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Supplementary Materials

Influence of the Water Source on the Carbon Footprint of Irrigated Agriculture: A Regional Study in South-eastern Spain

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1. Supplementary Materials

Table S1. Water resources and specific energy contributions to irrigation mix by scenario.

Water source	Water contribution to irrigation mix (%)			Specific energy (kWh/m³)	Specific energy contribution to irrigation mix (kWh/m³)		
	WS0	WS1	WS2		WS0	WS1	WS2
Surface	15.9	19.8	15.9	0.06 [1]	0.01	0.01	0.01
Groundwater	18.9	23.4	18.9	0.9 [1]	0.17	0.21	0.17
Reclaimed	6.1	7.6	6.1	0.78 [1]	0.05	0.06	0.05
Tagus-Segura transfer	59.1	32.2	0	1.21 [2]	0.72	0.39	0.00
Desalinated seawater	0	17	59.1	4.32 [3]	0	0.73	2.55
Total	100	100	100		0.94	1.41	2.78

WS0: concession scenario; WS1: current scenario; WS2: substitution scenario of Tagus-Segura water transfer by seawater desalination.

Table S2. Surface area and percentage of outdoor vegetables in the region in 2017 [4]. Selected crops for the study are in bold.

Crop	Surface area (ha)	Percentage (%)
Chard	140	0.28
Garlic	94	0.19
Artichoke	**7,540**	**15.18**
Celery	988	1.99
Eggplant	48	0.10
Cabbage	4	0.01
Thistle	6	0.01
Onion	885	1.78
Spring onion	20	0.04
Cabbage	505	1.02
Broccoli	**13,026**	**26.22**
Escarole	428	0.86
Asparagus	6	0.01
Spinach	890	1.79
Green pea	21	0.04
Been	579	1.17
Green been	50	0.10
Lettuce	**15,632**	**31.47**
Muskmelon	**5,738**	**11.55**
Turnip	15	0.03
Leek	21	0.04
Radish	6	0.01
Table beet	2	0.00
Watermelon	2,758	5.55
Carrot	36	0.07
Other vegetables	240	0.48

Table S3. Surface area and percentage of citrus in the region in 2017 [4]. Selected crops for the study are in bold.

Crop	Surface area (ha)	Percentage (%)
Grapefruit	801	2.08
Lemon	**24,492**	**63.48**
Lime and other citrus	54	0.14
Mandarin	**5,651**	**14.65**
Orange	**7,584**	**19.66**

Table S4. Surface area and percentage of non-citrus (fleshy fruit) in the region in 2017 [4]. Selected crops for the study are in bold.

Crop	Surface area (ha)	Percentage (%)
Apricot	**9,049**	**33.94**
Apple	71	0.27
Avocado	14	0.05
Cherry and sour cherry	338	1.27
Prickly pear	31	0.12
Custard apple	1	0.00
Fig	91	0.34
Kaki and raspberry	135	0.51
Medlar	6	0.02
Peach	**14,421**	**54.08**
Pear	1,267	4.75
Plum	844	3.17
Pomegranate	387	1.45
Quince	9	0.03

