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Analysing hydropower production in stressed river basins within the SEEA-W approach: the Jucar River case

A. Solera, M. Pedro-Monzonís, J. Andreu and T. Estrela

ABSTRACT

Hydropower generation represents an important contribution to meeting the challenges of today's increasing world energy needs. It uses about 44% of water in Europe, and it is the main user of water in most OECD countries. However, in most cases, the energy sector is not a water consumer. The largest part of these withdrawals is immediately returned into the environment, being able to be used by other sectors, which is its most prominent characteristic. In order to understand the water-energy nexus and the challenges that the environment and other water users face, the European Commission proposed the use of water accounts in order to measure the influence of each water user, infrastructure and management decision to the total economic value of water resources in a given basin. In this sense, the SEEA-W is the most well-known approach of hybrid accounting as it provides a standard approach to compare results between different regions. This research analyses hydropower production in the Jucar River Basin (Spain), which is currently water-stressed by consumptive demands, within the SEEA-W approach. The results demonstrate that the SEEA-W approach needs some improvement in order to represent hydropower production properly.

Key words | hydropower, Jucar River Basin district, system of environmental-economic accounting for water (SEEA-W), water accounts

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INTRODUCTION

Water is a central element for the existence of all who reside on our planet. From an environmental point of view, water represents the link between the atmosphere, the ocean, the surface of the Earth and the subsoil, between inanimate and living beings, and between nature and humans. From the point of view of society, water has been, is and will be a basic and irreplaceable component of socio-economic activities, agricultural and industrial production, energy generation, as a mean of transportation, among others.

In the coming years, as a consequence of climate change the reduction of water availability is expected, and this reduced water availability will have an impact on hydropower production, at least in Mediterranean areas (Pereira-Cardenal *et al.* 2014), requiring more efficient use of scarce water resources. The use of burning fossil fuels as a source of energy should be replaced, little by little, by renewable energy sources. As noted by Lehner *et al.* (2005) 'electricity generation from hydropower makes a substantial contribution to meeting today's increasing world electricity demands'. In this sense, hydropower production represents a renewable source of energy, which returns the total amount of water used. Moreover, hydropower plants (HPP) can start and stop when energy is required in only a few seconds. Some HPP can concentrate their daily production in some hours in order to obtain the best price of energy. However, as an inconvenience, HPP need to build important infrastructures which are responsible for water losses from evaporation and flow alterations that affect the

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environment (Scherer & Pfister 2016). Interpreting these properties, we could define many advantages and disadvantages of hydropower (Dincer 2000).

Knowing the amount of water available for the different uses in a river basin is quite challenging, particularly in stressed river basins where water requirements may be even higher than water availability. In this sense, water accounts, defined as the integration of physical and economic information related to water consumption and use, are presented as a tool to achieve the objective of water efficiency (UNDS 2012):

- they have become a very powerful tool for improving water management;
- their methodology is based on a water balance approach (Molden & Sakthivadivel 1999);
- they allow policymakers to compare results between different territories.

One of the most widespread water accounting approaches is the system of economic and environmental accounts for water (SEEA-W), which has been developed by the United Nations Statistic Division in conjunction with the London Group on Environmental Accounting (UNDS 2012). Its main objective has been to provide a conceptual framework for organising economic and hydrological information.

Although the SEEA-W approach seems relatively simple, Dimova *et al.* (2014) noted that its application involves collecting a great amount of data from many stakeholders and actors. In most cases the information is not complete or cannot be used directly. The difficulty of monitoring all the variables within the water cycle or the mismatch between administrative and river basin boundaries represent its main handicap. Several authors have resorted to the use of simulation models in order to estimate the great amount of information required (Dimova *et al.* 2014; Pedro-Monzonís *et al.* 2016a, 2016b; Vicente *et al.* 2016). Over the last few years, much effort has been invested by the European Commission's DG Environment in applying the SEEA-W approach through several pilot projects (ASSET, DURERO, GuaSEEAW +, PAWA, PROTAGUS, SYWAG, and WAMCD).

In this work, we analyse the main hydropower features and its production within the SEEA-W. We pay special attention to the significance of this source of energy in stressed river basins such as the Jucar River Basin in Spain. In systems like this, the hydropower sector only turbines the water releases for other water uses located downstream. Moreover, HPP can turbine water in cyclical systems, pumping and turbining the same volume of water several times in one day, as in the case of energy storage stations. As results show, the inclusion of water abstracted by the energy sector can distort water balances, since the volume abstracted is often larger than the rest of the uses in the river basin.

