R9 Land, water and energy: the crossing of governance

ABSTRACT

The paper focusses on the impact on dryland ecosystems of conflicting governance in the regulations of land use, water for irrigation and electric energy from photovoltaic installations (PV). The research uses the empirical results of a panel data model based on long time series that enable sensitivity of the main crops to energy cost and the viability of the solar panel system connected to the grid to be identified. We present evidence of the private and social benefits of investments in PV to improve the gross margin of farmers and decrease the carbon footprint of the irrigated areas. Relevant regional disparities in the sensitivity of the main crops explain the regional competition for low-cost water resources and the social conflicts associated with water governance. The Feed-In Tariff system for a PV system is evaluated as a tool to reach clean energy targets and preserve the populations working and living in irrigated drylands. An evaluation of the water desalination plants based on PV is analysed as an alternative to balance the hydric resources of intensive irrigated systems. The main conclusion is that coordinated regulation in energy and water policies may improve farmers' profitability and accelerate the speed in reaching environmental targets in drylands.

Keywords: Irrigation, water resources regulation, renewable energy, water price, agricultural electric FiT tariffs, photovoltaic systems, profitability of irrigated crops, adaptation to climate change, regional disparities in crops gross margin.

INTRODUCTION

The paper focusses on the conflictive relationship between regulations for the electricity market and those for water resources and the consequences it has had on irrigated agriculture as the leading consumer of water and the second leading consumer of energy at the national level. It also assesses the economic viability of grid-connected photovoltaic installations for irrigation in different environmental conditions, using a profit function model estimated for a representative sample of Spanish farms.

Our research includes the main crops in all the regions of Spain. To our knowledge, there is scant research on the profitability of investment in photovoltaic installations for the primary type of crops that include all the regions using the same methodology. Our approach allows us to assess the cases in which a photovoltaic installation at market price becomes attractive to the private sector, distinguishing between the different crops and regions where this clean technology may require a Pigouvian subsidy.

First, the paper explains how the clash between energy and water regulations, especially during the period when the European Commission liberalised the electricity sector, has affected the process of clean and competitive energy system enhancement. Second, we present the fixed effects panel data model of the profit function for the photovoltaic (PV) irrigation system. Third, we present the empirical results regarding the viability of PV and the disparities by crop in each region. Finally, we present the conclusions.

MOTIVATION

Farmers initially began to irrigate land in order to increase productivity for the growing demand for food fueled by population expansion. Early on, irrigation technology became critical to ensuring production in the cultivated areas of drylands. The transformation of rainfed into irrigated land represents the primary driver of land-use change, and the paper focusses on the economic (energy price versus water price) and regulatory changes that affect the speed of land-use changes.

The Spanish regions present agricultural diversity systems, dominated by drylands except for the north and northwestern regions. In most regions, the irrigated area is expanding, and climate change is accelerating this process. Adaptation to warmer average temperatures, more frequent droughts and more frequent extreme weather events means that farmers try to switch crops to preserve land gross margins (and hence farm profitability). Frequently, adaptation includes newly irrigated areas, even in traditionally rainfed crops, increasing pressure on water resources.

Traditionally, the dominant method had been superficial irrigation, where water is distributed by gravity through channels or flooding, which is very water-intensive. As irrigated areas increased, and the surface sources for water collection were scarce, groundwater from wells and boreholes began to be pumped, first mechanically and then also electrically. Productivity improvement has led to the development of sprinkler and drip irrigation systems since electric pumps can guarantee the pressure required for the operation of sprinklers, which means higher energy consumption for irrigation.

Among all the productive sectors (including urban water supply services), agriculture is the leading consumer of water. “Modern irrigation”, that is, of areas improved by the national irrigation plans, in the current state of the technology allows water and energy to be substitutable inputs to a certain degree. The primary outcome of “modernisation” used to be saving water at the cost of using more energy. However, with unstable energy prices, productivity not only means “crop per drop” but “crop per watt and drop”.

Climate change means that cultivation techniques must adapt to an increasingly drier and warmer climate. In this context of climate change, adaptation, which is already taking place, consists of moving crops towards more favourable locations. In addition, this is complemented by using plant varieties that are more resistant to drought (through genetic selection and modification) along with increasingly frequent use of irrigation with pressurised pipes, which entails higher energy expenditure — the opposite of traditional gravity irrigation that is intensive in water consumption but low in energy consumption. A side output of this technology is to better ensure productivity levels against the increasing volatility of rainfall.

This adaptation implies that certain shrubby crop areas, traditionally considered to be rainfed, have become the most extensively irrigated areas, such as olive groves and vineyards (Resco Sánchez, 2015; Ponti et al. 2014 and ESYRCE, 2019). In the modernised irrigation of the southern region (Andalusia), the main item in management, operation and maintenance (MOM) costs is energy, representing between 40% and approximately 65% in extreme situations. The so-called *modernisation of irrigation* also means permanently replacing water and labour with energy (Rodríguez-Díaz et al., 2011a and 2011b).

Until the electricity market liberalisation, power for irrigation enjoyed a lower tariff, which was called the R rate. Since the liberalisation of the energy market, the electricity bill of irrigators become substantially higher. The economic productivity of certain crops has deteriorated because of the evolution of the ratio input price/output price.

According to the national report on irrigation areas, crop and yields (ESYRCE, 2019), irrigated area has continued to grow in recent years, with 387,785 hectares more in 2018 than in 2005. Simultaneously, the reduction in the surface of irrigation by gravity can be attributed fundamentally to the modernisation plans for irrigation carried out during this period. These plans have produced a significant increase in energy consumption for the new irrigation systems.

Those who have reaped most benefit from the foregoing are the electricity companies, for whom irrigated agriculture is a new captive customer in need of enormous amounts of electricity to keep crops going after modernisation. These modernisation projects have contributed significantly to a much higher consumption of energy by irrigated agriculture, with a twenty-fold increase from 1950 to 2017. Irrigation is the second leading consumer of electricity, just behind ADIF, the managing company for the national railway infrastructure (González-Cebollada, 2015).

Berbel et al. (2018), based on updated Corominas (2010) data, illustrate the macro-scale evolution of the water-energy binomial, in terms of water withdrawals and energy consumption, confirming that between 2007 and 2013 the tendency to reduce the use of water continues. Moreover, there is a small decrease in energy consumption per hectare since 2013 but with later stabilisation (See Figure 1). This reduction is attributable to both the increase in electricity rates and the economic crisis. Moreover, from 2010 to 2014, energy costs have approximately doubled in the Castile-La Mancha, a region situated on a high plateau in the central Iberian Peninsula, focussed on cereals, vineyards and olive groves.

Optimisation of water-energy resources, which may guarantee sustainability in the medium and long term, is a relevant issue. A solution for this problem is “simultaneous operation” consisting in an assisted PV plant, meaning that it is connected to the grid. Hence, part of the power comes from the photovoltaic generator and the rest, to cover the needs of the irrigation system during consumption peaks, comes from the grid (Tarjuelo et al. 2015. p. 72). This introduction of alternative sources of renewable energy may be a significant source of reduction in unit energy costs for farmers, so we attempt to identify the relevant cases.

Our research estimates a panel data model of profit function for photovoltaic installations by the main irrigated crops aimed at examining the differential gross margin elasticities by regions. Our paper fine-tunes the fact that in the different geographical areas, investment in photovoltaic technology for irrigation may be profitable at the current market price, depending on the crop. We include the six most extended irrigated crops: corn, wheat, barley, vegetables, citrus and olive.

We test for which crop and in which region the installation of photovoltaic-assisted technology is beneficial for private investors versus the cases for which a Pigouvian subsidy will be required.

The added value offered by our research is that, to our knowledge, a study of this type is not available for the whole Spanish territory. This may allow better assessment of the regulatory changes necessary in both the water and energy norms to facilitate the introduction of clean energy.

PHOTOVOLTAIC ENERGY IN AGRICULTURE

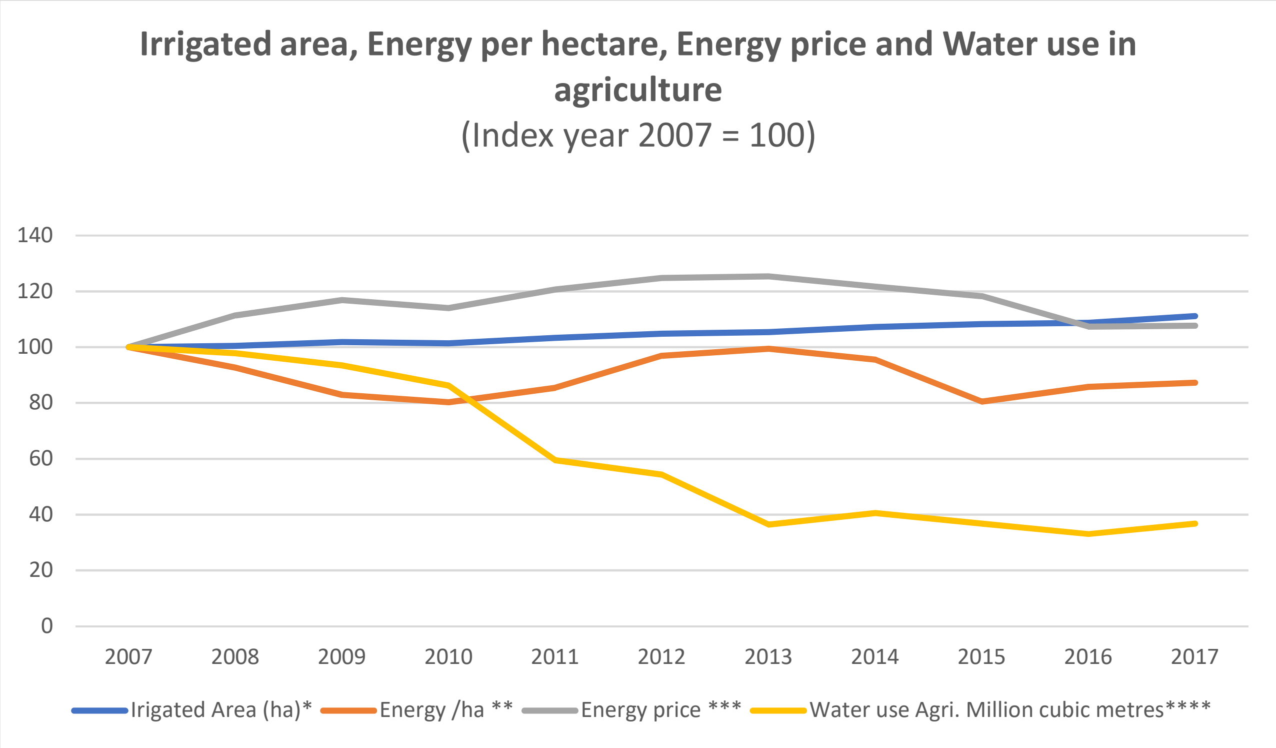
Irrigated agriculture is the most productive type, and it has enabled the Spanish agricultural export sector to become a reference in Europe, especially for fruit and vegetable productions. Drip and sprinkler irrigation has allowed producers to have more precise control over their water consumption. Water is a very scarce resource in some export areas, so conserving its use is critical. Accordingly, farmers adapting to more frequent droughts have turned to exploiting underground aquifers.

The price of electric energy and fossil fuel has followed a markedly increasing trend in recent years, which has resulted in a situation where much of the water costs stem from energy consumption. Energy consumption is one of the most significant inputs of irrigated crops.

