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Introducing the Water-Energy link in a General Equilibrium Model: ICES-WN

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1. Introduction

The Water-Energy-Food Nexus is increasingly recognized as a fundamental issue in both the academic and policy environment. Its relevance originates from its sensitivity to the risks of exhaustion and overexploitation [1]–[3] and its critical role for human wellbeing and societal development since all its three elements are fundamental human needs [4].
While the importance of this theme is widely recognized [5], [6] the explicit representation of all its nodes in General Equilibrium Models is significantly underdeveloped. In particular, there are very few global scale models and not many works that address the links other than the water-food one. Indeed, even in the most equipped frameworks in the literature, i.e. GTAP [7]–[9] and RESCU-Water [10], there are still some connections that are not well represented (e.g. the water-energy link).
Nevertheless, it is fundamental to integrate all the links in General Equilibrium Models, including the one between the energy sector and the water endowment, as this would allow to fully understand the economic consequences of policies and the potential impacts of macroeconomic shocks on the Nexus and general well-being of the countries.
Therefore the aim of this paper is to adapt a GTAP-based Computable General Equilibrium Model, ICES (Static version) creating ICES Water Nexus (ICES-WN) and analyze the effects of the modifications. In particular, this version is innovative in its direct inclusion of the link between water and energy, through the modification of the production function of the firms, including the energy sector, and the expansion of the original database to associate previously missing data to water for energy value-added. These modifications increase the possibility of addressing several issues undetected before, such as the potential impacts of climate change induced water scarcity on the energy sector. Moreover, it allows to evaluate the critical issue of water competition between fundamental sectors for these specific goods. Finally, it opens to the perceptions of undetected feedback of policies, such as potential water constraints to a carbon tax or energy and food security issues due to international trade taxes.

2. Initial Structure and Data

2.1. Database and additional data

The paper starts from the GTAP-W-BIO Database (The Baseline year 2011 - GTAP9 basis) [7] and introduces the water-energy link in addition to the existing crops-water link [11]. The procedure in the paper aligns with the suggestions made by Hertel and Liu [12]. It extracts the water value-added for

the non-agricultural sector (i.e. energy), splitting the value from the capital endowment value-added. The first step of the splitting process is built on the FAO estimated quantity of m3 of water withdrawn by irrigated agriculture embedded in the GTAP-W-BIO database. This information was used to calculate the value added of a singular m3 of water for the reference year of the different regions, providing the firm purchase prices (both at market and agent level) and endowment output overall price. These values are used together with the data provided by the IEA 2012 World Energy Outlook (WEO) [13] i.e. water withdrawal values for the energy sector diversified by regions to calculate the final amounts of value added associated with the energy sector specifically for the ten regions.
Indeed, the splitting process assumed the homogeneity of prices between sectors in the same region, i.e. agriculture and non-agriculture have the same regional price. This derives from the assumption that extraction/use cost and the risk of water shortages are the same according to the location. As shown in Table 1, the energy sector's water use, differentiated regionally, identifies the most water intensive regions (Energy-wise): OECD America, China and India. On the other hand, these shares show how the percentage of water value-added extracted from Capital in the Energy sector for Africa, and, most importantly, the Middle East, is close to zero. This reflects the low technological dependence on water of the energy sector in these regions, which are coherent with the technological diffusion and their physical availability (i.e. for the Middle East).

Table 1. Capital share of Energy and Water VA Extraction

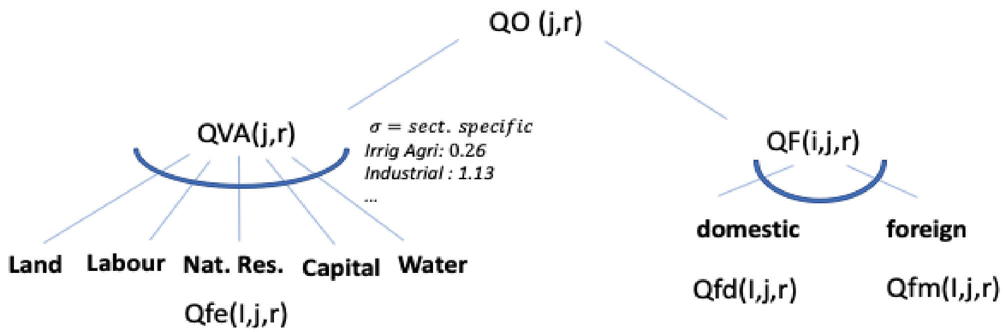
Region	Water Withdraw ENERGY (billion m3)	Water Value Added in Energy			Capital Value Added in Energy Sector			Share of Capital directed to Water (%)		
		VFM	EVFA	EVOA	VFM	EVFA	EVOA	VFM	EVFA	EVOA
OECDAmerica	241	11679.13	10268.46	10746.31	299185.50	309022.06	4823449.00	3.90	3.32	0.22
China	106	2993.30	2375.74	2959.75	95477.62	95614.33	2925523.25	3.14	2.48	0.10
India	40	974.11	974.66	938.75	36455.89	36476.50	684071.56	2.67	2.67	0.14
OECDEU	61	2475.15	2379.49	2282.06	260282.02	265589.34	6401322.50	0.95	0.90	0.04
Othereueurasia	95	1256.38	1274.56	1188.03	193118.69	196711.02	1151904.25	0.65	0.65	0.10
Latinamerica	16	487.48	492.12	453.73	128161.72	129286.97	1575094.00	0.38	0.38	0.03
Asia	11	165.07	166.05	155.09	92483.06	93151.92	1224403.50	0.18	0.18	0.01
OECDoceania	5	158.84	147.46	146.56	91064.69	93576.45	3067511.25	0.17	0.16	0.00
Africa	5	67.72	68.11	57.74	158781.41	160577.06	720084.19	0.04	0.04	0.01
Middleeast	3	45.04	45.52	43.58	522909.75	528546.44	1377191.75	0.01	0.01	0.00

The final version of the database is aggregated in five sectors, i.e. Irrigated agriculture, Rainfed agriculture, Industries, Energy and Services, and provides water uses for both the Irrigated agriculture and the Energy sectors. The database is also aggregated in 10 regions: Oecd-Europe, Oecd-America, Oecd-Oceania, Other Europe and Eurasia, China, India, Other Asia, Latin America and Caribbean, Africa and Middle East. The changes affected the values of three elements of the database: the Firm endowment market price, the Firm Endowment agent price and the Endowment output price i.e. respectively VFM, EVFA and EVOA. The final values are coherent with the overall literature of water withdrawal by sector [14]–[18].