STUDY AREA AND DATA

Spain has a high hydroelectric tradition, developed over more than a century. Within renewable energy, hydropower is the most established and with the higher degree of maturity, thanks to the terrain orography and to the existence of a large number of dams. In Spain there is a total storage capacity of 55,000 hm^3, of which 40% of this capacity corresponds to hydroelectric dams, one of the highest proportions in Europe and in the world. In 2015, the contribution of hydropower to the national electricity power accounted for 10% (IEA 2015). It was the fourth in production technology, behind nuclear (21%), wind (18%) and coal (20%).

The Jucar River Basin district is located in Spain, in the East of the Iberian Peninsula (Figure 1). It is composed of nine water exploitation systems.

Physically, the Jucar River Basin district is described as an interior mountainous zone, with spots at high altitude and a coastal zone composed of plains. The average precipitation is 510 mm/year, presenting a high spatial variability, and the average temperature is 13.6°C. Average natural resources reach 2,929 hm^3/year, which represents the top limit of the renewable resources of the basin. The total population depending on the Jucar River Basin district represents a water demand of 502 hm^3/year and the water demand for irrigated agriculture reaches 2,560 hm^3/year. The supply to urban areas comes mainly from wells and springs, although the main metropolitan areas, such as Albacete, Sagunto and Valencia, use surface/dammed water.

As is shown in Figure 2, comparing the total streamflows with the water demand for urban and agrarian use during an

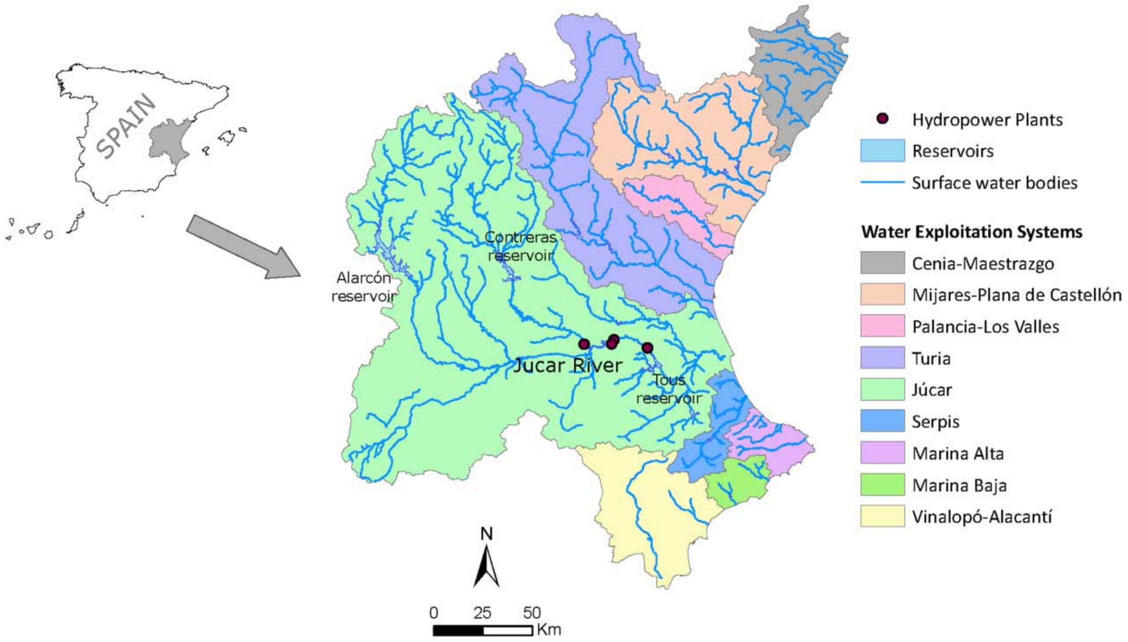


Figure 1 | Location of the Jucar River Basin district in the Iberian Peninsula.

average hydrological year demonstrates that consumptive uses and water resources are not synchronized in time. Water demands are concentrated in harvest months; however, natural resources are slightly higher during the winter and go down in summer. It is noteworthy that natural resources are not reduced dramatically in summer months due to the strong interaction between surface water and groundwater. Thus, joint management of surface and groundwater is carried out by the river basin authority in charge of water management (Pedro-Monzonís *et al.* 2016b).