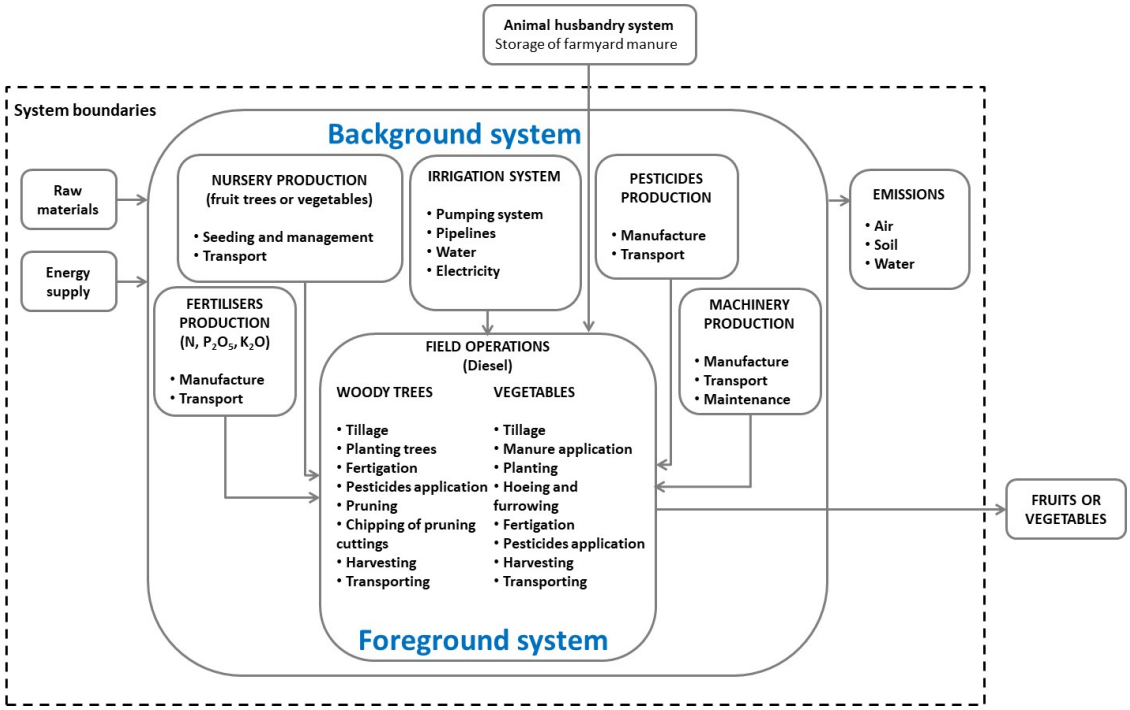

Figure S1. System boundaries for cradle-to-gate production of vegetable and woody crops (citrus fruits and non-citrus trees).

Table S5. Agricultural stages of Life Cycle Assessment.

Agricultural stage	Inputs included by stage
Fertilisers	This stage accounts for the manufacturing of N, P_2O_5 and K_2O, including the packaging and transport of primary and secondary materials to the production plants. N-fertilisers generate emissions to air (N_2O, NH_3, NO_x), water (NO_3^-) and soil, P_2O_5-fertilisers make emissions to water (P, PO_4^{3-}) and soil, and K_2O-fertilisers emit pollutants to water (K) and soil.
Pesticides	This stage includes the transport of primary and secondary materials to the production plants, the synthesis of the chemical components and the waste treatment or disposal.
Machinery	This includes the manufacture, transport, maintenance, repair, and waste management of the machinery used for field operations. The studied crops required tractors, tillage implements, air-blast sprayers (pesticides), boom sprayers (herbicides), chippers (pruning), and transport trailers.
Nursery	This stage includes agricultural machinery, mineral and organic fertilisers, pesticides used at the nurseries and the transport to the fields.
Irrigation	The following on-farm components are considered: (i) the manufacture and transport of the irrigation infrastructure (head, filters, fertiliser tanks, electrovalves, irrigation programmer, PVC and PE pipes); (ii) the construction of a shed for the irrigation head and farm machinery; (iii) the deployment of an irrigation reservoir, (iv) the water and energy required for irrigation; and (v) the emissions related to infrastructure and electricity. The latter includes indirect emissions due to the extraction, production, and transport of electricity, as well as electricity losses in the network.
Field operations	For woody crops (citrus fruits and fleshy fruits) included: tillage, tree planting, fertigation, pesticide application, pruning, chipping of pruning cuttings, harvesting and transporting. For outdoor vegetables included: tillage, manure application, planting, hoeing and furrowing, fertigation, pesticides application, harvesting and transporting. For the case of melon, plastic mulching and the deployment of low tunnels are also included.

Table S6. Life Cycle Inventory for the vegetable crops of the study.