2.2. Model structure and production function

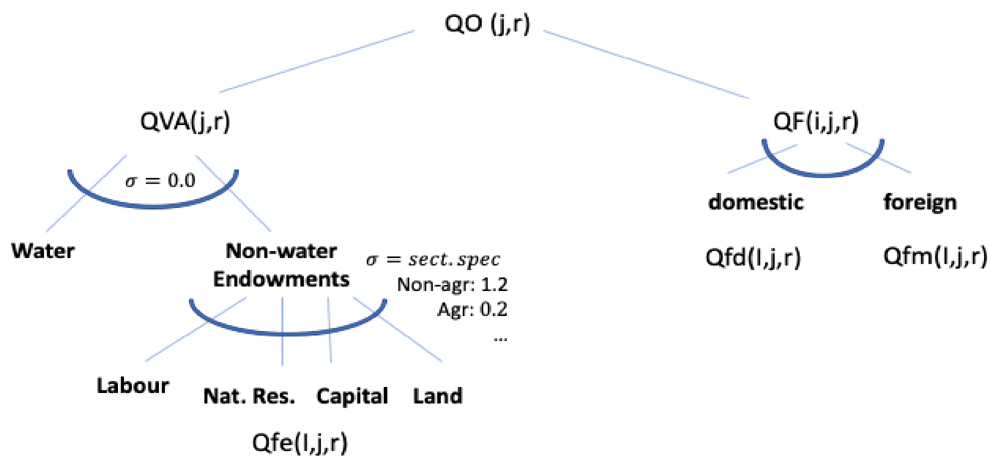
For what concerns the production functions, two different structures were implemented. The first version, i.e. *Original,* corresponds to the pre-existing ICES structure, a one-level production function with unique sector-specific elasticity of substitution between every factor. This version strongly simplifies the reality and is based on an approximated elasticities of substitution between endowments, which are only sector-specific and not endowment-specific (i.e. it is the same between every couple of endowments, as it was calibrated in the original GTAP9 Database). The original production function is shown in Figure 1 hereafter.

Figure 1. Original One Level Production Function (i.e. *Flat*)



The second, new version, on the other hand, modifies the production function on the basis of the work of Nechifor and Winnig [19]. This decomposition, i.e. ICES-WN, separates the endowments in two blocks, water and non-water, and impose a specific elasticity between the two blocks to almost zero, i.e. *quasi-Leontief,* as shown in Figure 2. The authors consider this structure more realistic since it assumes that in the complete absence of water, plants and turbines and farmers would be strongly constrained, no matter the amount of the other endowments involved. For what concerns the non-water block, the second level structure is identical to the original one, with all the endowments exchangeable with the others. The elasticities within the non-water block calibrated to the GTAP-W-BIO original ones.

Figure 2. Two level production function (i.e. ICES-WN)



The model's functioning has been tested with systematic shocks on the water endowment supply in order to evaluate the behaviour and economic coherency of the modified versions.

3. Water Scarcity Simulations: Testing the improved Nexus specification

To test the macroeconomic effects of the introduced changes were performed several systematic shocks simulating homogeneous water scarcity shocks. More specifically, it started with a 10% uniform reduction of the water endowment, systematically increased by 10 percent up to a 50% reduction, which was the highest reduction allowed by the less flexible versions. Despite the fact that some versions allowed also higher water endowment reductions, 50% seamed a reasonable upper limit, considering the literature on CGEs water simulations e.g. [20] and the expected physical global water scarcity projections [21], that expect a maximum of -30% in water availability in the water-scarce regions.

The first part of the results will highlight the impact of all the water scarcity shocks on the global GDP while the second part will highlight the regionally disaggregated impact of the higher reasonable water scarcity scenario[1] in the ICES-WN production function scenario, with mobile[2] land and water. Indeed, this was the version that was considered by the authors as the most realistic and better calibrated to realistically address the issue of water scarcity minimizing the eventual distortions.

For what concerns the mobility issue (i.e. the decision on the endowment characteristic) the definition of Slug endowment in the model is determined by the parameter binomial (zero-one) parameter SLUG, which determines which CET function describes the behaviour of the specific endowment. The possible CET are two: the first is the one where the endowment can be reallocated between sectors (mobile), with their specific elasticities described by the parameters reported in the production function (i.e. ESBVA in the Original version), and the other in which they can not move between sectors (slug, with elasticity zero or negative described by the parameter ETRAE). All the water scarcity simulations were conducted in three different scenarios altering the SLUG binomial parameter: Land and Water mobile between sectors, Land and Water non-mobile and Water mobile and Land non-mobile. The choice of changing the assumption on land to mobile between sectors is due to the fact we assume there is no need to assume that land could not redirected easily from irrigated to rainfed, as it does not imply new technology implementation, and that is the trend that would be triggered by hour simulation, not the other way around, which is the basis for the land sluggishness assumption. Indeed, Indeed, assuming mobile land helps mitigate the peak in irrigated agriculture prices, without changing significantly the results in other prices or rainfed agriculture output.

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Table 2 summarizes the different versions of the models according to their main characteristics (i.e. database and production function used, which corresponds to the main modification produced in this work).

Table 2. Versions used for systematic comparison

Version	**Original Database** (Water only for Irrigated Agr.)	**New Database** (Water for Energy and Irrigated Agr.)	**Original production function** (One level function - **Fig. 1**)	**New Production function** (Two level function - **Fig.2**)
Original	x		x	
Flat		x	x	
ICES_WN_Original	x			x
ICES_WN		x		x

3.1. Impacts on global GDP for the different model specifications

[1] In a precise water scarcity projection a -30% is the highest possible shock expected in the 2050 horizon, meaning it is supposed to affect only the most water scarce regions, and not the whole world. Nevertheless the purpose of this paper was to analyse the technical reaction of different structures and different shocks more than to focus on realistic future water scenarios, which will be the objective of future works.

[2] The mobility issue in this model only refers to mobility between sectors, as this framework does not allow mobility of any endowment between regions by construction. The decision of focusing on the mobile land and mobile water version was taken considering the results of the first simulations that conducted a systematic analysis of the impact of different assumptions in this regard.

Table 3 reports the percentage impacts on the global GDP due to the different shocks for the different versions under examination, with systematic variation of the mobility parameter for the two key endowments (Land and Water)[3].