Using the values of total water demands (3,062 hm^3/year) and total natural resources (2,929 hm^3/year) in the Jucar River

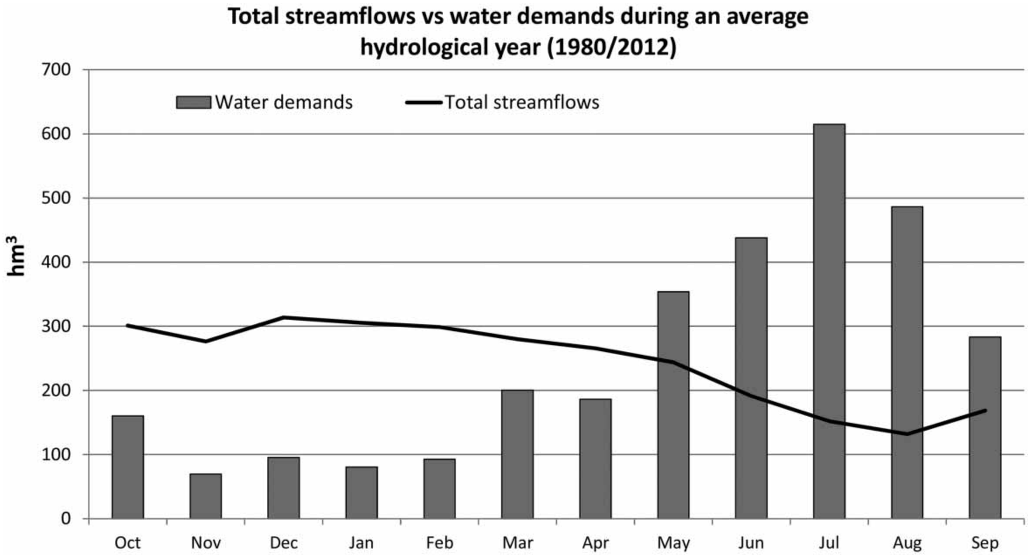


Figure 2 | Total streamflows versus water demands during an average hydrological year (1980/2012) for the Jucar River Basin district.

Basin District for the 1980/81–2012/13 period, a first indicator of the water stress in the district is deduced by the ratio between both values, resulting in a value of 104%, reflecting the high degree of exploitation suffered by this system.

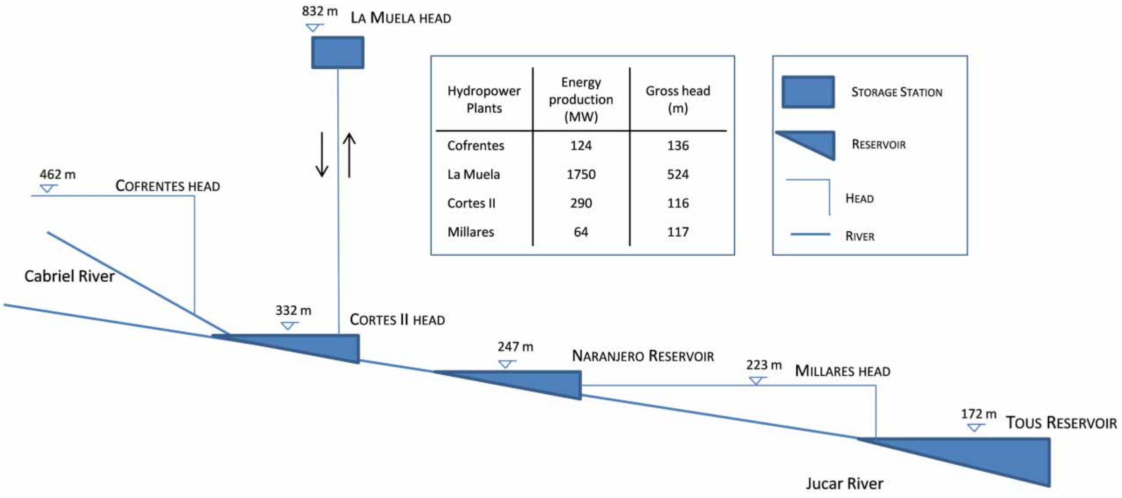
Turning to the hydropower sector in Jucar River Basin District, there are many HPPs, but most of them are small, being the reason why we will focus only on the most important HPPs, which are located in the Jucar Water Exploitation System. Only three of them are available to drive the production, and only one is able to store energy. These four HPPs are the largest in terms of power installed. Figure 3 represents a longitudinal view of the Jucar River where these HPPs are located.