Renewable energies have begun to play an essential role in alleviating problems of profitability as well as those of an environmental type. This is the case for photovoltaic solar energy, which has simultaneously reduced the irrigation systems' carbon footprint and the PV installation costs in recent decades due to technological progress in solar panel production. This type of irrigation provides a rational alternative to improve the efficient use of water and reduce energy emissions. It enables the pumping and electrical systems of a farm's irrigation facility to be powered by connecting solar panels to the grid to recover electricity not consumed in the irrigation system. When the regulatory framework allows the sale of reactive energy to the grid, a farmer's profitability improves at the same time that clean energy is added to the grid. Nevertheless, the final balance depends on the tariffs regulated to supply solar energy to the grid or the feed-in tariff, FiT.

On the one hand, solar radiation and crop evapotranspiration follow parallel curves. In other words, solar is an ideal source of energy for irrigation since it will be available just when a plant needs water. On the other hand, the significant reduction in the cost of solar panels in recent decades, currently around 0.4 €/W, makes its cost-competitive compared to other clean and conventional energy sources. Consequently, photovoltaic solar energy currently represents an option with great potential in the Mediterranean area, where the levels of solar irradiance throughout the year are high (See Figure 1).

Figure 1 ***Irrigated Area, Energy per hectare, Energy price and Water use in agriculture***



Source: Own elaboration, as explained in the text

REGULATION

In 2008, due to the liberalisation of the energy market and the consequent elimination of the special R rates for irrigation, farmers experienced a 400% increase in energy costs (Tarjuelo et al. 2015). These R rates were of great importance for a sector characterised mainly by its power consumption seasonality, since there is a high demand for power in the summer, but not the rest of the months of the year.

However, Law 1/2018 of *Urgent Measures Against Drought*, seems to have brought potentially significant changes. Its *Final Provision 3* stipulates that the irrigators will from now on be able to contract two different types of power throughout the year depending on the needs of each farmer: Resulting in a low power tariff for winter when irrigation is not required and a high-power tariff when the irrigation system is at full capacity, aiming to reduce the yearly power cost. However, this option is still pending regulatory development, and therefore, is not currently in effect.

An alternative way to ensure the introduction of clean technology even when the resulting monetary balance is negative for farmers is the enforcement of a FiT schedule. Feed-in Tariff (FiT) is the scheme by which farms or businesses that generate electricity from renewable sources receive compensation for the excess energy generated that is exported to the grid.

The capacity factor is simply the ratio of actual energy (KWh) generation over a period (typically a year) divided by the installed capacity (Barber, 2017). Solar PV installations have a capacity factor that ranges from 10% to 25% depending on the location. In southern Spain, with full tracking of solar movement, the capacity factor may reach 30% (Sheehy, 2017).

However, the European Union regulatory reforms remain trapped in the so-called “energy trilemma”: affordability, security and the environment (Pollitt, 2019).
Moreover, the liberalisation of the electric market led to higher power tariff for irrigators. Thus, given that electrical power accounts for 40% of modernised irrigation costs, farmers have experienced a profitability crisis due to the considerable rise in the cost of electricity that they have had to face (Rodríguez-Díaz et al. 2011b).

Irrigators have likewise suffered the consequences of the delay in PV development due primarily to the instability of photovoltaic energy policy in recent decades in Spain, which has been very changeable. Spain was among the top five EU countries in PV capacity installed (over 3.3 GW in 2008). However, the former Spanish government began changing the regulation to limit the growth of the photovoltaic sector and in January 2012 suspended the remuneration pre-assignment procedure for new renewable energy power. As a consequence, at present, only around 16% of the energy consumed is from a renewable source, while the Commission has set its target for 2020 at 20%. After a new government, the last change in the regulation took place, and new PV systems have reached 262 MWAC, with total capacity at 580 GWh (2018), contributing to 3% of overall generation (Jäger-Waldau, 2019).

According to the current regulation, depending on the period, being connected to the grid has been a profitable alternative or not for a photovoltaic irrigation system. In the 1998 regulation (R. D. 2818/1998), the premium for surplus energy powered by self-consumption appeared for the first time. This legal regulation adds the idea that facilities that do not participate in the primary electrical production market will receive a supplement for the reactive energy ceded to the grid. For photovoltaic installations, premiums will then be applied at 0.397 €/kWh for installations of less than 5 kW, and at 0.216 €/kWh for solar farms over 5 kW.

Later on, the 2004 regulation (R.D. 436/2004) defined the revision of tariffs, premiums and incentives published every four years as of 2006, leaving the rates set at 0.4 €/kWh and 0.22 €/kWh for facilities under 5 kW and greater than 5 kW, respectively. In these six years, despite the advance of technology, the remuneration remained the same, encouraging the creation of new self-consumption plants in a very limited way. After that, RD 661/2007 established the legal and economic system for electrical energy production activity in a special regime. The distributors, who previously did not receive remuneration, started to charge 0.005 €/kWh under the special regime for this commercialisation service of electricity.

Until 2007, there were no guarantees for connection to the distribution. However, they were contemplated for connection to the transport network for 2% of the amount of the installation (RD 661/2007). There still is a problem regarding the time it takes to create a facility of this type, due to procedures such as permits, licenses or authorisations, which significantly affect project costs. Although the guarantee required for photovoltaic installations since 2008 has been 500 €/kW, that required for other renewable technologies is only 20€ per kW (RD 1578/2008), which could be discriminatory. This distinction may be because photovoltaics are the easiest to install and the most productive for self-consumption because of logistical reasons.

Feed-in Tariff (FiT)[1] is the scheme by which PV generators receive a premium for the reactive energy they export to the grid. The price at which the producer sells the surplus to the grid remains the same. However, producers also need to add the subsidy, or *FiT premium,* they receive by kilowatt, which would cause small electric generators to receive for each kilowatt of surplus up to four times the current price in a traditional electricity contract.

If the FiT is calculated to cover the cost of the investment amortisation by guaranteeing the premium levels for the lifetime of the PV installation it reduces the investment risk and creates conditions for rapid growth. The consensus is that between the two major categories to choose from in the regulatory scheme, tradable green certificates (TGC) and feed-in tariffs (FiT), the experiences in Europe suggest that FiTs deliver larger and faster penetration of renewable energies than the TGC, at a lower cost. Additionally, FiTs are generally accepted as the most efficient and effective support schemes for promoting renewable electricity. (Fouquet and Johansson, 2008; Couture and Gagnon, 2010). Spain, as well as Denmark and Germany, adopted the FiT and experienced rapid development of renewable energies installation. This business was so lucrative that even the most important power companies, such as Iberdrola, joined the FiT, producing photovoltaic energy and pouring it into the grid in exchange for fixed prices and subsidies. Many owners of rural land thought that this was an excellent investment as it ensured guaranteed payment for 25 years. Thus, from 2007 to 2009, a boom in solar energy took place in Spain. However, what was not foreseen was that these green premiums would cause the final cost of the traditional electricity bill to skyrocket by 23%.

Hence, in 2012, the Spanish government ended these subsidies and the FiT scheme. Consequently, the FiT tariff in Spain was suspended for the new facilities in the special regime and eliminated for the existing facilities with the approval of RD 9/2013. The price of surplus energy being poured into the grid decreased to 0.14 €/kWh, almost a quarter of what had been established five years earlier. Thus, photovoltaic energy became a much less profitable business.

Individuals and small companies that invested in solar panels were responding to the incentives of the government, even if they were incentives in some way vitiated by public intervention. Furthermore, entry of new self-consumption agents with the possibility of returning surplus electricity to the grid was temporarily closed. Hence, this reactive energy FiT premium was halted until 2015 when the R.D. 900/2015 allowed the creation of new facilities. Since then, until the recent changes, all users paid fixed costs for photovoltaic self-consumption (the so-called *sun tax*), to cover the costs of the electrical grid system maintenance.

Thus, the current price of surplus electrical energy is 0.006 €/kW, which means it is only 1.5% of the amount paid per kilowatts in 2007. Even so, investment in photovoltaic plants has been growing in Spain since 2015, although more slowly, aided by incentives such as subsidies for solar panels, entering into force in 2017, and the world-wide drop in the solar panel market price. Photovoltaic installations have grown since 2019. Furthermore, technological progress and the considerable investment in research and development by individual governments point to a further reduction in the solar panel market price.

[1] Feed-in tariffs (FITs) are also known as Standard Offer Contracts, Feed Laws, Minimum Price Payments, Renewable Energy Payments and Advanced Renewable Tariffs. (Couture and Gagnon, 2010).

METHODOLOGY

Here a panel data model of Standard Gross Margin (SGM) is estimated. The term panel data refers to data that combines a time dimension with a cross-sectional one. A data set that collects observations of a phenomenon over time is known as a time series. These data sets are ordered, and the relevant information regarding the phenomenon studied is what provides its evolution over time. A panel data set collects observations on multiple phenomena over specified time periods. The temporal dimension enriches the structure of the data and is capable of providing information that does not appear in a single cross-section.

The study of time series is highly dependent on the asymptotic properties of the time dimension and, accordingly, it is necessary to have a sufficient number of observations. In the studied case, with the data of 45 years, we will thereby be able to obtain reliable results. However, panel data usually correspond to shorter series. For this reason, from a methodological point of view, how the time dimension is part of the analysis of panel data differs from the usual way in time series analysis.

A standard regression model for panel data analysis has the form:

$$y_{it} = a_i + bx_{it} + \in_{it}$$

where ***y*** is the dependent variable, ***x*** is the independent variable, ***a*** and ***b*** are coefficients, ***i*** and ***t*** are the index for individuals and time, and finally $\in_{it}$ is the error term. The hypotheses established on $\in_{it}$ determine that the model may be assumed to have fixed or random effects.

The random-effects model makes it possible to assume that each transversal unit has a different intercept ($\in_{it}$). To check if it is necessary to use the random-effects model or the grouped data model, the Breusch and Pagan test, known as the Lagrange Multiplier test for random effects, is used. The null hypothesis of this test is that if the test is rejected, it is preferable to use the random-effects method. In our case study, the p-value indicates that we can reject the null hypothesis Ho for all the crops analysed, therefore, the random effects are relevant, and it is preferable to use the estimation of random effects instead of the grouped one.

In order to know which of the two to use, the Hausman test is applied, whose Ho is that the estimators of random effects and fixed effects do not differ substantially. If we reject Ho, the estimators do differ, and the conclusion is that fixed effects are more appropriate than random effects.

It is possible to add temporary dichotomous variables to the model, that is, one for each year in the sample, which capture events common to all states during one period or another. We use an F test to find the joint significance of the temporal dichotomous variables in our crop model. The p-value of the F test indicates that Ho is not rejected, so it is possible to state that the temporal dichotomous variables are not jointly significant and belong to the model.

To verify that no endogeneity exists in the model, the correlations between variables of the same crop is verified. We apply the Durbin-Wu-Hausman test, from which we deduce that there are no endogeneity problems in the model.

Once we have verified that the most suitable method to estimate our model is Fixed Effects, we proceed to estimate the model using our database of Standard Gross Margin.

We obtain estimators of fixed effects used to verify for each crop, whether it is more beneficial to invest in photovoltaic energy or continue feeding the irrigation systems with the conventional electricity grid. The regression will be estimated using fixed effects at the regional level data (Eurostat NUTS2) for each type of crop.

In this regression, the dependent variable will be the Standard Gross Margin (SGM) of the crop and the independent variables the cost of the inputs; all the variables are in logs in order to directly obtain the elasticities.

The model allows the impact on the total cost of the energy per unit of surface to be calculated. This enables us to evaluate the impact of changes in energy cost (conventional and photovoltaic) on the profitability of the crop, taking into account its location. The function of the estimated fixed effects model is:

$$SGM_{ij} = \beta_0 + \beta_1 E_{ij} + \beta_2 F_{ij} + \beta_3 FIT_{ij} + \beta_4 FER_{ij} + \beta_5 SEM_{ij} + \beta_6 SUB_{ij} + C \qquad \text{[Equation 1]}$$

Where:

SGM = Standard Gross Margin. Average per hectare in the region j and crop i.