Table 3. Impacts on Global GDP

	-10%	-20%	-30%	-40%	-50%
Original_SlugLa_SlugW	-0.01	-0.04	-0.08	-0.16	-0.39
Original_MoveLa_SlugW	-0.01	-0.04	-0.08	-0.16	-0.38
Flat_MoveLa_MoveW	-0.02	-0.04	-0.08	-0.16	-0.32
Flat_SlugLa_MoveW	-0.02	-0.04	-0.08	-0.16	-0.32
Flat_SlugLa_SlugW	-0.02	-0.04	-0.09	-0.18	-0.42
ICESWN_Original_MoveLa_SlugW	-0.04	-0.56	-3.08	-8.21	-16.02
ICESWN_Original_SlugLa_SlugW	-0.04	-0.56	-3.09	-8.22	-16.02
ICESWN_MovLa_MoveW	-0.05	-0.4	-1.72	-5.01	-10.66
ICESWN_SlugLa_MoveW	-0.05	-0.4	-1.72	-5.02	-10.67
ICESWN_SlugLa_SlugW	-0.05	-0.63	-3.44	-9.08	-18.63

3.1.1 The role of the introduction of water data for energy use (Database changes)

The results show that with the original production function – database with Water only for irrigated agriculture (i.e. Original and Flat versions) - the impacts of water scarcity is more negative in the one sector with respect to the water for two sectors in terms of global GDP. Therefore, expanding the allocation possibilities widen the probability of finding an efficient equilibrium and increase the regional and sectoral adaptation capability, lowering the overall negative effect of a shortage on the GDP for the same shock entity. This, nevertheless, is only true if we assume the creation of a market that both the water demanding sectors can use and which can drive the reallocation between sectors. Indeed, in the case of no market, i.e. no water movement between sectors - slug water, the impacts on GDP are higher in the two sectors scenario. This output is reasonable considering that in this scenario there are two sectors suffering from the decline of the availability of a production endowment, but only a low possibility to adapt to the shock. In both the *one level* production models (Original – one sector, Flat – two sectors) it appears that the assumption on land mobility has very small impact on the overall GDP and its entity is negligible respect to the existence or no-existence of a water market effect. However, this could be linked to the nature of the shock under examination (i.e. direct reduction of an endowment), and, nevertheless, it does have an impact in terms of land prices fluctuations. Therefore, the effects of the assumption on the mobility of endowments, and particularly land on the overall framework should be further examined. The same trends can be detected considering the lower part of Table 3, which represents the values with the *two levels* production function. As a consequence, it is possible to deduce that the assumption on water mobility is an inverse multiplier of the impacts on the overall GDP: high mobility (i.e. presence of a market for sectoral allocation) leads to low impacts on the GDP while no mobility (slug endowment) leads to high impacts. Therefore, it can be suggested as a clear market for water accessible by all users could be fundamental in adapting to water scarcity and mitigate the relative GDP impacts.

3.1.2. The role of production function modification

A second stream of findings is related to analysis of the differences between the original production function and the ICES-WN functional specification. Indeed, the latter is a less flexible structure (i.e. almost Leontief), with no substitution of water with the other endowments, therefore the negative

[3] The One-sector database version was not tested for sectoral water mobility because it is assumed that since no other sector is using the endowment, by definition it cannot move.

shocks on the water endowment cannot be mitigated substituting a production factor with others. Interestingly, this has a stronger effect than the mitigating effect of spreading risk and efficiency opportunities created by the higher number of sectors. Indeed, with this structure and the limited substitution possibilities, the effects on the global GDP increase drastically in all the versions respect to the *one level* original production function. Therefore, as shown in the lower section of Table 3, in the context of mobile water and the creation of a multi-sectoral market for the endowment, the less flexible production function has higher GDP impacts in all the scenarios with respect to all the flat flexible versions. The worst case is the two sectors, two levels (Leontief), no movement of both water and land endowments, as, clearly, the ability to adapt to water scarcity are the lowest.

These simulations therefore underline the importance of the representation of water competition and of a common market for the water using sectors, as it can significantly influence the GDP impacts of water scarcity. Moreover, the simulations highlight the importance of understanding the role of water in the production of water-using sectors, as the elasticity between water and the other factors and the consequent overall dependency from water availability can have important effects on the overall macroeconomic impacts. Consequently, the introduction in the production structure of all the links of the Nexus is important since different constructions can significantly affect the simulation's results.

3.2. Price and output behaviours of different specification under water scarcity shocks

This section highlights the behaviour of prices and output for the four different model specifications (Original, Flat, ICES-WN_Original, ICES-WN) for the systematic water shocks for the two significant sectors (Irrigated agriculture and Energy). The results shown hereafter are the ones with mobile land and mobile water, as we wanted to address water competition and mobility between sectors. This assumption will be maintained for the rest of the paper. The figures showing the results described hereafter can be found in the Supplementary Information. For what concerns the output of irrigated agriculture, in all four the specifications the sector suffers greatly, as one of the main endowment (water) is increasingly reduced. The reductions are the highest in the ICES_WN_Original scenario, where there is no space for sectoral efficient allocation management and low endowment substitution possibility. For what concerns the role of competition and production structure, it can be inferred that both the versions with inflexible production functions have higher losses, while competition between sectors has the effect of changing international equilibrium and efficient allocations, but the entities between the original and Flat versions remain comparable. For what concerns irrigated agricultural prices, they also show a trend, with prices increasing in all the versions, and also for this variable the highest increase is in the ICES_WN_Original version, which still can be explained by the sector suffering from the lack of efficient allocation possibility and higher dependency. Even for irrigated agricultural prices it can be inferred that competition can lead to efficient allocations and decrease the negative impacts, but it has a lower impact of the more rigid production function, as it was found in irrigated agriculture quantities and in section 3.1. for global GDP.

For what concerns the sectoral output of energy production, the results are showing different regional trends. In the versions in which the endowments are substitutable (Original and Flat), impacts have low entities, with relatively higher impacts in Flat because of the introduction of dependency from water of the energy sector. On the other hand, both the versions with the inflexible production function have bigger impacts in absolute value, the ICES_WN_original is driven by the overall negative impacts on the economies, since in this version energy does not depend on water, and ICES-WN presenting regionally stronger impacts, meaning that water dependency accentuate the gains and losses of differently water endowed and dependent regions.

Finally, for what concerns the energy prices, the results show that in the non-dependent versions (Original and ICES-WN-Original) the prices decrease, more in the latter, which is a scenario that has the worst overall macroeconomic outputs. In the energy-water dependent scenarios, instead, the scarce water and increasing prices of this endowment drives up energy prices. While in the Flat version it is possible to substitute water for other endowments, which reduces the overall increase in the prices, in the ICES-WN version the prices increases linearly and by a higher entity. For this specific reason, also considering the strong dependence of several energy production techniques from water availability [13] we consider the ICES-WN as the most realistic version and in this scenario the water competition will be analyzed (Section 3.4).

3.3. Regional effects: impact of 30% uniform water reduction in different model specifications

This section will compare the effects of a uniform 30% global water scarcity impact, the peak value physically expected on earth in the 2050 horizon, in the Original, Flat and ICES-WN versions with mobile land and water, stressing the regional implications. The results will evaluate the impacts on the models *per se* and in comparison between them. This section will therefore illustrate the effects of the changes in the database, the creation of water competition between energy and agriculture and the two types of production functions for the different regions with regard to sectoral output, market prices and import share, which are some of the key variables addressed through this work. Table 4 reports the main quantitative findings.

