the equality requirement increases, as shown in Table 7 in Appendix B. In these cases, there is a clear trade-off between efficiency and equality. Moreover, as we move from an equal to a less equal distribution of the economic impacts, the efficiency gains exhibit diminishing returns, i.e. smaller marginal increases in efficiency are observed for the same increments in inequality as the latter deteriorates further. Likewise, water withdrawn from these sectors is reduced as inequality increases (Table 8 in Appendix B).

The sectors related to the agri-food industry (i05 to i07) show a distinctive response as equality requirements are relaxed. At first, efficiency tends to increase as the Gini increases, but at a certain inequality level, there is a turning point where economic losses in these industries increase together with sectoral inequality. The same pattern can be observed in water allocation (Table 8 in Appendix B). Consequently, the trade-off between efficiency and equality holds for all economic sectors in Andalusia, except agriculture and the agri-food industry.

Finally, as explained in the previous section, the water allocations from the existing drought warning plans and the optimal estimated by the model induce different economic impacts to non-affected sectors and regions through interconnected supply chains. Hence, it is also interesting to assess whether these indirect impacts are equally distributed or not, that is, if an optimal allocation policy that minimizes the economic impact in the affected region results in an equal or unequal sectoral distribution of the impacts observed abroad. To address this issue, since the NLP model accounts for both losses and gains resulting from substitution possibilities in non-affected sectors and regions, we use the normalized Gini coefficient developed by Raffinetti et al. (2015), which allows the incorporation of both negative and positive values.[10] The results of this normalized coefficient for the non-affected regions under the two different allocation policies are reported in Table 9 in Appendix B. They show that an optimal allocation in the affected region may induce higher inequality in terms of distributional losses/gains across sectors in other regions. This is the clear case of Extremadura, whose normalized Gini value increases from 0.591 when the drought warning policies are implemented in Andalusia, to 0.709 if the latter were to allocate water optimally to minimize the overall economic impact, for the warning 2 level. Similarly, although in a smaller proportion, the regions of La Rioja, Castile and Leon, Asturias, Valencia and Madrid would also experience a worsening in the equality levels of the distribution of their sectoral economic impacts if Andalusia optimally reallocates water. These regions would present significantly less negative and more positive economic impacts if an optimal allocation is implemented in Andalusia, with the case of Extremadura being particularly relevant, as it would shift from an aggregate regional loss in VA of –0.02% (DMP allocation) to a gain of + 0.05% (optimal allocation) in the warning phase 2 level. However, the increase in

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[10] Note that with this normalized Gini coefficient, maximum inequality (values close to 1) can now also represent a situation in which one sector experiences substantial relative economic losses, whereas another sector experiences large relative economic gains.

inequality in the distribution of the sectoral impacts in these regions would respond to different patterns. On the one side, the explanation for Extremadura and Madrid lies in that, although most of their sectors would experience less negative economic impacts under the optimal allocation, due to a smaller disruption of the supply chains from the less-water-constrained sectors in the affected region, their agricultural production would slightly increase whereas their food industry sectors would continue to lose as much, leading to a more polarized situation in terms of the distribution of the impacts. This highlights the strong dependence the food industries in these regions have on Andalusian agriculture. On the other side, the slight rise in inequality in La Rioja, Castile and Leon, Asturias and Valencia would be mostly driven by the increases in agricultural and agrifood production as a result of the potential substitution capabilities of these regions for these sectors, whereas the rest of their sectors would experience smaller economic impacts. The results also indicate that for some regions, the implementation of the optimal allocation policy in Andalusia seems to induce a more equal distribution of impacts, although the improvements in the Gini coefficients in these cases are somewhat negligible.

5 Discussion

The modeling approach proposed in this paper provides a non-linear IO-based framework to explore and account for the tradeoff between efficiency and equality in water resources allocation. The methodological contribution of the study is that it optimizes water allocations whilst prioritizing a more equitable distribution of economic impacts, as measured by the Gini coefficient based on the relative value-added losses across different economic sectors. The results show that it is possible to define more efficient and equal water allocation policies than the ones already in place to deal with the impacts of water shortages, which is in line with the demands from international organizations that call for the improvement of current water allocation schemes to help address the challenges posed by economic development and climate change (OECD 2015a; UNECE 2021).

The model has broad applicability, as its flexibility allows for implementation in both single- and multi-regional frameworks, whether at national or regional scales. It can therefore be used in global multisectoral models, such as EXIOBASE, WIOD, and EORA, which have large geographical multi-country coverage and are coupled to extensive environmental accounts, including water. Similarly, it can also be implemented in existing subnational water use-extended MRIO models, such as the one for the Chinese economy (Zhao et al. 2021), the United States (Ingwersen et al. 2024), Canada (Garcia-Hernandez and Brouwer 2020; Eamen et al. 2020), Mexico (López-Morales and Duchin 2011, 2015), Australia (Islam et al. 2021) and Brazil (Munoz et al. 2017), among others. The only requirement is that water accounts are available and linked to the System of National Accounts. As indicated by Vardon et al. (2023), up to 78 countries have compiled water accounts. However, although their usefulness is widely recognized, water accounting has not yet been fully integrated in decision-making processes. There is furthermore a need to increase the number of countries compiling water accounts on a more regular basis. Raising awareness of and understanding the usefulness of water accounting for informing integrated water management policy is expected to encourage greater uptake by decision-makers and consequently support government agencies responsible for their compilation (Vardon et al. 2023). The proposed modeling approach and the simulation here serve as an example of the benefits of having readily available multi-sectoral models coupled to associated water accounts. The design of alternative adaptation strategies during drought situations shows that there are opportunities for significant cost savings, and in order to tap into these benefits, these models and their results need to be made available to policymakers.