The pumped system (Cortes-La Muela) is one of the largest in Europe and it is an example of the ancient hydroelectric tradition in Spain. It consists of two functionally different elements, which are the Salto de Cortes II and the Pumped Storage Hydropower (PSH) Salto de la Muela. Iberdrola hydroelectric plant, which is composed of Salto de Cortes II and PSH Salto de la Muela, is located in Cortes de Pallás (Valencia) and is the largest pumping station in Europe. It is located on the right bank of the Jucar River and thanks to the four reversible groups installed it takes advantage of the height difference of 500 m existing between the reservoir of La Muela and impoundment of Cortes de Pallas. The plant is capable of producing 1,625 GWh and meets the annual demand of about 400,000 households (El Periódico de la Energía 2016).

METHODS

SEEA-W is an information system that feeds knowledge into decision-making processes, assisting policy makers in taking informed decisions on allocating water resources efficiently; improving water efficiency; understanding the impacts of water management on all users; getting the most value for money from investment in infrastructure; linking water availability and use, providing a standardized information system which harmonizes information from different sources, it is accepted by the stakeholders and it is used for the derivation of indicators; and getting stakeholders involved in decision-making (European Commission 2016).

The SEEA-W framework considers the flows between the environment and the economy. In relation to the environment, it comprises surface water, groundwater and soil water; and in relation to the economy, it includes the abstractions, imports, exports and returns of the most relevant economic agents. It comprises five categories of accounts: (1) Physical supply and use tables and emission accounts; (2) Hybrid and economic accounts; (3) Assets accounts; (4) Quality accounts; and (5) Valuation (economic) of water resources. This research has focused mainly on physical supply and use tables. As noted before, these tables involve collecting a vast amount of data. Two approaches can be used. The first one implies the use of official statistical data from different databases of diverse administrations. This approach requires a great availability of data and it may



Hydropower Plants	Energy production (MW)	Gross head (m)
Cofrentes	124	136
La Muela	1750	524
Cortes II	290	116
Millares	64	117

Figure 3 | Scheme of the hydropower production in Jucar River.

present information gaps and problems with closing balances. The second approach includes the use of simulation models in order to obtain the information required.

The methodology employed has been published in Pedro-Monzonís *et al.* (2016b). Here we present a brief summary (see Figure 4). The approach is represented as a modelling chain comprised of three steps. The first step lies in the hydrological model, which allows us to obtain the state variables and flows within the water cycle in natural regime. Secondly, this information is employed in the Decision Support System (DSS) in order to simulate the allocation of water resources, enabling us to obtain river flows, water supplies or the volumes of water stores in reservoirs. Thirdly, once we know the water allocated for the different uses in the river basin we are able to organise all the data and results in order to construct the tables defined according to the SEEA-W approach, representing the third stage. At this stage, an economic valuation of water services costs is proposed by using results achieved during the assessment of cost recovery of water services, as required by WFD (EP 2000). This economic component is not taken into consideration in this application.

To guide this work we have used PATRICAL hydrological model (Pérez-Martín *et al.* 2014), AQUATOOL DSS (Andreu *et al.* 1996) and the acquisition tool AQUACCOUNTS (Pedro-Monzonís *et al.* 2016b).

The PATRICAL model (Pérez-Martín *et al.* 2014) is a conceptual, large-scale, monthly and spatially distributed water balance model which includes water quality. It divides the river basin into two vertical layers: a lower zone (working as a semi-distributed model) and an upper zone (working as a distributed model). Its main inputs are monthly air temperature and precipitation. Currently, PATRICAL is used in the Jucar RBD for the River Basin Management Plan, in the analysis of nitrate concentration in groundwater bodies in Spain (Pérez-Martín *et al.* 2012) and also in the study of climate change impacts on water resources (Estrela *et al.* 2012).