Table 4. Main variable comparison

	Sectoral Output % Change						Market Prices % Change						Imports % Change					
	Irrigated Agriculture			Energy			Irrigated Agriculture			Energy			Irrigated Agriculture			Energy		
	ORIG	Flat	ICESWN	Origin	Flat	ICESWN	ORIG	Flat	ICESWN	ORIG	Flat	ICESWN	ORIG	Flat	ICESWN	ORIG	Flat	ICESWN
1 OECDEU	4.57	5.56	0.08	-0.49	-0.55	-43.13	14.70	8.28	833.16	-0.14	0.55	49.21	-3.34	-4.46	5.28	0.28	0.25	32.71
2 OECDAmerica	-5.36	-0.32	12.48	-0.33	-2.03	-57.54	26.77	15.28	873.81	-0.20	1.31	85.76	11.72	4.75	44.38	0.30	2.06	111.40
3 OECDAsiaOce	6.08	3.62	-21.31	-0.85	0.09	30.81	13.91	10.83	1073.24	-0.21	0.20	15.40	-13.94	-5.57	71.62	0.07	-0.18	-6.54
4 OthEUEuras	-6.48	-4.23	-33.39	-0.18	0.02	9.42	22.14	15.33	976.44	-0.25	0.41	26.52	12.74	8.88	42.37	0.07	-0.18	-6.16
5 Asia	-5.64	-6.28	-24.58	1.46	1.96	66.73	37.66	34.61	866.80	-0.79	-0.15	15.24	32.94	38.75	-13.76	-1.49	-1.55	-29.98
6 Cina	0.63	0.36	-10.77	-0.13	-0.94	-53.17	17.13	12.39	1178.29	-0.40	0.72	65.48	-10.33	-5.30	148.56	-0.16	1.21	105.21
7 India	-5.93	-5.69	-25.42	3.90	1.62	10.73	48.32	42.67	818.57	-2.66	-0.96	4.16	73.48	79.46	-31.61	-4.39	-2.52	-44.41
8 MiddleEast	1.52	-0.46	-20.01	-0.10	0.33	18.22	14.41	12.96	752.84	-0.43	0.28	24.62	-5.94	-0.87	-13.12	-0.21	-0.36	-9.39
9 Africa	4.15	1.13	-19.65	-0.05	0.56	35.63	13.75	11.65	876.28	-0.37	0.42	27.64	-12.26	-3.94	-12.54	-0.48	-0.31	-16.83
10 LatinAmerica	-2.35	-4.26	-25.49	-0.23	0.32	24.01	24.73	18.60	1081.94	-0.31	0.49	27.42	5.01	10.36	72.10	-0.15	-0.09	-3.68
Global Mean	-0.88	-1.06	-16.81	0.30	0.14	4.17	23.35	18.26	933.14	-0.58	0.33	34.15	9.01	12.21	31.33	-0.61	-0.17	13.23

For what concerns the sectoral output, with the original flexible one sector model, the impacts on agricultural production varies within the range of + and - 10% with five regions having a positive impact and five negatives. On the other hand, the inflexibility due to the reduced elasticity of substitution between water and the other factors of production drastically change the entity and the sign of most impacts, with 8 out of 10 regions clearly suffering of losses of around 20% and only one region that clearly improves its production of more than 10%, OECD America. The fact that this is mainly due to the stronger dependency to water of ICES-WN can be inferred by the fact that the Flat version (i.e. two sectors but original production structure) has a comparable distribution and entity of the impacts, meaning that it is not the competition between sectors that drives this spikes in production. For what concerns energy, we see that in the Original version the impact on the production of this sector is almost zero, with only a significant positive output in India, which increases of 4%. The impacts in the Flat version, similarly to the case of irrigation, are comparable to the original, with slightly different entities. Nevertheless, in the ICES-WN version, the strongly water dependent production function creates stronger effects, with three regions dropping drastically their production, i.e. more than 40% decrease. The other regions, on the other hand, sensibly increase their production of energy, Asia in particular, which increases its energy output of more than 60%.
Regarding the prices, a similar trend can be detected. For the case of irrigated agriculture, the differences between prices in the original version and ICES-WN is 20 to 70 times higher, driven by the reduced possibility of substitute water with the other factors and the water competition with energy. This can be deduced by the fact that, one again, while the prices in ICES-WN increase, the prices in the flat versions, while still growing because of its dependence from a reducing endowment, grow less than the original version. This means that competition could contain the spike in prices connected to

water scarcity, but assuming an inflexible production structure water scarcity would mean anyway to have strong, higher security issues. For what concerns energy prices we see a difference between the original and the flat version. While in the first case the prices of the energy sector had mostly negative, close to zero impacts, in the Flat version the introduced dependency of the sector from a scarce endowment drives the prices up, as expected from the basic economic theory. Once again, this trend is more marked in the ICES-WN versions, with prices also increasing by 85% (OECD America) because of both dependency and inflexible production structure.
Concerning the imports of irrigated products, introducing competition makes import decrease between the original and the flat the number of regions worsening or improving their import dependency is the same (i.e. five) but only three of them actually decrease their irrigated agricultural import dependency (i.e. OECDEU, OECD America and Other Eu-Eurasia). Nevertheless, with the inflexible production structure of ICES-WN, the shocks lead to only four regions decreasing their imports, while the other increase a lot their imports and therefore their food dependency, particularly China (+150%) and OECD Asia (+71%). Interestingly, introducing competition changes the entity but not the sign of import percentage change, meaning that if a country is expected to decrease their dependency from imports in a water scarcity scenarios, has the same result in a two water using sectors water scarcity scenario, but this is not true with an inflexible production structure, where five of the ten regions change their sign, meaning that strong dependency from water can change drastically their propensity to increase water-based products imports in water scarce scenarios or the inverse. Therefore, we can infer that assessing with precision water dependency of the different sectors can have an enormous impact in shaping the international trade trends in a context of water scarcity and climate change, at least for what concerns food products. For what concerns energy imports, the main trends are always the same in all the three versions, meaning that import dependent countries do not shift their trends in international trading, but it worsens their dependency the more energy production is water dependent. Asia and India are mainly decreasing their dependency from import, which is accentuated in ICES-WN where they have, respectively -30% and -44% change in imports, while OECD and China are expected to increase their import dependency, particularly in the ICES-WN version, where they have respectively a 111% and 105% increase in energy imported. The mean global trend is to increase irrigated agriculture of 31% for irrigated agriculture and +13% for energy, which reflects the higher water dependency of irrigated agriculture with respect to energy in terms of water content. Irrigated agriculture had a significant positive number also in the original version (+9%) meaning that water scarcity can increase the general reliance on imports from water abundant regions, and it is particularly true adding competition (which has 3% more, 12% overall) and inflexible production. Different is the situation for the energy sector in which the mean import dependency at a global level is low in the first two versions, actually a little better when introducing competition (flat version), but substantially increases (+13%) in the ICES-WN version. This high dependency on imports of water dependent goods in the inflexible, competing versions stress the needs of further research on the topic, as clearly underlines the risk of food and energy dependency and insecurity for many regions, that could lead to a failure in providing basic goods in a context of water scarce futures.