Inputs/Outputs	Units	Outdoor vegetables				Data source
		Artichoke	Broccoli	Lettuce	Melon	
Cycle length	months	12	6	4	4	[5]
Planting material	Unit ha-cycle $^{-1}$	7,400	38,074	65,576	10,554	[5]
Diesel for field operations	L ha-cycle $^{-1}$	380	310	310	335	[5]
Machinery	h ha-cycle $^{-1}$	76	62	62	67	[5]
Fertilisers:						
• N	kg ha-cycle $^{-1}$	249	190	211	165	[5]
• P_2O_5	kg ha-cycle $^{-1}$	99	64	47	58	[5]
• K_2O	kg ha-cycle $^{-1}$	171	117	152	172	[5]
• Manure [1]	Mg ha-cycle $^{-1}$	7.5	7.5	7.5	7.5	[5]
Agro-chemicals:						
• Fungicides and insecticides	kg ha-cycle $^{-1}$	13	8	8	9	[6]
• Herbicides	kg ha-cycle $^{-1}$	4	3	7	5	[6]
Plastic mulch	kg ha-cycle $^{-1}$	-	-	-	120	[5]
Drip irrigation system (on-farm) [2]						
• Irrigation head	kg ha-cycle^{-1}	3.75	1.88	1.25	1.25	
• PE pipeline and emitters	kg ha-cycle^{-1}	192	96	64	64	
• PVC pipeline	kg ha-cycle^{-1}	85	43	28	28	
• HPDE Film (reservoir)	kg ha-cycle^{-1}	36	18	12	12	
• Diesel for reservoir earthworks	L ha-cycle^{-1}	63	31	21	21	
• Water for irrigation	m^3 ha-cycle $^{-1}$	11,965	6,967	4,926	4,500	[7]
• Specific energy for irrigation in WS1 [3]	kWh m^{-3}	0.94	0.94	0.94	0.94	
• Specific energy for irrigation in WS2 [3]	kWh m^{-3}	1.41	1.41	1.41	1.41	
• Specific energy for irrigation in WS3 [3]	kWh m^{-3}	2.78	2.78	2.78	2.78	

[1] 1 Mg of manure provides 6 kg of N, 2 kg of P_2O_5, and 8 kg of K_2O [8], fertiliser ratio (1.5% N, 0.5% P_2O_5 and 2% K_2O and 40% dry matter). [2] Personal communication of farmers and technicians. [3] Calculated according to percentage of each water source contribution to irrigation mix (Table S1).

Table S7. Life Cycle Inventory for the woody crops (citrus and non-citrus trees) of the study.

Inputs	Units	Citrus trees			Non-citrus trees (fleshy fruits)		Data source
		Lemon trees	Mandarin trees	Orange trees	Apricot trees	Peach trees	
Cycle length	years ha $^{-1}$	1	1	1	1	1	[9]
Planting density	trees ha $^{-1}$	278	667	333	204	571	[9]
Tree spacing	m x m	6 x 6	6 x 2.5	6 x 5	7 x 7	5 x 3.5	[9]
Diesel for field operations	L ha-year $^{-1}$	535	520	535	430	430	[9]
Machinery	h ha-year $^{-1}$	107	104	107	86	86	[9]
Fertilisers:							
• N	kg ha-year $^{-1}$	182	214	197	106	129	[9]
• P_2O_5	kg ha-year $^{-1}$	36	43	40	33	55	[9]
• K_2O	kg ha-year $^{-1}$	132	95	125	124	161	[9]
Agro-chemicals:							
• Fungicides and insecticides	kg ha-year $^{-1}$	9	13	7	13	20	[6]
• Herbicides	kg ha-year $^{-1}$	4	6	5	6	9	[6]
Drip irrigation system (on-farm) [1]							
• Irrigation head	kg ha-year $^{-1}$	3.75	3.75	3.75	3.75	3.75	
• PE pipeline and emitters	kg ha-year $^{-1}$	227	227	227	85	85	
• PVC pipeline	kg ha-year $^{-1}$	68	68	68	68	68	
• HPDE film (reservoir)	kg ha-year $^{-1}$	36	36	36	36	36	
• Diesel for reservoir earthworks	L ha-year $^{-1}$	59	59	59	59	59	
• Water for irrigation	m^3 ha-year $^{-1}$	5,930	6,608	4,993	5,643	5,776	[7]
• Specific energy for irrigation in WS1 [2]	kWh m^{-3}	0.94	0.94	0.94	0.94	0.94	
• Specific energy for irrigation in WS2 [2]	kWh m^{-3}	1.41	1.41	1.41	1.41	1.41	
• Specific energy for irrigation in WS3 [2]	kWh m^{-3}	2.78	2.78	2.78	2.78	2.78	

[1] Personal communication of farmers and technicians. [2] Calculated according to percentage of each water source contribution to irrigation mix (Table S1).