Finally, while the present analysis focuses on identifying optimal allocation policies and assessing their distributional impacts in terms of sectoral and regional economic losses, it is also important to acknowledge that efficiency alone is not sufficient for successful water allocation. As highlighted by various authors (e.g. Babel et al. 2005; Ward 2022), water allocation policies must also be technically feasible and socially fair. Especially in regions with underdeveloped legal water management frameworks, the absence of a dedicated water management authority may create significant challenges in implementing efficient allocation policies. These regions often face systemic obstacles such as insufficient expertise and skills for data collection, ambiguous or overlapping responsibilities due to unclear regulatory structures, and weak mechanisms for monitoring, regulation, and enforcement, all of which hinder the implementation of efficient water management policies (Olagunju et al. 2019). Similarly, when water governance is shared among multiple institutions operating at different levels, the implementation of policies becomes more complex due to the need for coordination across these various levels of government. This issue is particularly critical in the context of transboundary river basins, where cooperation between countries or regions is essential. For example, Giordano et al. (2014) reviewed over 200 transboundary treaties and found that water allocation is a critical issue, with only 37% of the treaties including some form of water allocation mechanism. Baranyai (2019) also reviewed several bilateral and multilateral treaties for European river basins and found that, although some agreements include quantitative aspects, explicit rules for water allocation are often missing. In the few agreements where they are present, allocations are typically based on historical use rights rather than reflecting current needs or future water availability projections.

In addition, principles of social justice and fairness are advocated to guide the design of water allocation schemes (OECD 2015b). Allocating different percentages of water to various sectors based on their productive efficiency might lead to conflicts and opposition from the different water users, potentially entailing political costs such as loss of public support and the risk of losing votes (Wätzold and Drechsler 2005). Successful implementation of efficient water allocations requires thus engaging stakeholders to build consensus and support. By explicitly addressing the distribution of economic losses, the proposed approach can help improve trust and acceptance among water users, fostering a sense of fairness by ensuring that all relevant stakeholders are involved and no single group is disproportionately impacted. Our modeling approach can play a crucial role in providing a transparent basis for decision-making, offering clear guidance to support efficient allocation choices. The multisectoral nature of the model allows for capturing the interconnectedness of the entire economic system, optimizing not only the direct sectoral impacts resulting from the water shortages, but also the forward and backward impacts transmitted along the supply chains of the different economic activities. This transparency can help enhance stakeholder confidence and support for water management decisions and improve compliance with more efficient allocation regimes.

6 Conclusions

This paper presents a hybrid, nonlinear optimization model (Oosterhaven and Bouwmeester 2016) to assess the short-term economic impacts of a drought, modeling separately its effects on both green and blue water resources availability. Our approach adds to the existing literature by determining the economic optimal allocation of scarce water resources across economic sectors that minimizes the overall impact on GDP, while simultaneously addressing the (in)equal sectoral distribution of these impacts. The methodological novelty is that we identify the production possibility frontier of second-best optimal allocations that address both efficiency and equality concerns. This thus allows us to identify second-best water allocation policies that comply with predetermined water reduction requirements, as outlined in existing drought warning and emergency plans, and meet equality goals in terms of the distributional effects of the economic losses involved.

An application of the model to the Spanish region of Andalusia shows that significant economic gains can be achieved if water efficiency is taken into account when designing inter-sectoral water reallocation policies. Regardless of the water-stressed scenario, optimally allocating water across industries can significantly mitigate the economic impacts, with VA losses for the drought affected region up to three times lower than those that would occur under the measures foreseen in the drought contingency plans. The same pattern would be observed at national scale, with smaller negative effects on other regions if the drought-affected region efficiently reallocates water across sectors. The results of this study align with those of Koopman et al. (2017), who investigated the potential of water markets to mitigate the negative impacts of climate change using a CGE model for the Netherlands. Their analysis indicated that optimally reallocating water from agriculture to manufacturing could have positive effects on overall economic output. However, the results of both studies differ, as Koopman et al. (2017) found smaller changes in GDP when implementing optimal water allocation between sectors. These different results can be attributed to various factors, such as the use of different baseline scenarios (existing drought management policies in Spain compared to a uniform (equal) distribution of the water constraints in the Netherlands), the unique economic structures of the two countries, and the use of different macro-economic models.

Extending the analysis to incorporate equality concerns highlights that the optimal allocation that would minimize the overall economic impact in the short-term would result in a far more unequal distribution of these impacts (Gini coefficient equal to 0.746) than what would result from current drought contingency measures (Gini coefficient equal to 0.256). Hence, it is possible to mitigate the adverse economic impacts of a water shortage, but at the expense of more unequal allocations. Interestingly, the analysis also illustrates that based on existing drought warning and emergency plans, allocations lie outside the efficiency-equality frontier. In other words, there is an economically optimal water allocation that results in an equal distribution of the impacts as the one resulting from the implementation of the drought mitigation plans, yet with lower overall VA losses.

Finally, we also found significant economic gains in some regions due to the displacement of agricultural production to these areas. However, a drought affecting the Guadalquivir basin in Andalusia might also impact neighboring basins in other Spanish regions, potentially limiting the capacity of other agricultural areas to step in and compensate for part of the output loss. A detailed characterization of a widespread drought across the country could be modeled by assessing the extent to which the other regions may be affected by water constraints, as well as the application of the corresponding measures contained in each of the DMPs of the affected basins. In this case, less positive substitution effects would be expected to occur, as the production capacity of other regions and sectors would also be constrained because of the water shortages.