3.4. Water Competition implications under a 30% Water scarcity scenario in ICES-WN.

This section will focus on the analysis of the impacts that an homogeneous 30% water reduction scenario could have in ICES-WN (i.e. the final and most reasonable version to address water scarcity effects) in terms of water competition and food and energy security. Indeed, as shown in Table 4 a water scarcity scenario can have significant impacts on the water dependent sectors behaviour in all the regions. The results show that a 30% reduction shock could lead to a decrease in irrigated agriculture production of around 20% in most regions with prices of these goods spyke in all the regions. For what concerns the energy sector, instead, both prices and output rise in most of the regions. Nevertheless, for the few regions in which the prices are driven higher by water scarcity

(OECD Europe, OECD America and China, respectively +49%, +85% and +65% in energy market prices) the production of this sector suffers greatly, dropping production by about a half. These trends, in a context of efficient possible allocation between sectors, can lead to significant implication for the allocation shares of water between the two sectors, as shown in Table 5 hereafter.

Table 5. Main Findings regarding water competition in ICES-WN for a 30% water scarcity shock

Regions	% change Water Demand		Water Use % share			
	Energy	Irrig. Agr	Initial Energy	Initial Irrig. Agr	Energy	Irrig. Agr
1 OECDEU	-55.38	-13.33	39.65	60.35	25.27	74.73
2 OECDAmerica	-64.90	2.26	48.03	51.97	24.08	75.92
3 OECDAsiaOce	-1.43	-32.25	7.29	92.71	10.27	89.73
4 OthEUEuras	-12.36	-39.95	36.06	63.94	45.14	54.86
5 Asia	35.64	-31.05	1.57	98.43	3.05	96.96
6 Cina	-62.91	-21.92	19.71	80.29	10.45	89.56
7 India	-9.30	-31.17	5.34	94.66	6.91	93.09
8 MiddleEast	-7.79	-30.33	1.46	98.54	1.92	98.08
9 Africa	4.57	-30.78	2.22	97.79	3.31	96.69
10 LatinAmerica	-1.98	-33.14	10.07	89.93	14.11	85.90
Mean Global	-17.58	-26.17	17.14	82.86	14.45	85.55

Indeed, for most regions and as a global mean trend, water shifts toward irrigated agriculture, which is a percentual leader in water use and has a smaller demand elasticity of irrigated agriculture goods from households and governments. In a context where we assume an almost Leontief production function for water in the energy sector, it could lead to a problematic increase in energy security issues in water scarcity scenarios and/or energy dependency for the most affected regions. On the other hand, OECD Asia Oceania; Other Europe Eurasia, Latin America, and, with lower intensity for Asia, India and Africa, show an increase in the share of water attracted to energy, which could depend both to the presence of a significant rainfed agriculture sector and/or by the water intensity of the energy structure. Nevertheless, in the case of these specific regions the opposite trend could appear, and issues of food and nutritional security could arise, as well as food import dependency.

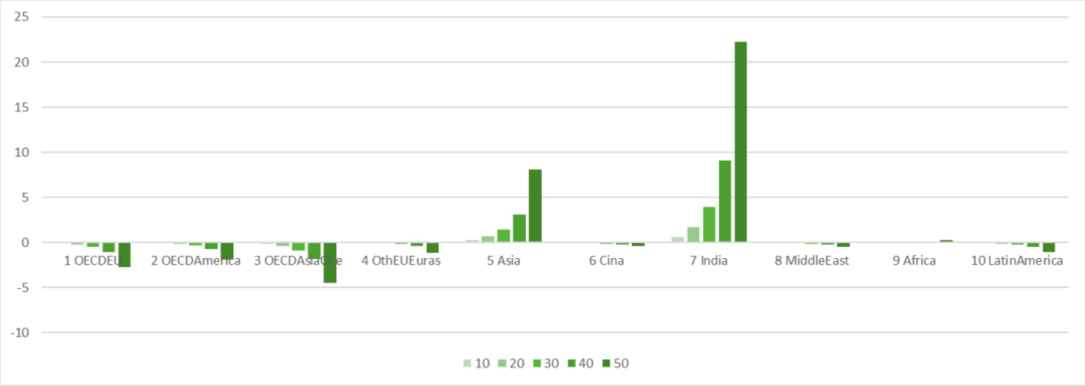
4. Conclusions

The aim of the paper was to show the effects of introducing water competition and a clear market for water, as well as testing the effect of different structures of the production function. The conclusions were mainly two. The first one is about competition, and the test carried out in this study showed that in presence of a clear market and the ability to allocate efficiently the resources between two using sectors, competition can lower the overall negative effects of a water scarcity shock. Nevertheless, this is not true in a context where the endowment cannot be redistributed across sectors (slug endowment), scenario in which now two sectors are suffering for endowment scarcity, therefore have higher overall impacts on gdp and production losses.
The second order of conclusions concerns the production function structure. The finding is that it is important to clearly understand the dependency of agriculture and energy from water and following the most recent suggestions in the literature brings to a very low elasticity of substitution between water and the other primary factors, which multiplies the eventual losses related to water scarcity.
In a context where extreme events and heatwaves can and will sensibly alter water availability in the short and mid-term future, it is important to have up-to-date models that perceive the importance of this endowments, as it could reflect on the ability to correctly advise policy makers and ensure food and energy security in a climate changing future.

Supplementary Information.