Table S8. Percentage of surface area by crop group in each ADU.

ADU	Percentage (%)			
	Outdoor vegetables	**Citrus**	**Non-citrus (fleshy fruit)**	**Others crops**
ADU 26	3	0	86	11
ADU 37	2	29	57	12
ADU 38	2	22	58	18
ADU 39	3	83	6	8
ADU 40	0	33	55	12
ADU 41	8	7	68	17
ADU 52	16	75	0	9
ADU 53	9	61	12	18
ADU 54	9	61	12	18
ADU 56	4	81	0	15
ADU 58	58	28	0	14
ADU 61	79	0	5	16
ADU 65	38	53	0	9
ADU 66	42	38	1	19
ADU 70	70	18	1	11
ADU 71	70	18	1	11
ADU 72	3	69	13	15
ADU 73	1	28	54	17

ADU: Agricultural Demand Units.

Table S9. Total annual values of carbon balance in each ADU for the considered scenarios.

ADU	Carbon balance (t CO_2/year)		
	WS0	**WS1**	**WS2**
ADU 26	-44,615	-41,811	-33,55
ADU 37	-56,888	-53,36	-42,97
ADU 38	-39,391	-36,944	-29,736
ADU 39	-85,019	-79,603	-63,653
ADU 40	-30,343	-28,529	-23,184
ADU 41	-11,652	-10,833	-8,422
ADU 52	-42,242	-38,802	-28,678
ADU 53	-144,209	-133,805	-103,175
ADU 54	-131,119	-121,66	-93,81
ADU 56	-156,073	-145,875	-115,848
ADU 58	-141,952	-111,232	-20,849
ADU 61	-27,113	-13,743	25,588
ADU 65	-113,586	-99,382	-57,583
ADU 66	-10,342	-8,752	-4,075
ADU 70	-13,144	-9,364	1,757
ADU 71	-12,768	-9,096	1,707
ADU 72	-114,747	-107,412	-85,814
ADU 73	-32,879	-30,877	-24,979
Total	-1,208,084	-1,081,080	-707,276

ADU: Agricultural Demand Units; WS0: concession scenario; WS1: current scenario; WS2: substitution scenario of Tagus-Segura water transfer by seawater desalination.

Table S10. Annual values of carbon balance per hectare in each ADU for the considered scenarios.

ADU	Carbon balance (t CO_2/ha-year)		
	WS0	**WS1**	**WS2**
ADU 26	-16.14	-15.13	-12.14
ADU 37	-16.31	-15.30	-12.32
ADU 38	-16.28	-15.27	-12.29
ADU 39	-16.20	-15.17	-12.13
ADU 40	-16.61	-15.62	-12.69
ADU 41	-15.27	-14.20	-11.04
ADU 52	-14.23	-13.07	-9.66
ADU 53	-15.18	-14.08	-10.86
ADU 54	-15.18	-14.08	-10.86
ADU 56	-16.01	-14.96	-11.88
ADU 58	-7.37	-5.78	-1.08
ADU 61	-3.70	-1.88	3.50
ADU 65	-10.94	-9.57	-5.55
ADU 66	-9.50	-8.04	-3.74
ADU 70	-5.88	-4.19	0.79
ADU 71	-5.88	-4.19	0.79
ADU 72	-16.16	-15.12	-12.08
ADU 73	-16.46	-15.45	-12.50

ADU: Agricultural Demand Units; WS0: concession scenario; WS1: current scenario; WS2: substitution scenario of Tagus-Segura water transfer by seawater desalination.

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