AQUATOOL (Andreu *et al.* 1996) is a user-friendly DSS composed of several modules that enables different analysis in water resources systems. One of them is the SIMGES module (Andreu *et al.* 1996) which can simulate the water resources system, on a monthly time scale. It can consider

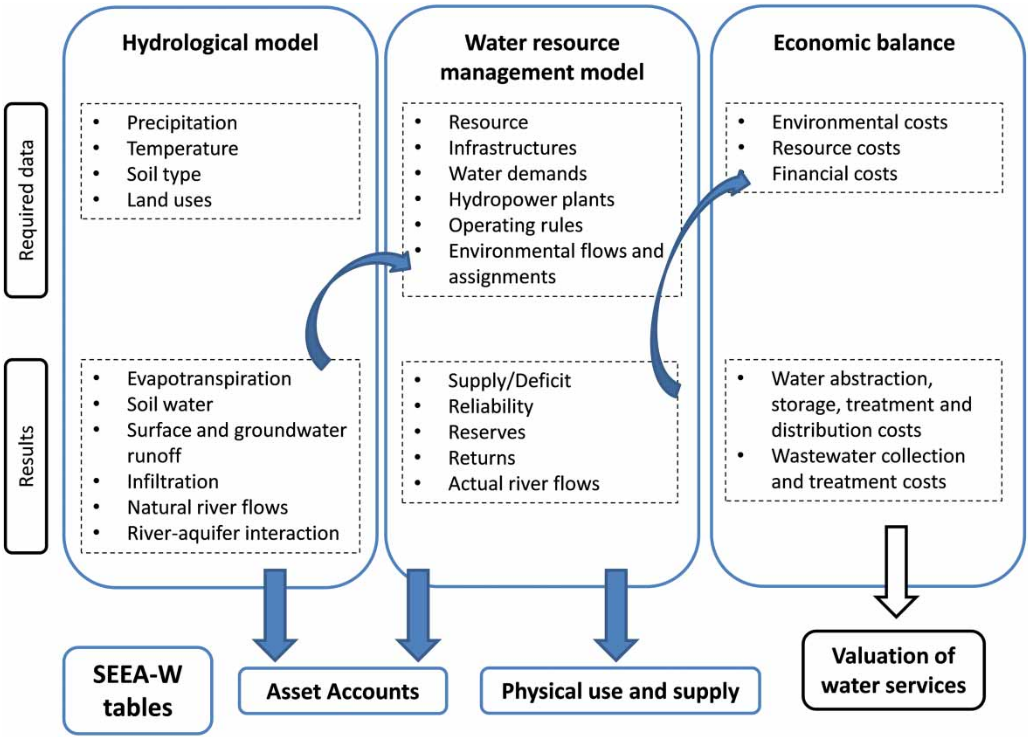


Figure 4 | Scheme of the approach to obtain SEEA-W tables by using different types of models related to water resources management. *Source:* Pedro-Monzonís *et al.* (2016b).

different water use priorities, the aquifers, the returns to the groundwater and surface environment, the consideration of environmental flows, the infiltration losses and evaporation from reservoirs, the energy production, as well as the definition of operating rules.

AQUACCOUNTS (Pedro-Monzonís *et al.* 2016b) enables the linking of central variables of the rainfall-runoff model such as actual evapotranspiration, precipitation, infiltration, surface runoff and river-aquifer interaction; with the results of the water allocation model, such as water allocations, reserves, evaporation in reservoirs, among others.

The models include: 28 artificial reservoirs, 18 lakes, 210 user groups and 116 groundwater bodies, identifying the detail and complexity of the system. The greatest amount of data required was provided by Jucar River Basin Authority. In the case of surface water bodies, they include all the rivers, reservoirs and lakes defined by the Centre for Public Works Studies and Experimentation (CEDEX 2005). On the other hand, there are many methodological decisions, such as the reliability criteria, the length of the time period used in the simulation among others which are recommended by the Spanish Guideline of Water Planning (MAGRAMA 2008) with normative status in Spain guaranteeing consistency of the results. The main features of the models built with PATRICAL and AQUATOOL DSS for the case study are accessible in Pérez-Martín *et al.* (2014) and Pedro-Monzonís *et al.* (2016b) respectively.