E = Conventional grid energy cost

F = Photovoltaic energy cost

FIT = Phytosanitary cost

FER = Fertiliser cost

SEM = Seed cost

SUB = Subsidies per hectare linked to the production

C = Error term

For all ***i*** = crops (the main ones in the cropped area of Spain: corn, barley, wheat, vegetables, citrus and olive) and all ***j*** = location (all NUTS2 regions in Spain, which are the 17 autonomous regions).

In the studied model shown in *Results and Discussion*, the nomenclature used is:

β_0= _cons

β_1= *lenergy_crop*

β_2= *lfoto_ crop*

β_3 = *lphytosanitary_ crop*

β_4 = *lfertilizers_crop*

β_5 = *lseeds_ crop*

β_6 = *lgrant_ crop*

The relationship between the dependent variable (SGM) and parameters is the following:

Parameter β_0_explains the value of *SGM, when the value of the parameters is equal to 0*

Parameter β_1_explains the relationship between E and *SGM*

Parameter β_2_explains the relationship between F and *SGM*

Parameter β_3_explains the relationship between FIT and *SGM*

Parameter β_4_explains the relationship between FER and *SGM*

Parameter β_5_explains the relationship between SEM and *SGM*

Parameter β_6_explains the relationship between SUB and *SGM*

We assume that the agricultural producer will try to maximise profits (SGM) by growing the product in each plot with expectations of generating the maximum gross margin (SGM).

Once we carry out this process for all crops, we can calculate the Sensitivity Index as the irrigation system average cost of management and operation by unit of irrigated area. The Sensitivity Index reveals the water and energy cost sensitivity by unit of land in each region. The main advantage of the present methodology is that the panel data estimation of the coefficients takes into account the yearly and regional availability of rain, sun and other environmental conditions, as well as the market price changes for inputs and outputs.

Under the real market condition of prices of input, output and the level of TFP provided by the current *state of the art*, the mentioned model provides the crops for which it is profitable to invest in photovoltaic installation connected to the grid.

Assuming that all the variables expressed per Standard Gross Margin unit of land (SGM/Ha) are constant, except the energy that can be conventional or photovoltaic, it is possible to compare the cost of grid energy (conventional power) with photovoltaic energy. The cost of PV energy results from the amortisation cost of investment in the solar panel systems.

During the years in which the regulations enforced the FiT tariff, solar panels connected to the grid could obtain a premium by dumping energy not consumed by irrigation into the grid, thus decreasing energy cost although certain restrictions have applied. For instance, RD 244/2018 does not allow the self-consumer producer to dump more energy into the grid than that produced during a specified period — a disadvantage for irrigators that could produce electricity during the winter or wet periods over the irrigation system consumption. Alternatively, a farmer could register as a company producer of PV electricity and general conditions would apply. However, that means assuming the red-tape burden of registering as a firm, liquidating VAT quarterly, paying company tax, and so on, which is affordable mainly for cooperatives or other types of associations.

In the model, it will be profitable to introduce photovoltaics when its negative elasticity is lower than the negative elasticity of conventional energy since that means that it reduces production costs. In other words, if ***lfoto_crop-lenergy_crop > 0*** then it is profitable for the farmer to introduce photovoltaic in that particular crop irrigation in the reference region where this inequality applies.

DATA

We calculate the SGM from the representative sample of the regional farms as the difference at the end of the year between the value of the crops cultivated and the summation of the value of the inputs costs. SGM also includes subsidies linked to the product but no other decoupled subsidies (e.g. direct payments). As we estimate the elasticities to the SGM for each input from a model of panel data using a long-run series of farm accounting data, the climatic differences between years, as well as the price variation, are taken into account in the estimate parameters of the model.

In a climate change scenario, the farmer will adapt by switching to the least costly source of water and energy to minimise risks and maximise the SGM. The main restriction in arid zones for crop viability in a plot is having sufficient water to irrigate the maximum profit crop in the location. If not, the farmer has to obtain information and capital, or credit, to make investments in innovation that conserves water. The adaptation usually means the introduction of "deficit irrigation schemes", seeds resilient to drought periods, and other technologies (See San Juan Mesonada, 1995).

The data to estimate the panel data came from our database of Standard Gross Margin (SGM) built up from the homogeneous series of the representative sample at the regional level of the Farm Accounting Data Network (FADN, see Mora, San Juan Mesonada and de la Torre, 2003).

The SGM series is updated to complete the series from 1973 to 2017 (Kubicki and San Juan Mesonada, 2018). The latter is in contrast with most published work that only uses case studies for a few years.

Moreover, these studies cannot take into account the high volatility in rainfall and evapotranspiration, which are relevant in determining irrigation cost. Moreover, our panel data model estimated coefficients take into account the volatility of both economic and environmental variables (See Wooldridge, 2002 Chap. 14 Appendix 14 A and Chap. 14).

RESULTS AND DISCUSSION

The results provide a general assessment for the main irrigated crops for the case of investment in photovoltaic energy systems. We determine the type of cultivation for which investment in photovoltaic will be profitable in comparison with conventional energy use by observing our model results that consider profit elasticities.

If: *lfoto_crop* - *lenergy_crop*> 0. [Equation 2]

Then it is profitable to invest in photovoltaic wheat irrigation systems where this inequality holds (in Appendix 1 the resulting estimation for Equation 2 can be found for all regions).

REGIONAL WHEAT DISPARITIES IN PV INVESTMENT PROFITS

The following tables show the estimators for the regions where the use of photovoltaic technology for irrigation has been most favourable and most disadvantageous. We start with wheat in Table 1, one of the most extended crops, with the most favourable elasticities for PV in Aragon and Catalonia, in contrast to the least advantageous ones for Madrid. For wheat cultivation, we conclude that the use of photovoltaic technology for irrigation is more favourable for farmers in all the regions studied, except for Madrid. Also, in Table 1 of Appendix 1, the resulting estimators are detailed for all regions.

The profit gap between the use of conventional and photovoltaic energy is more significant for Aragon and Catalonia than in the rest of the regions. So, in those northeast regions, the results reveal that for farming irrigated cereals, very significant opportunities to shift into photovoltaic energy are seen. This will generate a positive externality reducing the agricultural footprint and increasing the economic efficiency of farms shifting to PV.

In cases like the Madrid region, where investing in photovoltaic energy is not suitable for wheat growers, it may be argued that Pigouvian taxes are justified to reduce pollution. With Madrid being one of the most polluted areas due to urban traffic, industry and heating, photovoltaic installation still generates a social benefit equivalent to the opportunity cost-shifting from conventional grid electricity to photovoltaic. Similarly, the latter would justify a generous FiT premium tariff scheme for PV.

nlSGMwheat	Aragon	Catalonia	Madrid
lenergy_wheat	-1.38*** (0.13)	-1.50*** (0.13)	-0.03* (0.05)
lfoto_wheat	-0.01* (0.00)	-0.02* (0.01)	-0.13** (0.05)
lphytosanitary_wheat	-0.19* (0.08)	-0.46 (0.41)	-0.04 (0.05)
lfertilizers_wheat		0.27* (0.14)	-0.41** (0.17)
lseeds_wheat	-0.23* (0.11)	0.31 (0.21)	-0.94*** (0.22)
lgrant_wheat	0.42*** (0.06)	0.41*** (0.11)	0.35*** (0.13)
_cons	-1163695*** (0.25)	-1176184*** (0.32)	-90.10*** (0.39)
R2	0.98	0.9905	0.97
N	84	84	80
F	1313.55	1315.81	447.47
p-value	0.00	0.00	0.00

**** p<0.01, ** p<0.05, * p<0.1*

Note1: AC clusters robust standard errors in parenthesis. Clustered standard errors are a special kind of robust standard errors that account for heteroskedasticity across "clusters" of observations (such as regions, or crops); Fixed Effects (FE) in every regression. In most applications, the main reason for collecting panel data is to allow for the unobserved effect to be correlated with the explanatory variables. For example, in our equation, we want to allow the unmeasured region-crop factors that affect the SGM also to be correlated with the water-energy cost (See Wooldridge, 2002, Chapter 13)

Note2: All variables expressed in logarithmic terms.

Table 1: Gross margin elasticities of wheat in the selected regions

REGIONAL BARLEY DISPARITIES IN PV INVESTMENT PROFITS

Similarly, as in the case of wheat, investment of photovoltaic energy in barley cultivation would be profitable observing our model when equation 2 holds (Table 2).
From the results obtained, we deduce that the use of photovoltaic technology for irrigation does not represent a significant profit in Andalusia, and Castile-La Mancha, but investing in solar energy is advantageous in the rest of the regions where barley cultivation is significant: Aragon, the Canary Islands, Cantabria, Castile-Leon, Catalonia, Galicia and Murcia.

Regions with the most significant difference between the use of conventional and photovoltaic energy are Aragon and the Canary Islands. In these regions, the difference between the elasticity of the gross margin of conventional and PV energy is the highest; in other words, in these regions equation 2 (lfoto_ barley - lenergy_ barley > 0) achieves maximum values for barley. For a general overview, see Table 2 of Appendix 1, where we report the resulting estimators for barley for all regions.

nl SGMbarley	Asturias	Andalusia	Aragon	Canary I.
lenergy_barley	-0.33*** (0.09)	-0.01* (0.01)	-0.78*** (0.14)	-0.28*** (0.09)
lfoto_barley	-0.68* (0.04)	-0.06* (0.01)	-0.02* (0.01)	- 0.00*** (0.04)
lphytosanitary_barley	0.26 (0.26)	0.06 (0.13)	-0.00 (0.16)	0.72*** (0.19)
lfertilizers_barley	-0.38*** (0.10)	-0.10 (0.11)	-0.12 (0.09)	-0.43*** (0.09)
lseeds_barley	-0.73*** (0.17)	-20.19*** (0.27)	-0.50*** (0.16)	-0.79*** (0.17)
lgrant_barley	0.26*** (0.08)	10.24*** (0.23)	0.41*** (0.09)	0.15*** (0.05)
_cons	-100.42*** (0.51)	-110.22*** (0.59)	-110.42*** (0.49)	-90.13*** (0.38)
R^2	00.97	00.94	00.9803	00.97
N	84	82	42	84
F	5020.40	2000.03	6310.64	4940.78
p-value	00.00	00.00	00.00	00.00

**** p<0.01, ** p<0.05, * p<0.1*

Note1: AC clusters robust standard errors in parenthesis; FE in every regression.

Note2: All variables expressed in logarithmic terms

Table 2: Gross margin elasticity of barley in the selected regions

The general conclusion is that PV connected to the grid systems may in the long term substitute the single conventional energy in the operation of irrigation systems for cereals in the most relevant region. Furthermore, with the current FiT premium tariff, the profit elasticities of private investment will drive the shift to clean energy. This will add pressure on the competition for water in arid areas as drill systems as well as PV panels show a declining price trend.

REGIONAL CORN DISPARITIES IN PV INVESTMENT PROFITS

The case of corn reveals results opposite those for cereals. Investment in photovoltaic energy infrastructure is not profitable for irrigators in any region of Spain. In Table 3, we can observe the fixed effects estimators obtained for the regions where the use of photovoltaic technology for corn irrigation has been most unfavourable. In these regions, the difference between the profit elasticities of conventional and photovoltaic energy is maximum. In Table 3 of Appendix 1, we report the effect of estimators for all the regions.