Figure A1. Output quantity of Energy sector

1. **Original**



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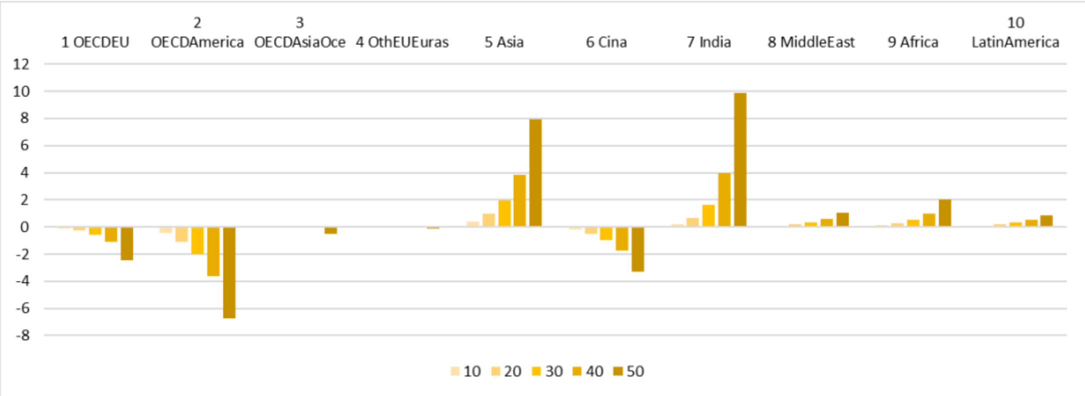
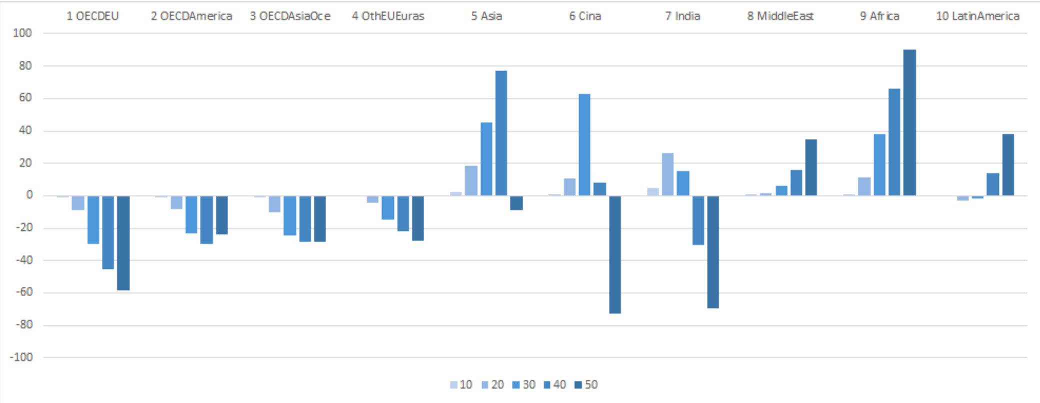


3. ICES-WN-Original



4. ICES-WN

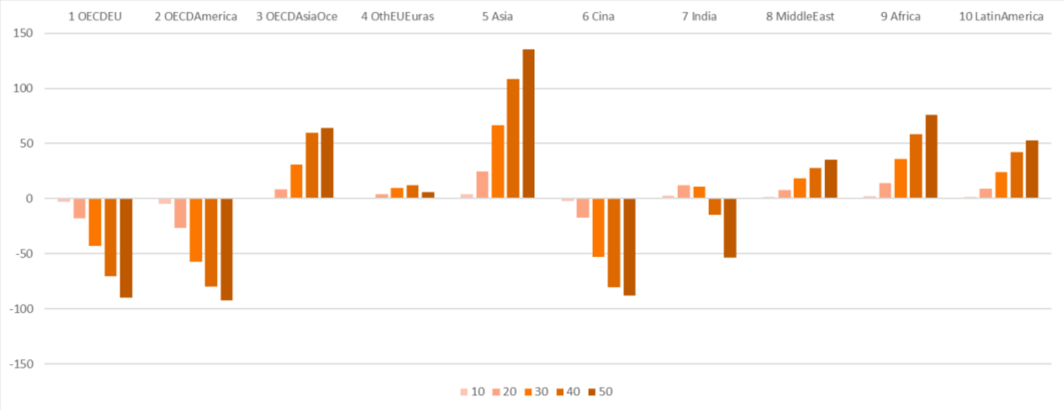
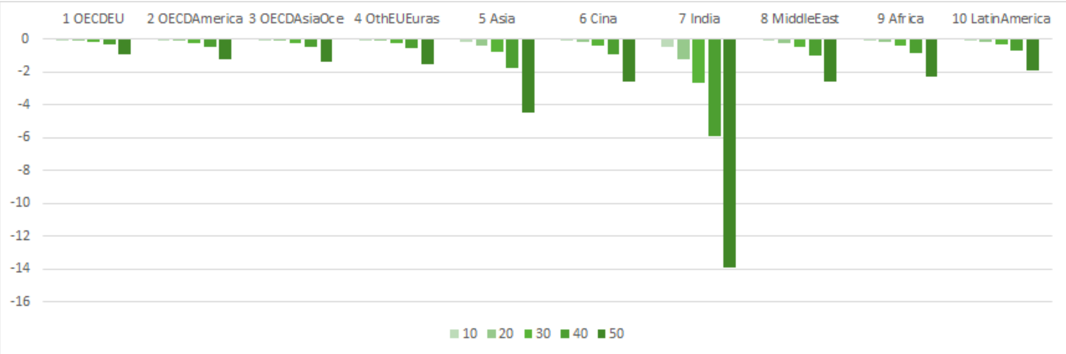


Figure A2. Market Prices of Energy sector

1. Original



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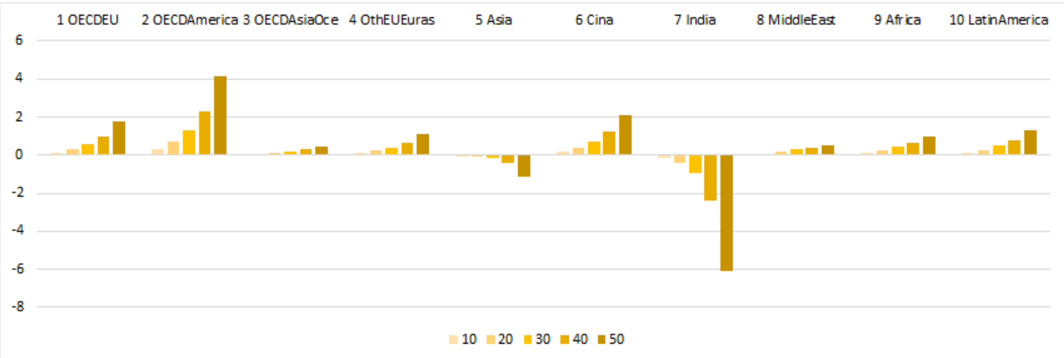
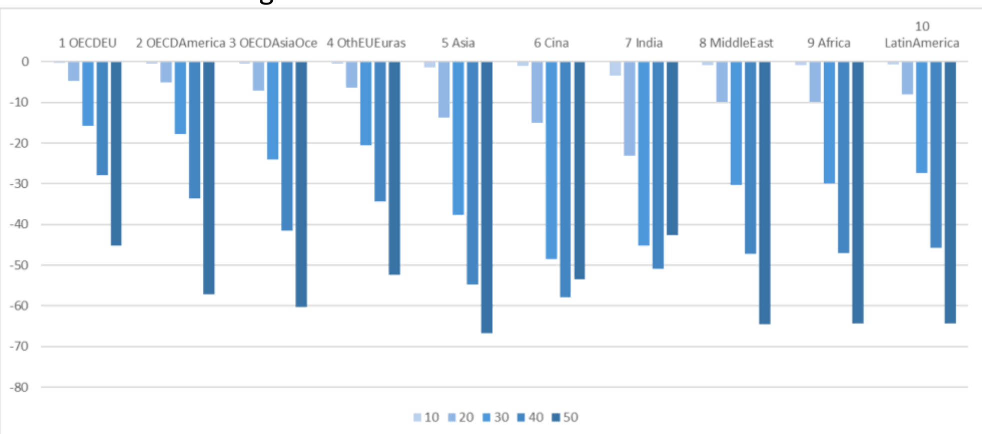