A number of simplifying assumptions have been made in this study. The MRIO model does not take into account any impact of drought conditions on water and output price levels. However, given the relatively low elasticity of demand for food products, the price increase in agricultural commodities is not expected to result in a much larger sectoral output shock, and a possible redistribution of agricultural activities across the country, which would affect the resulting inequality of the economic impact. However, technological changes might be induced by the higher water prices (e.g. improving irrigation efficiency). These adaptations have been shown to mitigate the impact of water scarcity on agricultural losses (Koopman et al. 2015). Given our focus on the short term and the used static MRIO modeling framework, these factors may not be fully reflected in the results. Despite these simplifying assumptions, the non-linear optimization approach presented here advances our understanding of the intricate interplay between efficiency and equality in water resource management and holds promise as a useful toolkit for the management of droughts in Spain and elsewhere. Its flexibility also allows for the inclusion of additional or alternative policy objectives. These may include social aspects, such as mitigating employment losses and their distribution across sectors, or environmental impacts, such as preserving environmental flows. These would be relevant extensions of the model, as employment concerns are always high on the political agenda and ecosystem demand for instream water is expected to increase as climate change exacerbates the frequency and severity of existing water shortages.

Appendix A

The Economic Model

The MRIO model considers all the economic interlinkages among industries and regions:

$$\mathbf{x} = \mathbf{Z}\mathbf{e} + \mathbf{Y}\mathbf{i} \tag{A.1}$$

where $\mathbf{x} = (x_i^r)$ is the vector rx$\,i$ of output, with x_i^r being the total output of industry i in region r, $\mathbf{Y} = (y_i^{rs})$ is the matrix of total final demand of regions, in which y_i^{rs} is the final demand for products of industry i in region r by region s and $\mathbf{Z} = \left[z_{ij}^{rs}\right]$ the multi-regional matrix of intermediate deliveries. Each representative element of $\mathbf{Z}$, z_{ij}^{rs}, informs on the volume of input i of region r that is used in the production of product j in region s. $\boldsymbol{e}$ and $\mathbf{i}$ are vectors of ones of dimensions rx$\,i$ and s, respectively.

Based on the MRIO table as defined in Eq (A.1), we apply the NLP model introduced by Oosterhaven and Bouwmeester (2016) to evaluate the direct and indirect economic impacts of different water allocation scenarios at sectoral level. The model simulates that, in the short run after a disruptive event, economic actors will try to return to their pre-established production and trade patterns as much as possible. This behavioral assumption is modeled by minimizing the difference in the information value between the post-event and pre-event economic transactions, where the latter, referred to as "ex", are taken from the original MRIO table as structured in (A.1):

$$
\begin{aligned}
Min \quad & \sum_{ij}^{rs}\left[z_{ij}^{rs}\left(\ln\frac{z_{ij}^{rs}}{z_{ij}^{rs,\ ex}}-1\right)+z_{ij}^{rs,\ ex}\right]+\sum_{i}^{rs}\left[y_{i}^{rs}\left(\ln\frac{y_{i}^{rs}}{y_{i}^{rs,\ ex}}-1\right)+y_{i}^{rs,\ ex}\right] \\
& +\sum_{j}^{s}\left[v_{j}^{s}\left(\ln\frac{v_{j}^{s}}{v_{j}^{s,\ ex}}-1\right)+v_{j}^{s,\ ex}\right]
\end{aligned}
\tag{A.2}
$$

where z_{ij}^{rs} denotes the flow of products from sector i in region r to be used as intermediate inputs by sector j in region s, y_i^{rs} is the final consumption of products of sector i in region r made by region s, and v_j^s is the VA generated by sector j in region s. This objective function is minimized subject to some baseline constraints. First, it is assumed that the economy remains in short-run equilibrium, that is, demand equals supply, per sector and region:

$$\sum_{js} z_{ij}^{rs} + \sum_{s} y_{i}^{rs} = x_{i}^{r}, \qquad \forall\ i, r \tag{A.3}$$

Second, it is assumed cost minimization under a Walrass-Leontief production function, per region and industry:

$$\sum_{r} z_{ij}^{rs} = a_{ij}^{*s} x_{j}^{s}, \qquad \forall\ i, j, s \tag{A.4}$$

$$v_{j}^{s} = c_{j}^{s} x_{j}^{s}, \qquad \forall\ j, s \tag{A.5}$$

where x_i^r is the total output of industry i in region r, a_{ij}^{*s} are the intermediate input coefficients (i.e., the intermediate inputs from sector i necessary to produce a unit of output j in region s, regardless of the region of origin) and c_j^s the coefficients determining the amount VA per unit of output. a_{ij}^{*s} and c_j^s are calculated from the original MRIO table as $a_{ij}^{*s} = \sum{}_{r} z_{ij}^{rs,\ ex}/x_j^{s,\ ex}$ and $c_j^s = v_j^{s,\ ex}/x_j^{s,\ ex}$, with $\sum{}_{i} a_{ij}^{*s} + c_j^s = 1\ \forall\ i, j$. Note that Eq. (A.4) does not allow for technology changes, but it includes the possibility of spatial substitution between inputs from one region for those from other regions. Third, the same assumption is used to model the composition of local final demand:

$$\sum_{r} y_{i}^{rs} = p_{i}^{*s} y^{s}, \qquad \forall\ i, s \tag{A.6}$$

where $y^s = \sum{}_{i}^{r} y_i^{rs}$ is the total final demand of region s and p_i^{*s} the coefficients that denote the need of products of industry i to meet the final demand of region s, regardless of the region of origin. These coefficients are also calculated from the original MRIO table as $p_i^{*s} = \sum{}_{r} y_i^{rs,\ ex}/y^{s,ex}$, with $\sum{}_{i} p_i^{*s} = 1\ \forall\ s$. Similar to Eq. (A.4), this constraint allows for spatial substitution between products from one region for those of other regions to meet the final demand. Finally, the last restriction imposes that all economic transactions must take semi-positive values:

$$z_{ij}^{rs},\ y_i^{rs},\ v_j^s \geq 0, \qquad \forall\ i, j, r, s \tag{A.7}$$

By solving (A.2) subject to (A.3–A.7) the model returns the actual values of the baseline MRIO tables.