Generalised drip irrigation may explain this result. Although the cultivation of corn is widespread in Spain and does not have high water requirements, the most used method for this crop is drip irrigation, which consumes much less energy than other techniques such as sprinkler irrigation.

nlSGMbarley	Andalusia	Canary I.	Catalonia
	-20.04***	-10.2***	-10.47***
lenergy_corn	(0.21)	(0.19)	(0.20)
	-0.13*	-0.05*	-0.15*
lfoto_corn	(0.03)	(0.01)	(0.04)
	40.477532***	10.51***	-0.95
lphytosanitary_corn	(0.49)	(0.25)	(0.77)
	-0.943***	-0.23**	0.66**
lfertilizers_corn	(0.14)	(0.11)	(0.24)
	-0.86***	-0.90***	-0.13
lseeds_corn	(0.23)	(0.21)	(0.37)
	-10.62***	-0.16***	0.91***
lgrant_corn	(0.30)	(0.04)	(0.20)
	-60.88***	-80.11***	-110.13***
_cons	(0.53)	(0.29)	(0.55)
R^2	0.98	0.97	0.97
N	84	84	84
F	703.78	595.77	493.78
p-value	0.00	0.00	0.00

**** p<0.01, ** p<0.05, * p<0.1*

Note1: AC clusters robust standard errors in parenthesis; FE in every regression.

Note2: All variables expressed in logarithmic terms

Source: Own elaboration as explained in the text

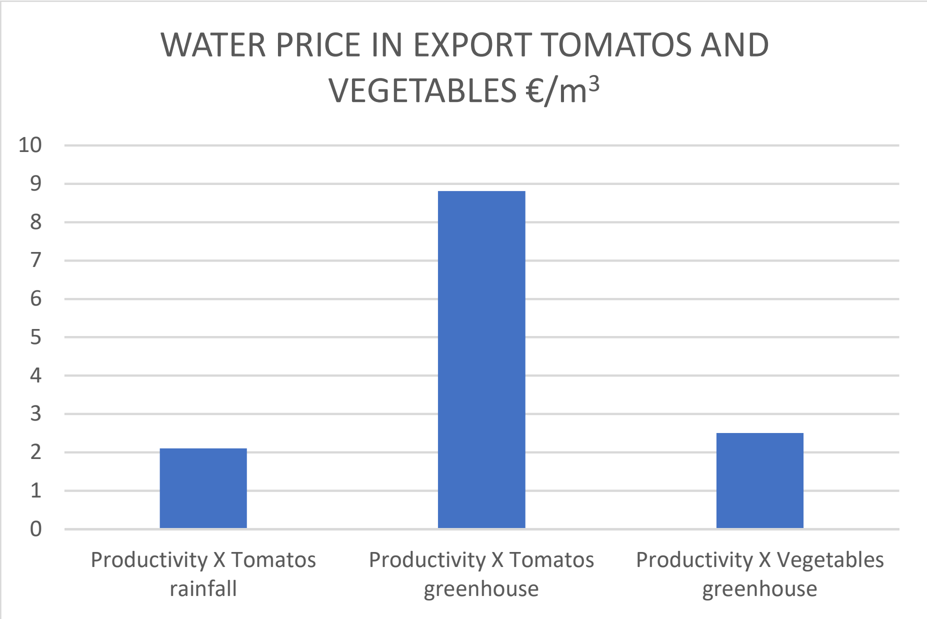
Table 3: Gross margin of corn in the selected regions

Regions, where the installation of photovoltaic technology for corn is least profitable, are Andalusia, the Canary Islands and Catalonia; in these regions ***lfoto_ corn -lenergy_ corn < 0***, see Table 3. In these regions, corn is not one of the relevant crops. On the other hand, in regions where the corn crop is more important, such as Castile-Leon (See Appendix 1, Table 3), although photovoltaic energy is still not the most profitable option, it is more convenient than in regions shown in Table 3.

REGIONAL VEGETABLE AND CITRUS DISPARITIES IN PV INVESTMENT PROFITS

The results for vegetables, one of the most important irrigated products exported, along with fruit, clearly reveal the advantage of PV irrigation over conventional systems for all the regions, even in the rainiest north region.

Figure 2 Water price in export tomatoes and vegetables (€/m³)



Note: X means export-oriented crops. Productivity refers to partial water productivity.

Source: Own elaboration, as explained in the text

Similarly, for both vegetables and citrus, the results show that the use of photovoltaic technology for irrigation is privately profitable in all regions (Appendix Table 5). As Mediterranean regions have a concentration of citrus production and exportation centres in addition to significant imbalances between water supply and demand, coherent regulation of water and energy is urgently required.

Thus, in this subsector, as well as in the case of citrus, such coherence between water and energy regulation will be crucial in future years. The pressure on water resources will increase as PV investment cost decreases. This may shift the focus to the availability of water during prolonged dry periods, so the desalination of seawater should be reviewed as an alternative for coastal areas with excess water demand (Appendix Table 4).

lnSGMvegetables	Asturias	Navarra	Basque Country
lenergy_vegetables	-0.92*** (0.13)	-0.65*** (0.13)	-0.82*** (0.15)
lfoto_vegetables	-0.05* (0.02)	-0.08** (0.04)	-0.07* (0.04)
lphytosanitary_vegetables	-40.44*** (0.47)	-20.99*** (0.31)	-20.91*** (0.48)
lfertilizers_vegetables	-10.26*** (0.13)	-10.06*** (0.14)	-0.90*** (0.17)
lseeds_vegetables	20.67*** (0.29)	-10.17*** (0.15)	-10.76*** (0.27)
lgrant_vegetables	0.43*** (0.10)	0.45*** (0.15)	0.08 (0.11)
_cons	-120.18*** (0.32)	-120.48*** (0.31)	-120.00*** (0.35)
R^2	0.99	0.99	0.99
N	84	84	84
F	2365.00	2400.63	1916.71
p-value	0.00	0.00	0.00

**** p<0.01, ** p<0.05, * p<0.1*

Note1: AC clusters robust standard errors in parenthesis; FE in every regression.

Note2: All variables expressed in logarithmic terms

Source: Own elaboration, as explained in the text

Table 4: Gross margin of vegetables in the selected regions

lnSGM citrus	Cantabria	Galicia
lenergy_citrus	-0.67** (0.26)	-0.01* (0.00)
lfoto_citrus	-0.11* (0.07)	-0.15** (0.06)
lphytosanitary_citrus	-20.94*** (0.98)	-30.71*** (0.79)
lfertilizers_citrus	-0.91*** (0.20)	-0.66*** (0.13)
lseeds_citrus	-10.50** (0.73)	-10.60*** (0.52)
lgrant_citrus	0.21 (0.18)	0.48** (0.20)
_cons	-60.77*** (20.02)	-50.15*** (10.74)
R^2	00.98	00.98
N	84	84
F	12200.74	11860.89
p-value	00.00	00.00

**** p<0.01, ** p<0.05, * p<0.1*

Note1: AC clusters robust standard errors in parenthesis; FE are included in every regression.

Note 2: All variables expressed in logarithmic terms.

Note 3 Regions with the most significant difference between the use of conventional and photovoltaic energy are Cantabria and Galicia (Table 5). Only regions with extreme results for photovoltaic investments are included (e.g., if a region is a most favourable case, Cantabria, or least favourable one, Asturias).

Note 4: For a general overview, the effect estimators can be found for all regions in Table 5 of Appendix 1.

Source: Own elaboration, as explained in the text.

Table 5: Gross Margin elasticities of citrus in the selected regions

OLIVE REGIONAL DISPARITIES IN PV INVESTMENT PROFITS

For olive groves, the PV system is also more advantageous than conventional grid electricity in all regions (Table 6). Currently, the irrigated area of olive predominantly uses drip irrigation to conserve water.

lnSGMolive	Aragon	Asturias	Castile La Mancha
lenergy_olive	-0.12* (0.01)	-0.14* (0.02)	- 0.12* (0.07)
lfoto_olive	-0.69* (0.09)	-0.15* (0.08)	-0.08* (0.03)
lphytosanitary_olive	-0.17 (0.37)	-0.35 (0.47)	-0.27 (0.24)
lfertilizers_olive	-0.60*** (0.16)	-0.52*** (0.16)	-0.44*** (0.12)
lseeds_olive	-10.23*** (0.29)	-0.88*** (0.27)	-10.56*** (0.18)
lgrant_olive	0.00 (0.18)	0.01 (0.14)	0.31** (0.14)
_cons	-100.80*** (0.66)	-110.69*** (0.45)	-100.90*** (0.56)
R^2	0.94	0.9606	0.96
N	84	84	82
F	230.23	309.09	383.59
p-value	0.00	0.00	0.00

**** p<0.01, ** p<0.05, * p<0.1*

Note1: AC clusters robust standard errors in parenthesis; FE are included in every regression.

Note2: All variables expressed in logarithmic terms

Source: Own elaboration as explained in the text

Table 6: Gross margin elasticities of olive in the selected regions

DISCUSSION

As PV technology advances, it offers more effective systems at more affordable prices, thus shortening the amortisation time of the facilities. It is a source of clean, renewable, non-exhaustible and silent energy, does not consume fossil fuels, offers the possibility of selling excess power, requires little maintenance and is an increasingly affordable technological investment. In particular, PV technology solves the paradox of modern irrigation systems that conserve water at the cost of increasing emissions.

These reasons have led to PV connected energy being a valid alternative to conventional electric energy for irrigation. Our study indicates that for the main crops and in most regions, this alternative has gone from being an ecological alternative for the future to becoming an economically profitable reality. The empirical results prove that at current market prices, photovoltaic energy is, in most cases, the best private and social option for sustaining irrigated crops.

Although the installation of photovoltaic technology involves a significant initial investment for farmers, results prove that in the majority of regions, investment in PV connected installations for irrigation is profitable and brings private benefits over the life cycle, in addition to positive externalities for the rest of society.

The foregoing makes it desirable to provide a legal and regulatory framework that is stable and focussed on reaching greenhouse emission targets. Installation of photovoltaic technology in irrigation means a reduction of 2.5 kg of CO_2 emitted into the atmosphere for each kilowatt produced.

As irrigators are the second-highest electric energy consumers at the country level, this reduction in emissions of greenhouse gases in an activity that requires so much energy during the summer is very relevant. Other clean primary energies, such as hydroelectric, need to deal with the issue of reservoir water shortage during the summer months, while wind turbines have to contend with low wind speeds[2].

The conclusions obtained from our research are original, as to our knowledge, there is no study offering general results with regional comparisons and for the main crops in Spain.

Moreover, we provide regulators with specific, realistic figures to establish the appropriate FiT tariff in irrigation depending on the crop and region, if the target is to decrease emissions incentivising PV installations.

At the same time, we are seeing a continuous fall in production costs for renewable energy technologies. Furthermore, the resulting price at which electricity must be generated from a PV installation to break even over the project's lifetime (LCOE, see Jäger-Waldau, 2019), as a result of industry learning curves is declining. Financial lines, explicitly targeting investments in clean energy, and a regulatory framework that avoids delay in the approval of new projects may have a vital role in incentivising the PV installations.

Nevertheless, conflict with water conservation regulation in critical areas may arise as the PV and perforation cost of new wells decrease. Lower investment cost in drillings creates increased incentives for irrigators to overexploit groundwater resources. In 2019, the environmental police (SEMPRONA) sealed a record number of illegal wells in the south.

The agricultural sector suffers from the existing contradictions between energy regulations, trying to introduce competition and promote clean energy, and water regulations. The number of water taxes skyrocketed at the national, regional and municipality levels without any coordination (Adame, 2019). Some of these taxes only pursued window-dressing effects, while others are purely income seeking.