3. ICES-WN-Original



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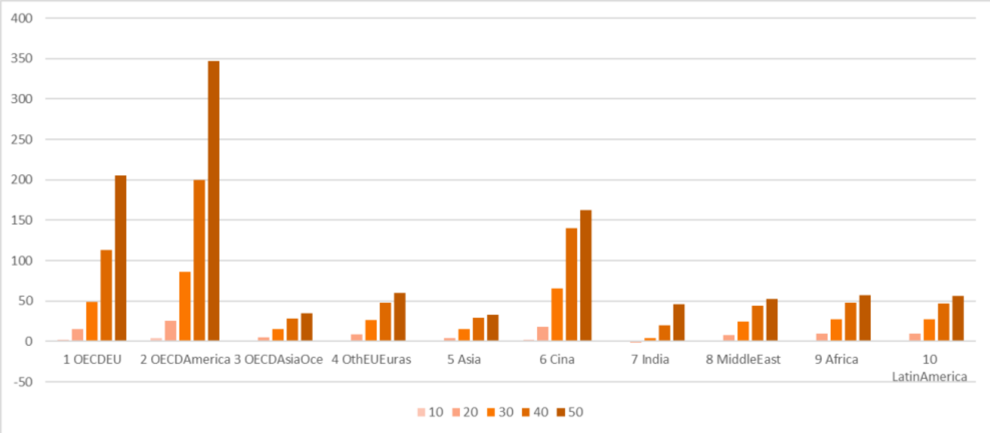
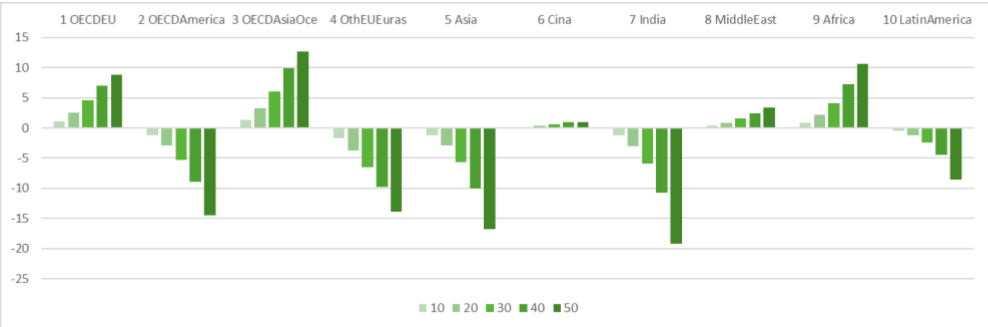


Figure A3. Output quantity of Irrigated Agriculture sector

1. Original



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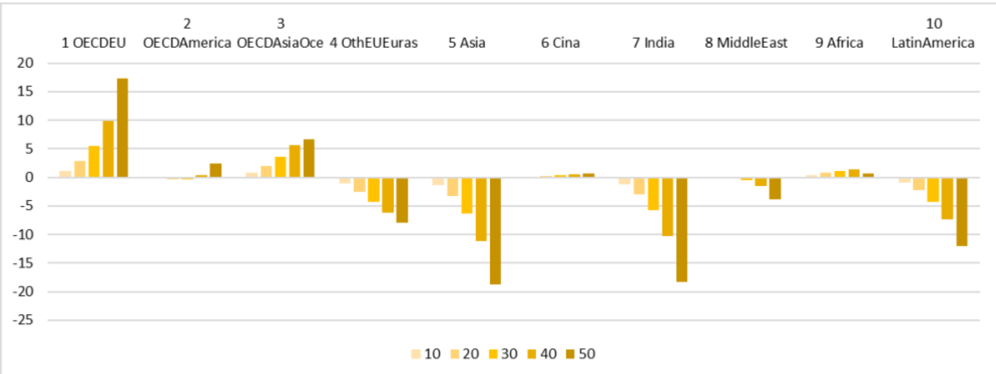
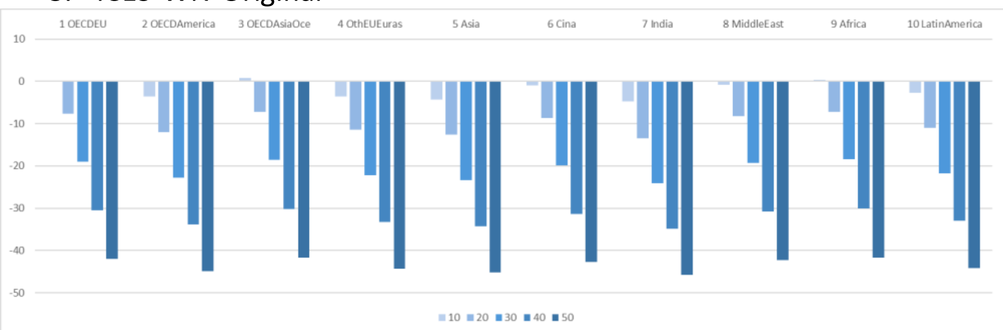