Appendix B

See Tables 4, 5, 6, 7, 8 and 9.

Table 4 Water restrictions defined in the DMP of the Guadalquivir river basin

		Measures (restrictions) during warning phase		
UTE*		Urban	Industry	Irrigated agriculture
UTE 0101	Guadiamar		Up to 5% (energy production)	
UTE 0102	Madre de las Marismas	Up to 5%		Between 25–50%
UTE 0201	Rivera de Huelva	Up to 5%		
UTE 0202	Rivera de Huesna	Up to 5%		
UTE 0301	Abastecimiento de Córdoba	Up to 5%		
UTE 0401	Abastecimiento de Jaén	Up to 5%		
UTE 0501	Hoya de Guadix	Up to 5%		
UTE 0601	Bermejales	Up to 5%		
UTE 0602	Vega Alta y Media de Granada	Up to 5%		
UTE 0603	Vega Baja de Granada	Up to 5%		
UTE 0701	General Regulation	Up to 5%	Up to 5%	From 17.4–61.4%**
UTE 0702	Dañador	Up to 5%		
UTE 0703	Aguascebas	Up to 5%		
UTE 0704	Fresneda	Up to 5%		
UTE 0705	Martín Gonzalo	Up to 5%		
UTE 0706	Montoro-Puertollano	Up to 5%	Up to 5%	
UTE 0707	Sierra Boyera	Up to 5%		
UTE 0708	Viar			
UTE 0709	Rumblar	Up to 5%		
UTE 0710	Guadalentín	Up to 5%		
UTE 0711	Guardal			
UTE 0801	Bembézar-Retortillo	Up to 5%		

Note: *UTE stands for "Unidades Territoriales de Escasez", which translates as Territorial Water Scarcity Units. These smaller units of management are the ones responsible for the assessment of their own drought situation (according to their own drought indicator) and the implementation of the corresponding measures defined in the DMP. **These percentages have been estimated based on the proposed water discharges defined in the DMP. **Source**: (CHG 2018)

Table 5 Output-water elasticities

Sector		Elasticity	MRIO sectors
1	Agriculture	0.620	i01
2	Mining, energy, water supply and waste management	0.758	i02-i04
3	Food, beverages and tobacco	0.763	i05-i08
4	Textiles, wearing apparel, leather and related products	0.813	i09
5	Wood and cork, paper and graphic arts	0.758	i10,i11
6	Manufacture of chemical and pharmaceutical products	0.752	i12
7	Manufacture of rubber, plastics products and other non-metallic mineral products	0.775	i13,i14
8	Manufacture of basic metals and fabricated metal products, except machinery and equipment	1.408	i15,i16
9	Manufacture of computer, electrical, electronic and optical products	1.351	i18
10	Manufacture of machinery and equipment	0.833	i17
11	Manufacture of transport equipment	0.671	i19
12	Other manufacturing, repair and installation of machinery and equipment	0.658	i20,i22
13	Construction	0.388	i21
14	Wholesale and retail trade	1.316	i23,i24
15	Accommodation and food service activities	1.613	i25,i26
16	Financial and insurance activities	0.186	i30,i31
17	Real estate activities	0.467	i32,i33
18	Human health and social work activities	1.111	i36,i38
19	Arts, entertainment and recreation	1.149	i37
20	Other service activities	0.885	i27-29,i34,i35,i39,i40

Source: the elasticity value for agriculture (1) has been obtained from Berbel et al. (2011), elasticities for manufacturing industries (2–13) from Gracia-de-Rentería et al. (2019) and for the service sectors (14–20) from Gracia-de-Rentería et al. (2021)

Table 6 Distribution of VA and blue water consumption among andalusian sectors in the original data

Industry	Sector	VA base	Blue water
i01	Agriculture, livestock, hunting, fishing and related services	5.87%	69.81%
i02	Extraction of energy products and refining	1.37%	0.49%
i03	Production and distribution of electricity and gas	1.31%	1.53%
i04	Water collection, treatment and distribution	0.66%	7.20%
i05	Meat industry	0.43%	0.08%
i06	Dairy industry	0.14%	0.06%
i07	Other food industries	0.04%	0.08%
i08	Beverage and tobacco processing	1.49%	0.44%
i09	Textile, clothing and leather industry	0.46%	0.04%
i10	Wood and cork industry	0.25%	0.89%
i11	Paper and printing industry	0.60%	0.73%
i12	Chemical industry	1.49%	6.75%
i13	Rubber and plastics industry	0.31%	1.44%
i14	Non-metallic minerals	1.20%	1.11%
i15	Metallurgy	0.48%	0.05%
i16	Manufacture of metal products	1.10%	1.62%
i17	Machinery and mechanical equipment	0.56%	0.01%
i18	Manufacture of computer, electronic and optical products	0.47%	0.24%
i19	Manufacture of motor vehicles and other transport equipment	0.74%	0.20%
i20	Furniture and other manufacturing industries	0.74%	0.13%
i21	Construction	13.38%	0.26%
i22	Sale and repair of motor vehicles; motor fuel trade	1.80%	0.01%
i23	Wholesale trade and intermediaries	3.62%	0.35%
i24	Retail trade; repair of personal effects	5.72%	0.42%
i25	Hospitality	1.12%	0.35%
i26	Restaurants	4.89%	2.66%
i27	Transport	2.82%	0.36%
i28	Activities ancillary to transport	1.18%	0.18%
i29	Post and telecommunications	1.94%	0.22%
i30	Financial intermediation and support activities	3.36%	0.02%
i31	Insurance and pension funding	0.55%	0.01%
i32	Real estate and related activities	10.53%	0.14%
i33	Rental and leasing activities, computing and R&D activities	1.20%	0.10%
i34	Other business activities	5.17%	0.40%
i35	Education	5.32%	0.25%
i36	Health, sanitation and social work activities	7.19%	0.38%
i37	Arts, entertainment and recreation	2.44%	0.00%
i38	Miscellaneous personal service activities	0.53%	0.00%
i39	Public administration	6.63%	0.92%
i40	Households employing domestic staff	0.92%	0.07%