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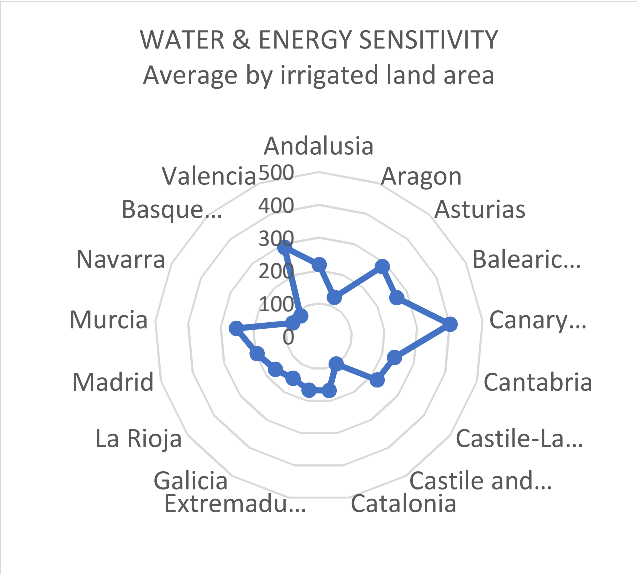
[2] *"A typical modern turbine will start to generate electricity when wind speeds reach ten to fifteen kilometers per hour, known as the cut-in speed. Turbines will shut down if the wind is blowing too hard (roughly 90 Km/h) to prevent equipment damage."* AWEA, 2020. https://www.awea.org/wind-101/basics-of-wind-energy#:~:text=A%20typical%20modern%20turbine%20will,hour)%20to%20prevent%20equipment%20damage. (Last visit 15/06/2020)

Finally, we should underline the fact that water and energy cost sensitivity by unit of land is very different by region, see Figure 3. The sensitivity index is calculated here as the irrigation system average cost of management and operation by unit of irrigated area. The index range goes from less than 100 to more than 400.

It can be observed that water and energy cost sensitivity by unit of land is higher in low rainfall regions, where agriculture is an essential activity, as is the case of Murcia or Canary Islands. Moreover, for the opposite circumstances, this is so in regions where the amount of rain per year is very high as it occurs in Basque Country or Asturias.

Figure 3 Water and energy sensitivity (Average by irrigated land area)



Source: Own elaboration, as explained in the text

DESALINATION

Those drylands where there are increasingly frequent long droughts, and the overuse of hydric resources is more probable, may rely on desalinated water if there are possibilities of locating crops near the sea. At present, desalination plants are a commercial alternative for fruit and vegetables in the Mediterranean and southern regions. Commercial desalination technologies are already available and are usually classified into two leading thermally-driven technologies (Multi-stage flash MSF; Multi-effect desalination, MED and adsorption desalination, AD), and membrane separation reverse osmosis (RO) processes. In addition, there are different emerging technologies under R&D, with one of their main objectives being the reduction of energy requirements and emissions per unit of freshwater generated. The use of seawater, in the current state of the art, requires between 2.6 to 8.5 kWh/m^3 of energy, far higher than that required by groundwater (0.48) or lake/river (0.37) water, which translates, multiplied by the applicable tariff of electricity, into a cost of desalinated water usually beyond competitive alternatives (Shahzad et al. 2017). Nevertheless, these technologies provide a necessary alternative in prolonged periods of drought, primarily for irrigated areas with higher gross margin crops near the coastal line, e.g. those exporting greenhouse flowers and vegetables.

The main disadvantage of small photovoltaic reverse osmosis (PV-RO) installations for desalination at the farm scale is the land area required to install the solar panels, approximately 26.5 to 28 m^2 to obtain one water cubic meter with an energy consumption of 8 kWh/m^3. In regions with high population density where farmers and tourist installations compete for land, the investment cost may be an issue[3]. Consequently, regulation may be an incentive for R&D to use PV panels as a part of the greenhouses to conserve soil and improve investment profitability.

An alternative could be the large-scale photovoltaic seawater reverse osmosis (PV-SWRO) plants. Currently, large scale PV-SWRO is in a learning process, and R&D could lead to lowering water costs from renewable energy-operated desalination processes to 1.81 € /m^3 from the current range of 1.81 to 29 € /m^3 depending on the size of the plant, technology[4] and renewable energy potential (See Fig. 7 Shahzad et al. 2017 p. 59). Water and energy regulation must be coherent and drive technical change to reach higher performance ratios in the commercial desalination processes.

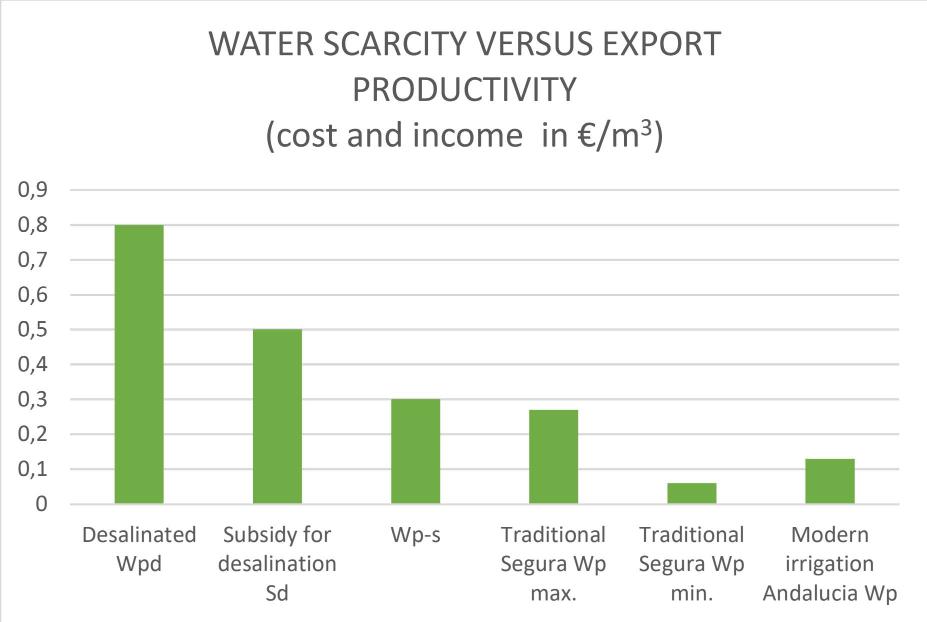
In decreasing the equivalent heat of evaporation required to desalinate one cubic meter of seawater the performance ratio increases and as such the energy cost measured as kWh_{elec} per cubic meter (See Shahzad et al. 2017 p. 55).

For drought situations, Law 1/2018 establishes a maximum price for desalinated water of 0.3 €/m^3 theoretically subsidising around 0.5 €/m^3. However, in January 2020, the continued administrative delay and the lack of funds forced the non-application of the "drought tariff". The difference from the actual cost of desalination, 0.8 €/m^3 would mean a subsidy of around 0.5 euros per cubic meter premium under long dry spells. Moreover, even with this drought premium, the final cost would be well above the 0.1 €/m^3 costs of reservoir water (San Juan Mesonada, 2019). There are frequent farmer complaints that desalted water squeezes crop margins, and consequently, it is mainly used in high added-value productions. However, for long and medium-term contracts, the prices range from 0.18 to 0.33 €/m^3 (estimated cost in 2017 by Cosí, 2017).

Research and development progress in PV desalination technologies are currently reducing water cost. Moreover, its wider use is still limited due primarily to high energy requirements, especially when facing rising fossil fuel prices. The use of PV systems energy sources is relevant for meeting the growing demand for water desalination (Ghaffour et al. 2015; Martínez Fernández, J. & Esteve Selma, M. A. 2004).

A recent innovation is the installation of PV for self-consumption after the liberation of the electric market in Spain. The new regulation allows PV plant for self-consumption of the desalination disconnected from the greed, conditioned to the power of PV generation under the total consumption. In the pioneer PV installation of the Mazarron desalination plant "*Virgen del Milagro,"* the estimated reduction of water cost is 0.6 €/m^3 in the first phase and 0.20 €/m^3 after the amortisation of the investment. The later may allow approaching the cost of the desalinated water to other alternative sources. Additionally, PV self-consumption is improving energy efficiency by reducing energy consumed from the greed and therefore improving its carbon footprint, reducing the CO_2 emissions in an estimated 5,225 tonnes per year. The floating structure of solar panels, over the regulating reservoir, improve the efficiency of that desalination plant. The floating cover structure that supports the PV panels allows reducing the evaporation of desalinated water in an estimated 42,000 cubic meters per day (data provided by the contractor Tedagua in 2019 see https://www.tedagua.com/en/project/c-de-regantes-de-mazarron-desalination-plant).

Figure 4 Water scarcity versus productivity (cost and income in €/m³)



Climate change drives cultivation techniques adapting to the drier and warmer environment. Adaptation means moving crops towards locations that are more favourable and switching to plant varieties resistant to drought and increasingly frequent use of irrigation, which entails higher energy expenditure. Desalinated water is of higher quality and can have less negative impact on soils and crops than the direct use of brackish water. Furthermore, PV desalination systems costs are currently declining (Beltrán & Koo-Oshima, 2006; Shahzad et al. 2017).

CONCLUSIONS

The study provides an assessment of the regional diversity on the profitability of investment in photovoltaic installations for irrigation using panel data models of gross margin elasticities by crop. The main conclusion has significant policy implications for understanding the water-energy trade-offs. The results allow us to verify the opportunity cost of photovoltaic versus conventional grid electric power for all regions and main crops. The methodology also enables us to assess the level of subsidies or FiT schedules required to internalise the positive externalities shifting from single conventional to grid-connected photovoltaic installations.

The panel data model based on the standard gross margin of the irrigated crop ensures that the data take into account the fact that land productivity is dependent on weather and market conditions. In this respect, previous literature based on a short series of field studies may be biased by the period of study chosen. Conversely in each region-crop, using SGT long term series, the random effects of the volatility of economic and environmental variations are taken into account when the coefficients of the panel data model are estimated.

The contradictory and time unstable regulations on water and energy send conflicting signals and have slowed the path to reaching a clean irrigation system. Regulations often reflect pressure from the electricity lobbies, who have been placing the burden for ensuring their oligopoly income on irrigators' shoulders. Our main conclusion is that the European Commission has a relevant task in coordinating regulations, not only among the Member States but also coordinating water and energy regulations within each country. However, water regulations are time and location sensitive, so the rules are complicated to generalise, and further comparative research is required.