3. ICES-WN-Original



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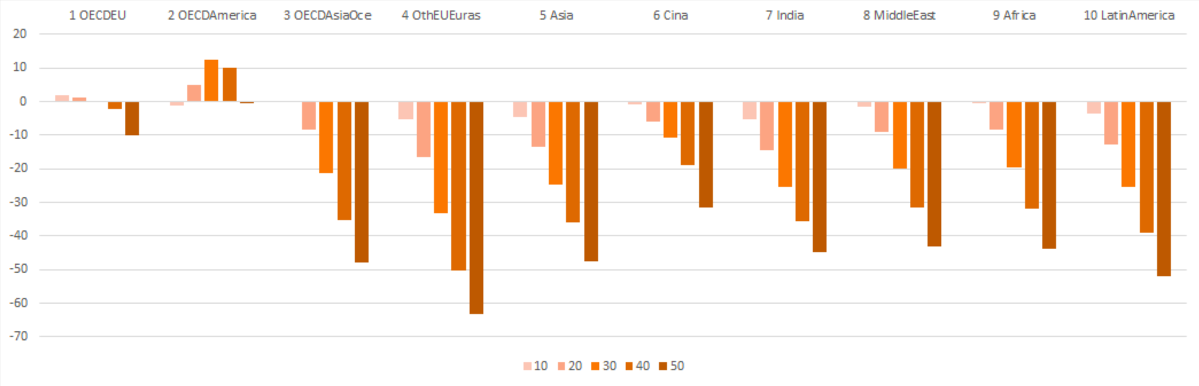
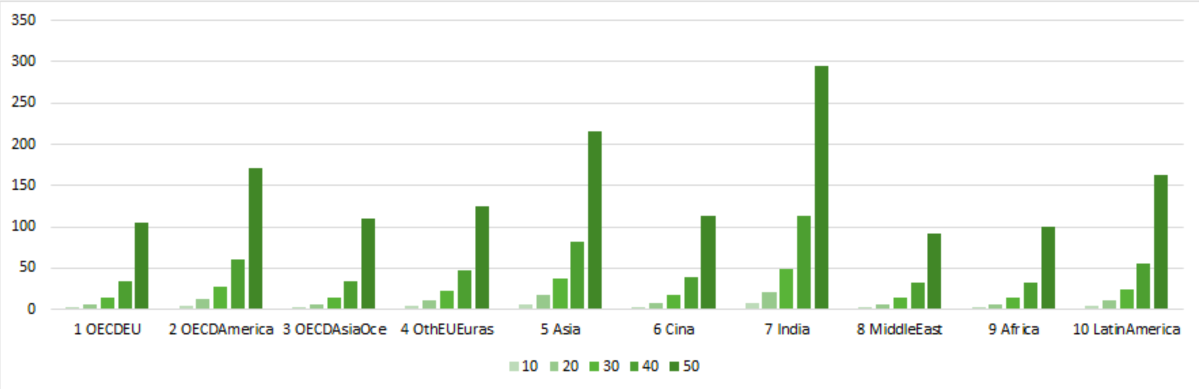
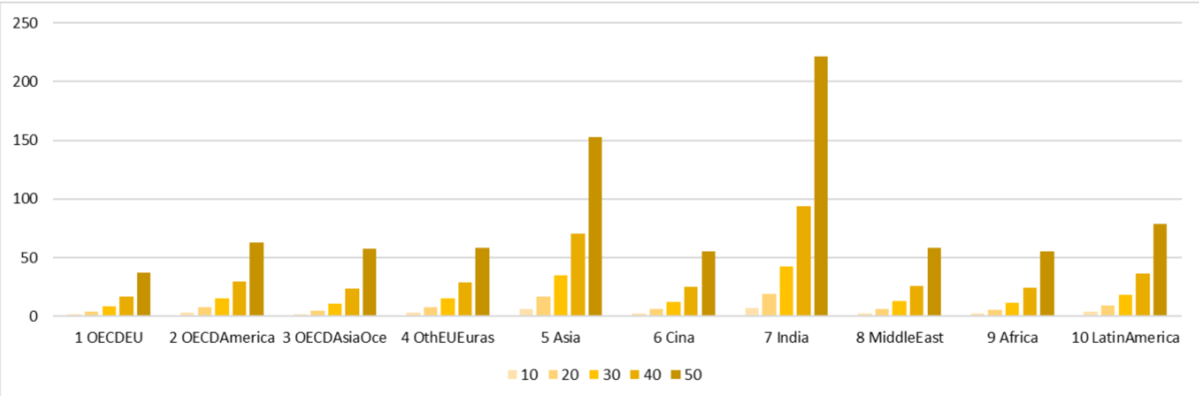


Figure A4. Market Prices of Irrigated Agriculture sector

1. Original



2. Flat



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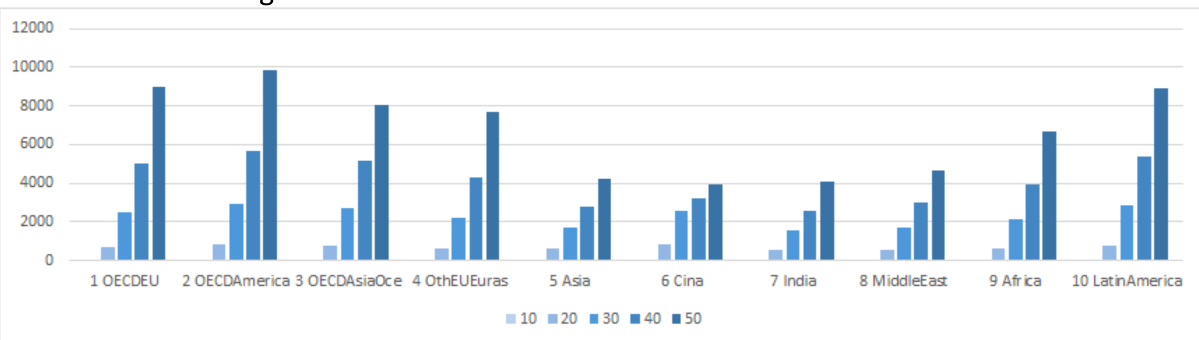

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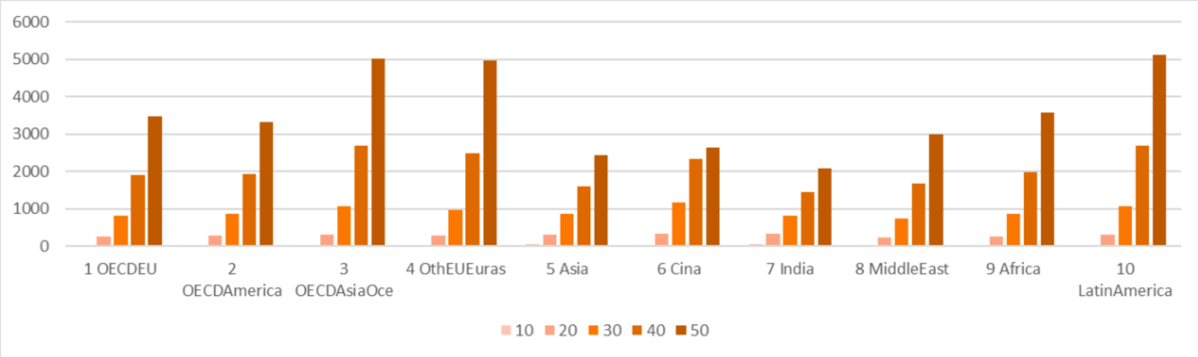

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