Table 7 Sectoral VA change in Andalusia conditioned to different levels of equality

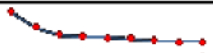
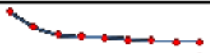
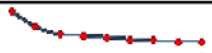
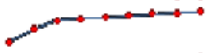
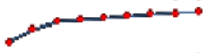
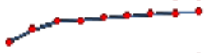
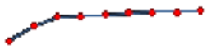
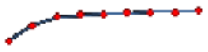
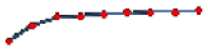
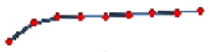
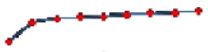
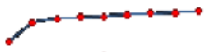
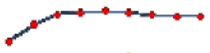
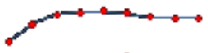
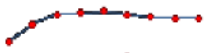
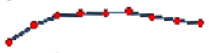
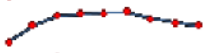
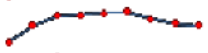
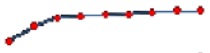
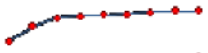
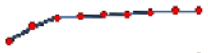
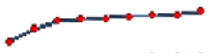
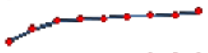
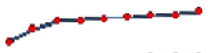
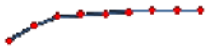
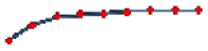
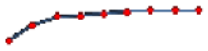
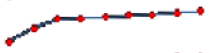
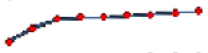
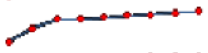
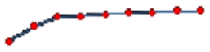
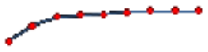
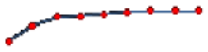
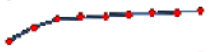
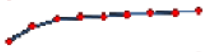
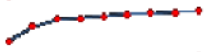
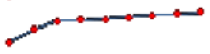
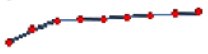
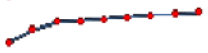
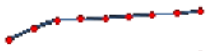
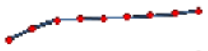
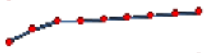
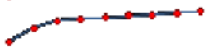
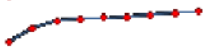
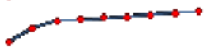
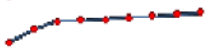
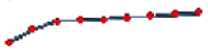
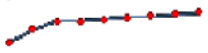
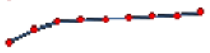
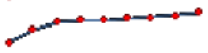
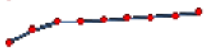
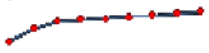
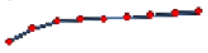
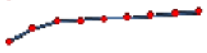
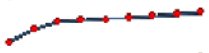
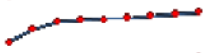
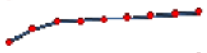
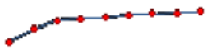
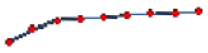
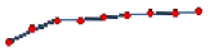
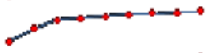
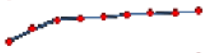
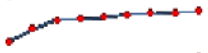
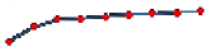
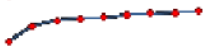
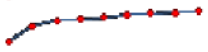
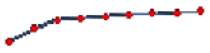
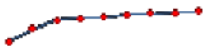
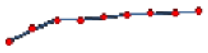
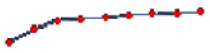
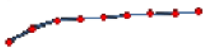
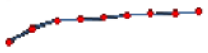
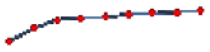
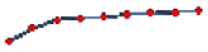
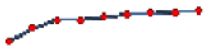
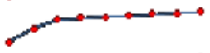
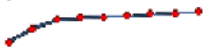
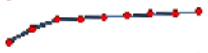
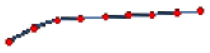
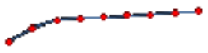
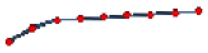
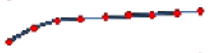
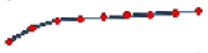
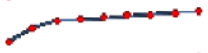
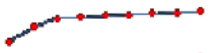
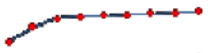
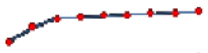