REFERENCES

1- Adame, F. 2019. La fiscalidad autonómica sobre el agua. In La fiscalidad del agua: Situación actual y perspectiva de reforma. Tirant Lo Blanch. Valencia. pp. 127-176.
2- Alcon, F., García-Bastida, P.A., Soto-García, M., Martínez-Alvarez, V., Martin-Gorriz, B. and Baille, A., 2017. Explaining the performance of irrigation communities in a water-scarce region. Irrigation Science, 35(3), pp. 193-203.
3- Barber, S. 2017 comment in SUNMatrix https://sunmetrix.com/what-is-capacity-factor-and-how-does-solar-energy-compare/ September 28, 2017 at 6:26 AM.
4- Beltrán, J. M., & Koo-Oshima, S. (2006). Water desalination for agricultural applications. FAO Land and water discussion paper, 5, 48.
5- Berbel, J., Gutiérrez-Martín, C., Rodríguez-Díaz, J.A., Camacho, E. and Montesinos, P., 2015. Literature review on rebound effect of water saving measures and analysis of a Spanish case study. Water Resources Management, 29(3), pp. 663-678.
6- Berbel, J., Gutiérrez-Martín, C., Rodríguez-Díaz, J.A., Camacho, E. and Montesinos, P. 2015. Literature review on rebound effect of water saving measures and analysis of a Spanish case study. Water Resources Management, 29(3), pp. 663-678.
7- Berbel, J., Gutiérrez-Martín, C. and Expósito, A. 2018. Impacts of irrigation efficiency improvement on water use, water consumption and response to water price at field level. Agricultural water management, 203, pp.423-429.
8- Berbel, J., Gómez-Limón, J.A. and Gutiérrez-Martín, C. 2017. Modernización de regadíos y ahorro de agua. Cajamar.
9- Borrego-Marín, M.M. and Berbel, J. 2017. Impacto de la modernización de regadíos sobre el uso del agua y otras variables socioeconómicas en comunidades de regantes de Andalucía Occidental. Berbel J, Gutiérrez Martín C (eds) Efectos de la modernización de regadíos en España, Economía, 30, pp.345-354.
10- Camacho, E., Rodríguez, J.A. and Montesinos, P., 2017. Ahorro de agua y consumo de energía en la modernización de regadíos. Berbel, J. y Gutiérrez-Martín, C. (coords.): Efectos de la modernización de regadíos en España. Almería. Cajamar, pp.221-249. .
11- Carrillo-Cobo, M. T. Y Rodriguez-Diaz, J. A., Camacho-Poyato, E. 2010. The role of energy audits in irrigated areas. The case of ‘Fuente Palmera’ irrigation district (Spain). Spanish Journal of Agricultural Research, pp. 152-161.
12- Castillo, M., Borrego-Marín, M.M. and Berbel, J., 2017. Perspectiva del agricultor sobre el efecto de la modernización de regadíos en la distribución de cultivos. El Impacto de la Modernización de Regadíos en España; Berbel, J., Gutiérrez-Martín, C., Eds, pp.330-343.
13- Corominas, J., 2010. Agua y energía en el riego, en la época de la sostenibilidad. Ingeniería del agua, 17(3), pp.219-233.
14- Cosí, C. 2017. **iagua** http// iagua.es/blogs/carlos-cosin/evolucion-tarifas-desalacion-parte-i).
15- Couture, T. and Gagnon, Y., 2010. An analysis of feed-in tariff remuneration models: Implications for renewable energy investment. *Energy policy*, *38*(2), pp.955-965.
16- Crespo Chacón, M., Rodríguez Díaz, J.A., García Morillo, J. and McNabola, A., 2019. Pump-as-Turbine Selection Methodology for Energy Recovery in Irrigation Networks: Minimising the Payback Period. Water, 11(1), p.149.
17- Embid-Irujo, A. 2017. El marco jurídico de la modernización de regadíos. En: J. Berbel y C. Gutiérrez-Martín, Efectos de la modernización de regadíos en España. pp. 14-36. Cajamar.

18- ESYRCE. 2019. Encuesta sobre superficies y rendimientos de cultivos. Ministerio de Agricultura, Alimentación y Medio Ambiente. https://www.mapa.gob.es/es/estadistica/temas/estadisticas-agrarias/agricultura/esyrce/

19- Fernández García, I., Rodríguez Díaz, J.A. and Camacho Poyato, E., Montesinos, P. 2013. Optimal operation of pressurized irrigation networks with several supply sources. Water Resources Management, 27(8), pp. 2855-2869.

20- Fouquet, D. and Johansson, T.B., 2008. European renewable energy policy at crossroads—Focus on electricity support mechanisms. Energy policy, 36(11), pp. 4079-4092. https://doi.org/10.1016/j.enpol.2008.06.023
21- González Perea, R., Poyato, E.C., Montesinos, P. Rodríguez Díaz, J. A. 2015. Irrigation Demand Forecasting Using Artificial Neuro-Genetic Networks. Water Resour Management, 29, pp. 5551-5567.
22- Gonzalez Ponce, A. 2016. Bombeo solar con variadores de frecuencia para aplicaciones de regadío IDAE. Ahorro y eficiencia energética en Comunidades de Regantes. Ministerio de Industria, Turismo y Comercio, Madrid.
23- González-Cebollada, C., 2015. Water and energy consumption after the modernisation of irrigation in Spain. WIT Transactions on The Built Environment, 168, pp. 457-465.
24- Ghaffour, N., Bundschuh, J., Mahmoudi, H., & Goosen, M. F. 2015. Renewable energy-driven desalination technologies: A comprehensive review on challenges and potential applications of integrated systems. Desalination, 356, pp. 94-114.
25- IDEA. 2011. Evolución tecnológica y prospectiva de costes de las energías renovables. Estudio Técnico PER 2011-2020. Instituto para la diversificación y el ahorro de la energía.
26- Jäger-Waldau, A. 2019. PV Status Report 2019 Commission JRC, 2019. Doi:10.2760/326629 ISBN 978-92-7612608-9
27- Kubicki, J. and San Juan Mesonada, C. 2018. A quantitative effect of water expenditure on irrigated land's profits by autonomies in Spain. WPJM-UC3M 2018/1.
28- Lecina, S. Isidoro, D., Playán, E. & Aragüés, R. 2010. Irrigation modernization and water conservation in Spain: The case of Riegos del Alto Aragón. Agricultural Water Management, 97. pp. 1663–1675.
29- Martínez Fernández, J. & Esteve Selma, M. A. 2004. The dynamics of water scarcity on irrigated landscapes: Mazarrón and Aguilas in south-eastern Spain System Dynamics Review, 2, vol. 20, pp. 117–137.
30- Mora, R. San Juan Mesonada, C. and de la Torre, J. E., 2003 The representativeness of the Spanish RICA Survey, in K. Poppe, Povellato, A. and Krijgsman, K. (eds.), European Farmers and the Growing of Data. LEI. Hague. 2003, pp. 115-141.
31- Moreno, M. A., Córcoles, J. L., Tarjuelo, J. M. &Ortega, F.J. 2010. Energy efficiency of pressurised irrigation networks managed on-demand and under a rotation schedule. Biosyst Eng., 107(4), pp. 349-363.
32- Pollitt, M.G. (2019) The European Single Market in Electricity: An Economic Assessment. Rev Ind Organ 55, 63–87. https://doi.org/10.1007/s11151-019-09682-w
33- Ponti, L., Gutierrez, A. P., Ruti, P. M., & Dell'Aquila, A. 2014. Fine-scale ecological and economic assessment of climate change on olive in the Mediterranean Basin reveals winners and losers. *Proceedings of the National Academy of Sciences,* 111(15), 5598-5603.
34- Resco Sánchez, P. J. 2015. Viticultura y Cambio Climático en España: Vulnerabilidad en las distintas regiones y estrategias de adaptación frente al desarrollo de nuevas políticas. *Recovered from* http://oa. upm. es/37877/1/PABLO_JOSE_RESCO_SANCHEZ. pdf.
35- Rocamora C., Abadia R., Ruiz A. 2008. Ahorro y eficiencia energética en las Comunidades de Regantes. Instituto para Diversificación y Ahorro de la Energía, IDAE. Serie divulgación Ahorro y Eficiencia energética en Agricultura. Ministerio de Industria, Turismo y Comercio. Madrid.

36- Rodríguez-Díaz, J. A., Camacho Poyato, E., & Blanco Pérez, M. 2011b. Evaluation of water and energy use in pressurised irrigation networks in Southern Spain. Journal of irrigation and drainage engineering, 137(10), 644-650.
37- Rodríguez-Díaz, J.A., Pérez-Urrestarazu, L. Camacho-Poyato, E. & Montesinos, P. 2011. The paradox of irrigation scheme modernization: more efficient water use linked to higher energy demand.
38- San Juan Mesonada, C. 1995. Environmental Strategies and Farm Production Function, in E.A.A.E. Environmental and Land Use Issues. An Economic Perspective. Wissenschaftsverlag Vauk. Kiel. 1995. pp. 99-119 ISBN 3-8175-0196-X
39- Soto-García M., Martínez Álvarez V., Martin-Gorriz B. 2014. El regadío en la Región de Murcia. Caracterización y análisis mediante indicadores de gestión. Sindicato Central de Regantes del Acueducto Tajo-Segura. p. 267.
40- . Tarjuelo, J.M., Rodriguez-Diaz, J.A., Abadía, R., Camacho, E., Rocamora, C. and Moreno, M.A., 2015. Efficient water and energy use in irrigation modernization: Lessons from Spanish case studies. Agricultural Water Management, 162, pp.67-77.
41- Rodríguez-Díaz, J. A., L. Pérez-Urrestarazu, E. Camacho-Poyato y P. Montesinos. 2011a. The paradox of irrigation scheme modernization: more efficient water use linked to higher energy demand. Spanish Journal of Agricultural Research vol. 9(4), 1000-1008. http://dx.doi.org/10.5424/sjar/20110904-492-10
42- Shahzad, M. W., M. Burhan, L. Ang, K. Choon Ng. 2017. Energy-water-environment nexus underpinning future desalination sustainability. Desalination, Vol. 413, 52-64. ISSN 0011-9164. https://doi.org/10.1016/j.desal.2017.03.009. http://www.sciencedirect.com/science/article/pii/S0011916417303703
43- Tarjuelo, J. M., J. A. Rodriguez-Diaz, R. Abadía, E. Camacho, C. Rocamora, M. A. Moreno. 2015. Efficient water and energy use in irrigation modernisation: Lessons from Spanish case studies. Agricultural Water Management. Vol. 162, pp. 67-77 https://doi.org/10.1016/j.agwat.2015.08.009
44- Wooldridge, J. M. 2010. Introductory Econometrics. A Modern Approach. 2º Edition. Cambridge, MA: MIT Press, 2010.

APPENDIX 1

nlmbtrigo	Andalucia	Aragón	Asturias	Baleares	Canarias	Cantabria	Castilla La Mancha	Castilla leon	Cataluña	Extremadura	Galicia	Madrid	Murcia	Navarra
lenergia_trigo	-0.523967***	-1.381141***	-0.773102*** (	-0.7586998***	-0.6071566	-10.710879***	-0.2381459***	-0.4853522***	-1.502389***	-0.0929866*	-10.138309***	-0.0313255*	-0.678163***	-0.4018148***
	(0.1770515)	(0.1382588)	0.1051269)	(0.11982)	(0.117394)	(0.1102064)	(0.076689)	(0.1169163)	(0.133987)	(0.0606613)	(0.0988188)	(0.0586899)	(0.1074127)	(0.0920901)
lfoto_trigo	-0.1501218***	-0.0185077*	-0.0296706*	-0.0237902*	-0.0410127***	0.001498*	-0.1031361**	-0.0315841*	-0.0209431*	0.0981076**	-0.0160269*	-0.1358229**	-0.011217*	-0.0165039*
	(0.052738)	(0.00326014)	(0.0365925)	(0.00399692)	(0.00377109)	(0.00243376)	(0.0399904)	(0.00417045)	(0.0131019)	(0.0449414)	(0.0204697)	(0.0523691)	(0.00358045)	(0.0143428)
lfitosanitarios_trigo	0.428767*	-0.1918869*	-0.2962029		0.535367	-10.164824***		-0.3459292*	-0.4698149	-0.8956275***	-0.57253**	-0.0494492	-0.0298157	0.5332306
	(0.2425418)	(0.0807918)	(0.2255313)		(0.1682954)	(0.4112791)		(0.2118144)	(0.4192608)	(0.2406527)	(0.3049504)	(0.05857512)	(0.2021399)	(0.3907629)
lfertilizantes_trigo	-0.1314661		-0.189122** (	-0.2937621***	-0.3767285	0.1949948**	-0.3836226***	-0.1837161*	0.2745353*	-0.0357214*	0.1779697**	-0.4187503**	-0.4149322***	-0.4078476**
	(0.130443)		0.0881387)	(0.0730998)	(0.0837916)	(0.0855198)	(0.0718713)	(0.102958)	(0.1470818)	(0.1200001)	(0.0697664)	(0.1736683)	(0.0778097)	(0.1829149)
lsemillas_trigo	-1622529***	-0.2339689*	-0.0767628	-0.2115005**	-0.3681456**	10.135613***	-0.6719891***	-0.8818759***	0.3174368	-0.9899341***	10.050276***	-0.9485816***	-0.4716578***	-0.9126969***
	(0.2654601)	(0.112709)	(0.1584871)	(0.1174151)	(0.1582796)	(0.3048598)	(0.1215139)	(0.1481735)	(0.2152283)	(0.1849216)	(0.2375668)	(0.2212765)	(0.1489515)	(0.2063773)
lsubvencion_trigo	0.8422935***	0.4276948***	0.3749216***	0.3002346***	-0.1626282	0.5465527***	0.343023***	0.8858147***	0.4189932***	0.8786534***	-0.5179288***	0.3564872***	0.6236248***	0.2122214
	(0.1974192)	(0.0634728)	(0.0683049)	(0.074746)	(0.0431067)	(0.0786451)	(0.0857375)	(0.1586831)	(0.1171522)	(0.1673606)	(0.0629356)	(0.1313984)	(0.123741)	(0.1942818)
_cons	-12.10767***	-1163695***	-110.99286***	-110.62727***	-10.1121	-15.44989***	-100.32836***	-1185721***	-1176184***	-100.94018***	-160.84974***	-90.102127***	-110.78212***	-110.01656***
	(0.6100143)	(0.2544053)	(0.440349)	(0.3688901)	(.3994483)	(.6239869)	(0.2539543)	(0.5416161)	(0.3287782)	(0.5090398)	(0.9641723)	(0.3960928)	(0.4363336)	(0.5979753)
R2	0.9575	0.9884	0.9856	0.9810	0.9831	0.9939	0.9812	0.9812	0.9905	0.9513	0.9975	0.9739	0.9850	0.9800
N	84	84	84	84	84	84	84	84	84	64	84	80	84	84
F	285.05	1313.55	870.01	795.59	737.81	2059.40	802.51	802.51	1315.81	182.24	5101.03	447.47	830.68	620.04
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