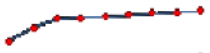
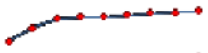
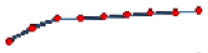
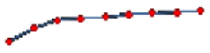
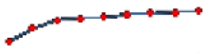
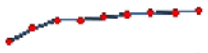
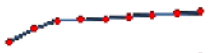
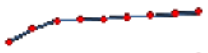
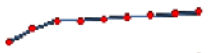
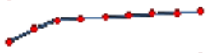
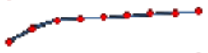
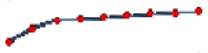
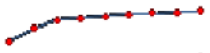
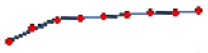
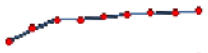
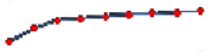
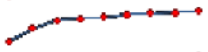
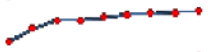
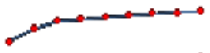
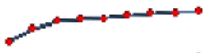
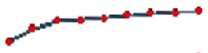
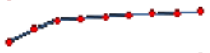
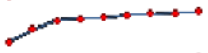
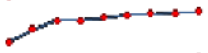
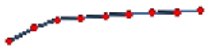
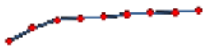
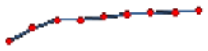
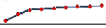
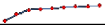
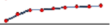
Industry	Warning 1		Warning 2		Warning 3	
	Gini [<=0.05, <=0.749]	Graph	Gini [<=0.05, <=0.746]	Graph	Gini [<=0.05, <=0.745]	Graph
i01	[-4.78 , -4.84]		[-14.61 , -14.76]		[-19.65 , -19.85]	
i02	[-1.73 , -0.03]		[-4.90 , -0.10]		[-6.53 , -0.14]	
i03	[-1.74 , -0.26]		[-4.91 , -0.82]		[-6.54 , -1.11]	
i04	[-1.74 , -0.57]		[-4.92 , -1.75]		[-6.54 , -2.36]	
i05	[-1.74 , -0.66]		[-4.91 , -2.09]		[-6.54 , -2.85]	
i06	[-1.74 , -0.91]		[-4.91 , -2.81]		[-6.54 , -3.80]	
i07	[-1.74 , -1.60]		[-4.91 , -4.97]		[-6.54 , -6.75]	
i08	[-1.74 , -0.21]		[-4.91 , -0.64]		[-6.53 , -0.87]	
i09	[-1.74 , -0.05]		[-4.91 , -0.17]		[-6.54 , -0.23]	
i10	[-1.74 , -0.29]		[-4.91 , -0.90]		[-6.54 , -1.22]	
i11	[-1.74 , -0.14]		[-4.91 , -0.42]		[-6.54 , -0.58]	
i12	[-1.74 , -0.26]		[-4.91 , -0.82]		[-6.54 , -1.13]	
i13	[-1.74 , -0.18]		[-4.91 , -0.57]		[-6.54 , -0.78]	
i14	[-1.74 , -0.06]		[-4.91 , -0.19]		[-6.54 , -0.25]	
i15	[-1.74 , 0.00]		[-4.91 , 0.00]		[-6.54 , 0.00]	
i16	[-1.74 , -0.10]		[-4.91 , -0.31]		[-6.54 , -0.42]	
i17	[-1.74 , -0.06]		[-4.91 , -0.20]		[-6.54 , -0.27]	
i18	[-1.74 , -0.01]		[-4.91 , -0.03]		[-6.54 , -0.05]	
i19	[-1.74 , -0.03]		[-4.91 , -0.09]		[-6.54 , -0.12]	
i20	[-1.74 , -0.02]		[-4.91 , -0.07]		[-6.54 , -0.10]	
i21	[-1.73 , -0.04]		[-4.91 , -0.11]		[-6.55 , -0.15]	
i22	[-1.80 , -0.17]		[-5.11 , -0.51]		[-6.81 , -0.69]	
i23	[-1.74 , -0.30]		[-4.91 , -0.93]		[-6.54 , -1.25]	
i24	[-1.72 , -0.02]		[-4.88 , -0.06]		[-6.51 , -0.08]	
i25	[-1.74 , -0.09]		[-4.92 , -0.27]		[-6.55 , -0.37]	
i26	[-1.72 , -0.02]		[-4.89 , -0.08]		[-6.51 , -0.10]	
i27	[-1.73 , -0.14]		[-4.90 , -0.45]		[-6.53 , -0.61]	
i28	[-1.74 , -0.11]		[-4.91 , -0.34]		[-6.54 , -0.46]	
i29	[-1.74 , -0.12]		[-4.91 , -0.36]		[-6.54 , -0.49]	
i30	[-1.74 , -0.22]		[-4.91 , -0.69]		[-6.54 , -0.93]	
i31	[-1.74 , -0.14]		[-4.91 , -0.43]		[-6.54 , -0.59]	
i32	[-1.72 , -0.03]		[-4.89 , -0.09]		[-6.52 , -0.12]	
i33	[-1.74 , -0.07]		[-4.91 , -0.22]		[-6.54 , -0.30]	
i34	[-1.73 , -0.09]		[-4.90 , -0.27]		[-6.53 , -0.37]	
i35	[-1.73 , -0.02]		[-4.90 , -0.07]		[-6.52 , -0.09]	
i36	[-1.75 , -0.07]		[-4.98 , -0.21]		[-6.63 , -0.28]	
i37	[-1.74 , -0.03]		[-4.91 , -0.11]		[-6.53 , -0.15]	
i38	[-1.72 , -0.02]		[-4.88 , -0.06]		[-6.51 , -0.08]	
i39	[-1.72 , -0.02]		[-4.88 , -0.05]		[-6.51 , -0.07]	
i40	[-1.72 , -0.02]		[-4.88 , -0.05]		[-6.51 , -0.07]	

Table 8 Sectoral change in water allocation in Andalusia conditioned to different levels of equality

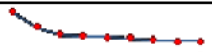
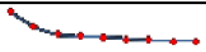
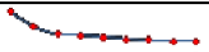
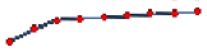
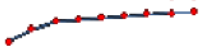
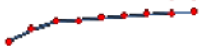
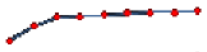
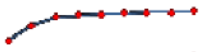
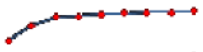
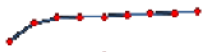
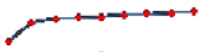
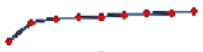
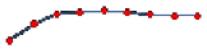
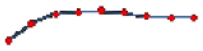
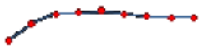
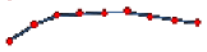
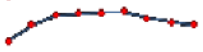
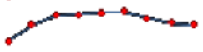
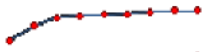
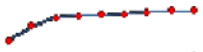
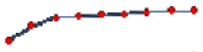
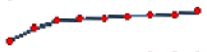
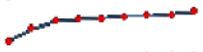
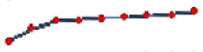
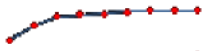
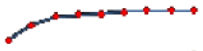
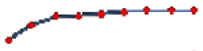
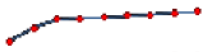
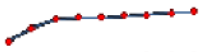
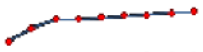
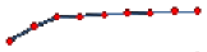
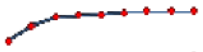
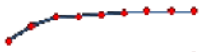
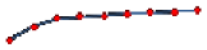
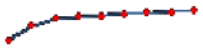
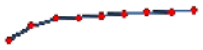
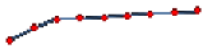
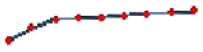
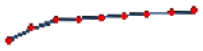
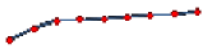
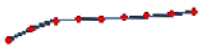
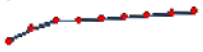
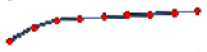
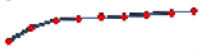
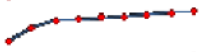
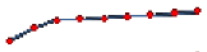
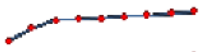
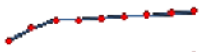
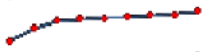
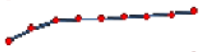
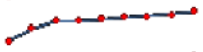
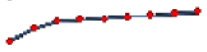
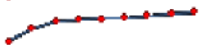
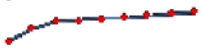
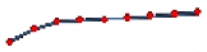
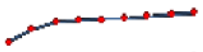
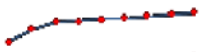
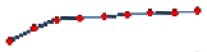
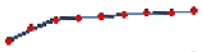
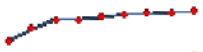
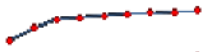
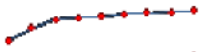
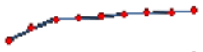
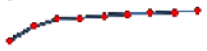
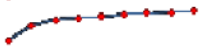
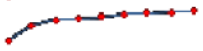
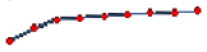
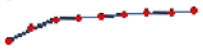
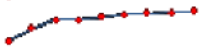
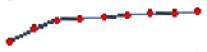
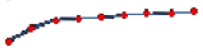
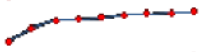
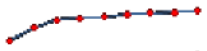
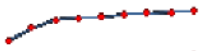
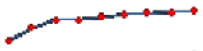
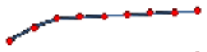
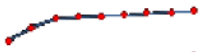
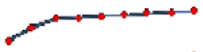
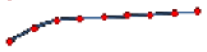
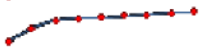
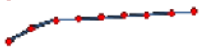
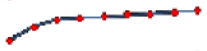
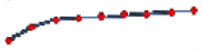
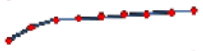
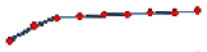
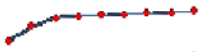
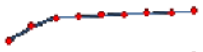
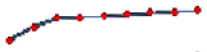
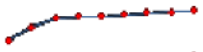
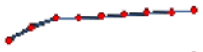
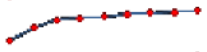
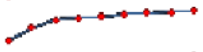
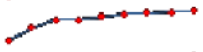
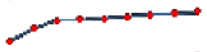
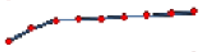
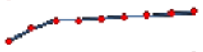
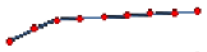
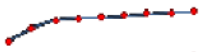
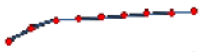
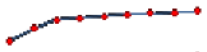
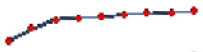
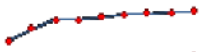
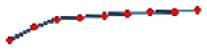
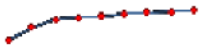
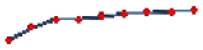
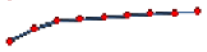
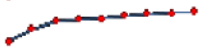
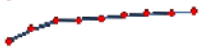
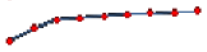
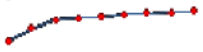
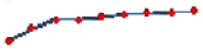
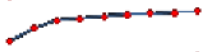
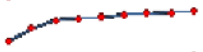
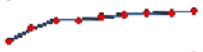
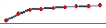
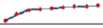
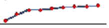
Industry	Warning 1		Warning 2		Warning 3	
	Gini [<=0.05, <=0.749]	Graph	Gini [<=0.05, <=0.746]	Graph	Gini [<=0.05, <=0.745]	Graph
i01	[-15.58 , -17.67]		[-25.47 , -31.26]		[-55.37 , -63.05]	
i02	[-4.01 , -0.08]		[-11.36 , -0.23]		[-15.13 , -0.32]	
i03	[-3.83 , -0.58]		[-10.82 , -1.80]		[-14.41 , -2.44]	
i04	[-4.37 , -1.43]		[-12.34 , -4.38]		[-16.43 , -5.91]	
i05	[-3.65 , -1.39]		[-10.31 , -4.38]		[-13.73 , -5.98]	
i06	[-3.65 , -1.90]		[-10.31 , -5.90]		[-13.73 , -7.99]	
i07	[-3.65 , -3.36]		[-10.31 , -10.44]		[-13.73 , -14.17]	
i08	[-4.14 , -0.49]		[-11.70 , -1.53]		[-15.59 , -2.09]	
i09	[-3.79 , -0.11]		[-10.72 , -0.36]		[-14.28 , -0.50]	
i10	[-4.33 , -0.72]		[-12.23 , -2.24]		[-16.29 , -3.05]	
i11	[-4.01 , -0.31]		[-11.34 , -0.98]		[-15.10 , -1.33]	
i12	[-4.01 , -0.60]		[-11.32 , -1.90]		[-15.08 , -2.60]	
i13	[-3.97 , -0.41]		[-11.22 , -1.30]		[-14.94 , -1.78]	
i14	[-4.04 , -0.14]		[-11.40 , -0.43]		[-15.19 , -0.59]	
i15	[-2.15 , 0.00]		[-6.07 , 0.00]		[-8.08 , 0.00]	
i16	[-2.24 , -0.13]		[-6.34 , -0.40]		[-8.44 , -0.54]	
i17	[-3.70 , -0.13]		[-10.46 , -0.42]		[-13.94 , -0.57]	
i18	[-2.30 , -0.01]		[-6.49 , -0.05]		[-8.64 , -0.06]	
i19	[-4.72 , -0.08]		[-13.35 , -0.25]		[-17.78 , -0.33]	
i20	[-4.80 , -0.06]		[-13.55 , -0.20]		[-18.05 , -0.28]	
i21	[-7.70 , -0.16]		[-21.83 , -0.50]		[-29.09 , -0.68]	
i22	[-4.86 , -0.45]		[-13.84 , -1.38]		[-18.45 , -1.86]	
i23	[-2.30 , -0.40]		[-6.50 , -1.23]		[-8.65 , -1.66]	
i24	[-2.23 , -0.02]		[-6.33 , -0.08]		[-8.44 , -0.11]	
i25	[-1.92 , -0.10]		[-5.43 , -0.30]		[-7.23 , -0.40]	
i26	[-1.86 , -0.03]		[-5.27 , -0.08]		[-7.03 , -0.11]	
i27	[-3.43 , -0.29]		[-9.71 , -0.88]		[-12.93 , -1.20]	
i28	[-3.44 , -0.22]		[-9.72 , -0.68]		[-12.95 , -0.92]	
i29	[-3.37 , -0.23]		[-9.51 , -0.70]		[-12.67 , -0.95]	
i30	[-16.46 , -2.11]		[-46.50 , -6.49]		[-61.94 , -8.77]	
i31	[-16.45 , -1.33]		[-46.45 , -4.10]		[-61.87 , -5.54]	
i32	[-6.48 , -0.11]		[-18.37 , -0.34]		[-24.49 , -0.46]	
i33	[-6.53 , -0.26]		[-18.44 , -0.82]		[-24.56 , -1.11]	
i34	[-3.44 , -0.17]		[-9.73 , -0.53]		[-12.96 , -0.73]	
i35	[-3.41 , -0.04]		[-9.67 , -0.13]		[-12.89 , -0.19]	
i36	[-2.70 , -0.10]		[-7.68 , -0.32]		[-10.24 , -0.43]	
i37	[0.00 , 0.00]		[0.00 , 0.00]		[0.00 , 0.00]	
i38	[0.00 , 0.00]		[0.00 , 0.00]		[0.00 , 0.00]	
i39	[-3.45 , -0.03]		[-9.78 , -0.10]		[-13.03 , -0.15]	
i40	[-3.36 , -0.03]		[-9.54 , -0.10]		[-12.71 , -0.14]	