**** p<0.01, ** p<0.05, * p<0.1*

Note1: Robust standard errors in parenthesis are clustered by AC; FE are included in every regression.

Note2: All variables expressed in logarithmic terms

Table 1: Gross Margin of wheat in regions

nlmbcebada	Andalucia	Aragón	Asturias	Canarias	Cantabria	Castilla La Mancha	Castilla León	Cataluña	Galicia	Murcia
lenergia_cebada	-0.0102533*	-0.7853672***	-0.3377906***	-0.2889273***	-10.771117***	-0.3628365***	-0.4026189***	-0.860197***	-10.220778***	-0.0791127*
	(0.01670359)	(0.1424405)	(0.096961)	(0.0985842)	(0.1033846)	(0.084515)	(0.0976355)	(0.1358602)	(0.0906925)	(0.0265291)
lfoto_cebada	-0.0623046*	-0.0258501*	-0.681099*	- 0.0069222***	-0.011743*	-0.524874*	- 0.0050928*	-0.0097751*	-0.095843*	-0.0086781*
	(0.01554448)	(0.01465819)	(0.0451054)	(0.0443868)	(0.00229063)	(0.0398243)	(0.0043308)	(0.00408191)	(0.0188529)	(0.01459889)
lfitosanitarios_cebada	0.0608174	-0.0010419	0.266773	0.7293629***	-10.044315***	0.2350826*	-0.4218065*	-10.111439**	-0.457553	-0.0175176
	(0.1383477)	(0.1604998)	(0.2672094)	(0.1961555)	(0.3851056)	(0.1374025)	(0.2306763)	(0.5217074)	(0.279379)	(0.1887994)
lfertilizantes_cebada	-0.1022038	-0.1220426	-0.3818279***	-0.4386588***	-0.2597781***	-0.3179312***	-0.1538676	-0.4076439**	0.2363345***	-0.5748415***
	(0.1154274)	(0.0977453)	(0.1015815)	(0.0960453)	(0.0801138)	(0.0797087)	(0.1036204)	(0.18735)	(0.0639585)	(0.0906071)
lsemillas_cebada	-20.196787***	-0.5085916***	-0.7392628***	-0.7978032***	0.9898342***	-0.8673152***	-0.8733669***	-0.2568122	-0.9531247***	-10.030244***
	(0.2756397)	(0.168645)	(0.1755544)	(0.1717879)	(0.2853209)	(0.1301739)	(0.1782855)	(0.2451283)	(0.2175432)	(0.1525038)
lsubvencion_cebada	10.245496***	0.4124901***	0.2656***	0.1504867***	0.565524***	0.3756178***	0.879674***	0.7907075***	0.5125782***	0.7190998***
	(0.2316698)	(0.0971509)	(0.0835404)	(0.0506306)	(0.0736794)	(0.0930522)	(0.1550193)	(0.15157)	(0.0576979)	(0.1467925)
_cons	-110.22886***	-110.42779***	-100.4235***	-90.130757***	-160.33851***	-100.71045***	-120.09717***	-120.40149***	-120.64535***	-100.58274***
	(0.5979046)	(0.4958589)	(0.5154123)	(0.3895048)	(0.6584803)	(0.3626234)	(0.597341)	(0.435481)	(0.5396641)	(0.4199733)
R^2	00.9419	00.9803	00.9754	00.9750	00.9943	00.9801	00.9756	00.9818	00.9978	00.9710
N	82	42	84	84	84	84	84	84	84	84
F	2000.03	6310.64	5020.40	4940.78	21930.72	6230.34	5070.04	6830.18	58600.35	4240.21
p-value	00.0000	00.0000	00.0000	00.0000	00.0000	00.0000	00.0000	00.0000	00.0000	00.0000

**** p<0.01, ** p<0.05, * p<0.1*

Note1: Robust standard errors in parenthesis are clustered by AC; FE are included in every regression.

Note2: All variables expressed in logarithmic terms

Table 1: Gross Margin of barley in regions

nlmbcebada	Andalucia	Aragón	Baleares	Canarias	Castilla La Mancha	Castilla León	Cataluña	Extremadura	Galicia	La Rioja	Madrid	Murcia	Navarra	Pais Vasco
	-20.041068***	-10.474142***	-10.427165***	-10.210824***	-10.341655***	-10.332746***	-10.470169***	-10.139523***	-10.359594***	-10.864389***	-10.196557***	-10.281121***	-10.576012***	-10.384322***
lenergia_maiz	(0.2175254)	(0.2177605)	(0.1959117)	(0.1938862)	(0.1734017)	(0.2336083)	(0.2008709)	(0.1968016)	(0.1020196)	(0.1606156)	(0.1633414)	(0.1848591)	(0.2019536)	(0.1167021)
	-0.130577*	-0.0300285*	-0.0132083*	-0.0500859*	-0.0167874*	-0.199325*	-0.154271*	-0.17109*	-0.0118345*	-0.0112617*	-0.019245*	-0.453354*	-0.127877*	-0.15504*
lfoto_maiz	(0.0396657)	(0.01486273)	(0.0442981)	(0.0142049)	(0.00383415)	(0.0505923)	(0.0454527)	(0.0370849)	(0.00209238)	(0.00306628)	(0.00358536)	(0.0411981)	(0.0045361)	(0.0261918)
	40.477532***	0.2564208	10.456657***	10.510184***	0.8089589***	10.844316***	-0.9599333	0.335196	-10.336417***	-0.0100572	0.2824247	0.4598448	30.220485*	-0.7811729**
lfitosanitarios_maiz	(0.4996841)	(0.7840879)	(0.3102971)	(0.257308)	(0.406414)	(0.6340642)	(0.7771317)	(0.4129654)	(0.3163649)	(0.2869279)	(0.3606979)	(0.4095844)	(0.4291667)	(0.2953339)
	-0.9409573***	0.3511202	-0.2185595*	-0.2310139**	-0.1144539	-0.2525328	0.6612295**	-0.0212947	0.3239816***	0.5073965***	0.2344649	-0.1697615	-0.8390584***	0.2101243*
lfertilizantes_maiz	(0.149676)	(0.2714117)	(0.1231889)	(0.1127353)	(0.1278001)	(0.162414)	(0.249746)	(0.1219242)	(0.0722377)	(0.1338413)	(0.1844299)	(0.1133721)	(0.2057141)	(0.1125243)
	-0.8614747***	-0.8183723***	-0.9557913***	-0.9035585***	-0.4452486*	-10.301393***	-0.1312089	-0.5792357***	10.506125***	-0.3348463*	-0.7623438***	-0.7136445***	-10.028839***	0.7343615
lsemillas_maiz	(0.2373556)	(0.2938302)	(0.2311435)	(0.217469)	(0.2134915)	(0.2716375)	(0.3790621)	(0.1890104)	(0.2467661)	(0.1917685)	(0.1796001)	(0.2262213)	(0.2393355)	(0.1842714)
	-10.62306***	0.7052109***	0.155944	-0.1619798***	0.0937775	0.0593644	0.9134555***	0.4153144**	-0.1327649**	0.7127617***	0.4600644***	0.7146643***	-0.776544***	0.2443746
lsubvencion_maiz	(0.3069425)	(0.2784327)	(0.0947524)	(0.0472978)	(0.1486768)	(0.2982902)	(0.2050482)	(0.1654388)	(0.0651612)	(0.0893302)	(0.145527)	(0.1851338)	(0.2254435)	(0.0717116)
	-60.884239***	-100.73609***	-80.740831***	-80.113706***	-90.219471***	-70.585929***	-110.13682***	-100.15307***	-130.10623***	-110.13559***	-100.21381***	-100.21372***	-50.281704***	-120.63995
_cons	(0.5322826)	(10.081892)	(0.4266869)	(0.2960172)	(0.688773)	(10.078861)	(0.5527468)	(0.534993)	(0.6427791)	(0.2333402)	(0.5686936)	(0.5828858)	(0.6999312)	(0.2374515)
R^2	0.9823	0.9705	0.9768	0.9792	0.9845	0.9699	0.9750	0.9850	0.9969	0.9880	0.9855	0.9799	0.9756	0.9935
N	84	84	84	84	84	84	84	84	84	84	84	84	84	84
F	703.78	417.17	533.21	595.77	803.59	408.41	493.78	833.65	4052.00	1046.07	858.73	617.78	507.04	1948.14
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

**** p<0.01, ** p<0.05, * p<0.1*

Note1: Robust standard errors in parenthesis are clustered by AC; FE are included in every regression.