Table 9 Normalized Gini coefficients for the non-affected regions based on the relative value-added losses and gains of the different sectors for both the DMP and optimal allocations implemented in Andalusia

Region	Warning 1		Warning 2		Warning 3	
	DMP	Optimal	DMP	Optimal	DMP	Optimal
Aragon	0.680	0.694	0.680	0.694	0.687	0.694
Asturias	0.712	0.764	0.715	0.760	0.697	0.760
Balearic Islands	0.787	0.797	0.786	0.794	0.786	0.795
Cantabria	0.790	0.813	0.789	0.807	0.778	0.807
Canary Islands	0.867	0.832	0.866	0.831	0.858	0.831
Catalonia	0.670	0.690	0.670	0.690	0.676	0.690
Castilla-La Mancha	0.705	0.745	0.708	0.748	0.706	0.750
Castile and Leon	0.763	0.820	0.765	0.819	0.751	0.820
Extremadura	0.589	0.704	0.591	0.709	0.590	0.711
Galicia	0.747	0.780	0.749	0.783	0.750	0.784
La Rioja	0.750	0.818	0.751	0.817	0.738	0.818
Madrid	0.643	0.686	0.644	0.686	0.642	0.687
Murcia, Ceuta and Melilla	0.718	0.695	0.716	0.695	0.725	0.695
Navarre	0.708	0.699	0.706	0.697	0.719	0.699
Basque Country	0.648	0.682	0.649	0.683	0.660	0.684
Valencia	0.611	0.662	0.613	0.665	0.618	0.667
European Union	0.654	0.684	0.656	0.685	0.661	0.685
Rest of the World	0.791	0.757	0.790	0.758	0.805	0.758

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