Note2: All variables expressed in logarithmic terms

Table 3: Gross Margin of corn in regions

	Aragón	Asturias	Baleares	Canarias	Cantrabria	Extremadura	Madrid	Murcia	Navarra	Pais Vasco
lenergia_horticolas	-0.796244***	-0.9292002***	-0.7848251***	-0.6120223***	-0.7606638***	-0.4241024**	-0.548775***	-0.657385***	-0.6560378***	-0.8251924***
	(0.138933)	(0.1364293)	(0.1473254)	(0.1331418)	(0.1533319)	(0.1680978)	(0.1254396)	(0.117687)	(0.1321792)	(0.1543969)
lfoto_horticolas	-0.0535755*	-0.0531105*	-0.0726342*	-0.0401539*	-0.0683168*	-0.0686497*	-0.0570954*	-0.041173*	-0.0896654**	-0.0718706*
	(0.0260419)	(0.02440704)	(0.0488031)	(0.01430021)	(0.0485894)	(0.0449922)	(0.0396408)	(0.0138747)	(0.0422939)	(0.0487287)
lfitosanitarios_horticolas	-40.466416***	-40.446493***	-20.491489***	-20.809608***	-20.244761***	-30.900489***	-40.696464***	-40.000634***	-20.993356***	-20.913397***
	(0.7168523)	(0.4737364)	(0.234512)	(0.1808801)	(0.5586083)	(0.4071202)	(0.374913)	(0.2625144)	(0.3156091)	(0.4849668)
lfertilizantes_horticolas	-10.386841***	-10.26127***	-0.7672578***	0.8263043***	0.7247246***	-10.063462***	-10.73376***	-0.8987415***	-10.060348***	-0.90155***
	(0.2252029)	(0.1364042)	(0.0906296)	(0.0764785)	(0.1151238)	(0.1110157)	(0.1666879)	(0.0708268)	(0.1419189)	(0.1747087)
lsemillas_horticolas	-20.200612***	20.676812***	-10.566489***	10.75387***	-10.361911***	-10.71485***	-10.668151***	-10.997318***	-10.170509***	-10.763449***
	(0.2813975)	(0.2963835)	(0.1745277)	(0.1524106)	(0.4163654)	(0.1612621)	(0.1391405)	(0.1472725)	(0.1502116)	(0.279823)
lsubvencion_horticolas	0.6879891**	0.4358288***	0.0405391	0.1578893***	-0.0626613	0.5596564***	0.8539012***	0.7615902***	0.4541488***	0.0873106
	(0.2336135)	(0.101533)	(0.0681922)	(0.0318822)	(0.1070568)	(0.1520765)	(0.1354043)	(0.1114019)	(0.1521192)	(0.1106868)
_cons	-110.60828***	-120.18382***	-110.99921***	-120.10011***	-110.8372***	-110.16029***	-100.92285***	-100.82547***	-120.48393***	-120.00048***
	(0.3721695)	(0.3204402)	(0.3551846)	(0.3079378)	(0.369006)	(0.3927645)	(0.3307459)	(0.3243513)	(0.3163049)	(0.3533934)
R^2	0.9942	0.9947	0.9934	0.9950	0.9936	0.9944	0.9957	0.9959	0.9948	0.9934
N	84	84	84	84	84	84	84	84	84	84
F	2169.98	2365.00	1909.94	2518.59	1960.91	2242.06	2902.45	3077.88	2400.63	1916.71
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

**** p<0.01, ** p<0.05, * p<0.1*

Note1: Robust standard errors in parenthesis are clustered by AC; FE are included in every regression.

Note2: All variables expressed in logarithmic terms

Table 3: Gross Margin of vegetables in regions

	Andalucia	Aragón	Asturias	Baleares	Cantabria	Catilla La Mancha	Castilla León	Cataluña	Extremadura	Galicia	La Rioja	Madrid	Murcia	Navarra	Paiz Vaco	Valencia
lenergia_citricos	-0.5450958*	-0.5420048**	-0.5739693**	-0.5642316**	-0.6790539**	-0.5682672**	-0.5474021*	-0.5581729**	-0.4901787*	-0.0174552*	-0.5792034**	-0.5101727*	-0.5053432**	-0.5422879*	-0.5733393**	-0.488606*
	(0.2777938)	(0.2722089)	(0.2663229)	(0.2729444)	(0.2690852)	(0.275794)	(0.2758233)	(0.273353)	(0.2773342)	(0.0038680)	(0.2764932)	(0.2709236)	(0.2667245)	(0.273592)	(0.272228)	(0.397848)
lfoto_citricos	-0.1471096*	-0.1562194*	-0.16491*	-0.1439794*	-0.1177491*	-0.1403372*	-0.1483875*	-0.146883*	-0.1584711*	-0.1542974**	-0.1454085*	-0.161047*	-0.1661181**	-0.1519249*	-0.1505624*	-0.05189019***
	(0.087632)	(0.0872417)	(0.0852471)	(0.0878881)	(0.0721723)	(0.0879041)	(0.0878622)	(0.0876474)	(0.0867424)	(0.0609027)	(0.0875841)	(0.0860043)	(0.0848201)	(0.0872453)	(0.087321)	(2109521)
lfitosanitarios_citricos	-10.878966***	-20.035375***	-20.352257***	-10.858403***	-20.941285***	-10.83070***	-10.901674***	-10.929046***	-20.034452***	-30.714176***	-10.889957***	-20.099856***	-20.087747***	-10.930789***	-20.009342***	-10.619657***
	(0.3567385)	(0.3958495)	(0.4287536)	(0.3585884)	(0.9843257)	(0.3887036)	(0.3705727)	(0.4169782)	(0.3757922)	(0.7923751)	(0.3838571)	(0.3772001)	(0.354032)	(0.3623595)	(0.4281533)	(0.5664714)
lfertilizantes_citricos	-0.7616696***	-0.8135854***	-0.887185***	-0.7553581***	-0.9134817***	-0.7488493***	-0.7632954***	-0.7788793***	-0.7954687***	-0.6636685***	-0.775028***	-0.8726037***	-0.7740855***	-0.7940096***	-0.8119065***	-0.7283143**
	(0.1558988)	(0.1657611)	(0.1660658)	(0.1555605)	(0.2040751)	(0.1601632)	(0.156037)	(0.1705269)	(0.1565841)	(0.1327413)	(0.1746304)	(0.1705046)	(0.1498365)	(0.1633916)	(0.1790299)	(0.18702779)
lsemillas_citricos	-0.6691849*	-0.7335741**	-0.9547298***	-0.6894102**	-10.508094**	-0.6851386**	-0.6897971**	-0.7163259**	-0.6847574**	-10.60584***	-0.7083905**	-0.6719416**	-0.7230243**	-0.6633987**	-0.7616812**	0.0607786
	(0.3133334)	(0.3120569)	(0.3336882)	(0.3105451)	(0.7374541)	(0.3121183)	(0.3099557)	(0.3198407)	(0.3072684)	(0.5252702)	(0.3190073)	(0.3055535)	(0.3020613)	(0.3106979)	(0.329698)	(0.5704779)
lsubvencion_citricos	0.0274938	0.0683916	0.1260831*	0.0106074	0.215076	-0.0038226	0.0307158	0.0258704	0.0838146	0.4835508**	0.0188929	0.1065056	0.1394132**	0.0522913	0.0443518	0.1106159
	(0.0707552)	(0.0705866)	(0.0659395)	(0.062309)	(0.1878433)	(0.0699079)	(0.070911)	(0.0694641)	(0.0693493)	(0.2074431)	(0.0660555)	(0.0689641)	(0.0669289)	(0.0696392)	(0.0676592)	(0.1239646)
_cons	-90.105501***	-80.871845***	-80.326618***	-90.138771***	-60.776816***	-90.188287***	-90.066493***	-90.03845***	-80.864388***	-50.155412***	-90.089384***	-80.813846***	-80.632593***	-90.035081***	-80.914217***	-110.77866***
	(0.8463263)	(0.8807014)	(0.9226554)	(0.8525121)	(20.025679)	(0.8788903)	(0.8637517)	(0.9033814)	(0.860036)	(10.749597)	(0.8783565)	(0.8487931)	(0.8468063)	(0.8463275)	(0.9160689)	(20.16259)
R^2	00.9874	00.9876	00.9880	00.9874	00.9897	00.9874	00.9874	00.9874	00.9876	00.9894	00.9874	00.9878	00.9877	00.9875	00.9875	1280.90
N	82	82	82	82	84	82	82	82	82	84	82	82	82		82	56
F	9670.88	9780.30	10140.22	9660.27	12200.74	9650.93	9680.37	9670.72	9850.20	11860.89	9660.97	9970.42	10230.24	9730.34	9710.57	00.9416
p-value	00.0000	00.0000	00.0000	00.0000	00.0000	00.0000	00.0000	00.0000	00.0000	00.0000	00.0000	00.0000	00.0000	00.0000	00.0000	00.0000

**** p<0.01, ** p<0.05, * p<0.1*

Note1: Robust standard errors in parenthesis are clustered by AC; FE are included in every regression.

Note2: All variables expressed in logarithmic terms

Table 5: Gross Margin of citrics in regions

	Andalucía	Aragón	Asturias	Canarias	Cantabria	Castilla La Mancha	Galicia	La Rioja	Murcia	Navarra	Pais Vasco
lenergia_olivar	-0.3837415*	-0.1246857*	-0.1409782*	-0.4817234***	-0.628342***	- 0.1264738*	-0.0439776*	-0.36706*	-0.3550236*	-0.0337684*	-0.2583521*
	(0.288362)	(0.01544155)	(0.02219216)	(0.1841272)	(0.2373669)	(0.0700055)	(0.0132765)	(0.2178719)	(0.2402036)	(0.0422735)	(0.1221238)
lfoto_olivar	-0.1297484*	-0.694505*	-0.151954*	-0.526423*	-0.106622*	-0.0811051*	-0.039502*	-0.156836*	-0.536816*	-0.0835322*	-0.202264*
	(0.0907172)	(0.0903996)	(0.0809289)	(0.0659352)	(0.0633708)	(0.03741117)	(0.00366901)	(0.0791596)	(0.0681014)	(0.04781218)	(0.0794254)
lfitosanitarios_olivar	0.553919	-0.1796645	-0.3540758	-0.1104303	-30.530034***	-0.2713737	-0.5944505**	-0.8095445*	0.4419006	-0.2102346*	-0.9497345*
	(0.6743137)	(0.3756013)	(0.4714683)	(0.2516798)	(0.8849857)	(0.2471002)	(0.2346544)	(0.4075549)	(0.4030656)	(0.1188810)	(0.4811323)
lfertilizantes_olivar	0.1180017	-0.6009882***	-0.5264997***	-0.4206811***	-0.3217028*	-0.440014***	-0.3693059***	0.7618682***	0.6427646***	0.2267556	-0.7581035***
	(0.2125506)	(0.1671521)	(0.1666054)	(0.1178005)	(0.1830063)	(0.1215111)	(0.0813637)	(0.1955359)	(0.129275)	(0.2427316)	(0.2005954)
lsemillas_olivar	-0.2804221*	-10.238529***	-0.8852923***	-10.057654***	-40.201463***	-10.564462***	0.1592079	-0.7847074***	-0.3110777**	-0.659027**	-0.7201318**
	(0.1594967)	(0.2960318)	(0.2712573)	(0.1927309)	(0.6525364)	(0.1822432)	(0.1695621)	(0.2409075)	(0.1411495)	(0.2568738)	(0.2557953)
lsubvencion_olivar	0.9428748**	0.0079576	0.0154876	0.373998 ***	0.5786989***	0.3118132**	0.940415***	0.2889507*	10.337767***	0.296012*	0.2599125*
	(0.3752108)	(0.1840667)	(0.1405305)	(0.0582084)	(0.1756286)	(0.1480721)	(0.1186076)	(0.158843)	(0.2297606)	(0.2277937)	(0.1525634)
_cons	-90.033629***	-100.80379***	-110.6944***	-130.21649***	-110.1981***	-100.90567***	-70.979976***	-120.534***	-90.162473***	-100.06764***	-120.26342**
	(0.8170992)	(0.6620868)	(0.4517539)	(0.3888473)	(0.346874)	(0.5620714)	(0.3497759)	(0.6038434)	(0.3613367)	(0.6460721)	(0.5106607)
R^2	0.9592	0.9479	0.9606	0.9745	0.9767	0.9688	0.9953	0.9623	0.9773	0.9705	0.9621
N	84	84	84	84	84	82	84	84	84	84	84
F	297.47	230.23	309.09	483.79	531.32	383.59	2692.95	323.05	546.00	417.18	321.33
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000	0.000	0.000

**** p<0.01, ** p<0.05, * p<0.1*

Note1: Robust standard errors in parenthesis are clustered by AC; FE are included in every regression.

Note2: All variables expressed in logarithmic terms

Table 6: Gross Margin of olive in regions