In relation to hydropower modelling, it is included in the water balance model through the incorporation of the data related to the maximum turbinable flow, along with its operating rules that reflect in which conditions hydropower users can exploit the system's water resources. In our case study, HPPs cannot release water from reservoirs; they only can exploit the circulating flow that is released for other purposes. Moreover, among the data required to model HPPs, there is the minimum previously established flow that cannot be turbined and it is supposed to flow through the river in order to minimize the environmental impacts of hydropower. The water balance model also utilizes gross head data and the plant efficiency data to calculate energy production results. These results can then be used in the economic balance step together with an estimated energy price in order to obtain economic outcomes.

RESULTS AND DISCUSSION

The physical use table and the physical supply table within the SEEA-W approach are presented below. The reference period used for the determination of these tables is the average year 1980/81–2011/12. The economic activities are classified according to the International Standard Industrial Classification of All Economic Activities (ISIC) (UN 2008), distinguishing the following groups:

(a) ISIC divisions 1–3, which include agriculture, forestry and fishing;
(b) ISIC divisions 5–33 and 41–43, which include mining and quarrying, manufacturing, and construction;
(c) ISIC division 35: electricity, gas, steam and air-conditioning supply;
(d) ISIC division 36: water collection, treatment and supply;
(e) ISIC division 37: sewerage;
(f) ISIC divisions 38, 39 and 45–99, which correspond to the service industries.

ISIC division 35 includes mainly the hydropower sector and the production of nuclear energy in Cofrentes nuclear power plant. It is noteworthy to highlight that although this division includes other industries linked with the energy sector, such as gas, steam and air-conditioning supply, in the case study, their use of water is irrelevant. Focusing on ISIC division 35, Tables 1 and 2 show that total abstraction comes from surface water resources and that 99.5% of these abstractions return to the environment. The rest of the abstractions (0.5%) are consumed during the evaporation of hydropower reservoirs (12 hm^3) and for the cooling system of the nuclear power plant (20 hm^3). These turbined flows (6,622 hm^3) correspond to 1,131 MW of energy production.

Figure 5 focuses on the influence of the different water uses of the case study. The horizontal axis represents the water uses. In this sense, we distinguish between industries and households. In relation to the legend, as presented in Tables 1 and 2, total abstractions comprise the abstractions from inland water resources (surface, groundwater and soil water), the collection from precipitation and the abstractions from the sea. Total returns represent the returns into the environment, distinguishing surface, groundwater, soil water and other sources (sea water). The use of water

Table 1 | Physical use table for the average year 1980/81–2011/12 (hm^3)

A. Physical use table (hm^3)		**Industries (by ISIC category)**							**Households**	**Rest of the world**	**Total**
		1–3	**5–33, 41–43**	**35**	**36**	**37**	**38, 39, 45–99**	**Total**			
From the environment	1. Total abstraction (=1.a + 1.b = 1.i + 1.ii)	7,772	95	6,622			114	14,603	376		14,979
	1.a Abstraction for own use	7,772	95	6,622			114	14,603	376		14,979
	1.b Abstraction for distribution										
	1.i From inland water resources	7,772	95	6,622			114	14,603	376		14,979
	1.i.1 Surface water	1,236	0	6,622			37	7,895	122		8,018
	1.i.2 Groundwater	1,062	95				77	1,234	254		1,488
	1.i.3 Soil water	5,474						5,474			5,474
	1.ii Collection of precipitation										
	1.iii Abstraction from the sea						1	1	3		4
Within the economy	2. Use of water received from other economic units of which:	150	6				9	165	31	0	196
	2.a Reused water	109	6					115			115
	2.b Transfers from other territories	41					9	50	31		81
	3. Total use of water (=1 + 2)	7,922	101	6,622	0	0	124	14,768	407	0	15,175

Table 2 | Physical supply table for the average year 1980/81–2011/12 (hm^3)

B. Physical supply table (hm^3)		**Industries (by ISIC category)**							**Households**	**Rest of the world**	**Total**
		1–3	**5–33, 41–43**	**35**	**36**	**37**	**38, 39, 45–99**	**Total**			
Within the economy	4. Supply of water to other economic units of which:	0	0	0	0	0	27	27	88	81	196
	4.a Reused water						27	27	88		115
	4.b Transfers from other territories									81	81
Into the environment	5. Total returns (=5.a + 5.b)	835	81	6,590	0	0	91	7,598	301	0	7,898
	5.a To water resources	726	81	6,590	0	0	57	7,454	187		7,641
	5.a.i Surface water	271	81	6,590			57	6,999	187		7,186
	5.a.ii Groundwater	455	0				0	455	0		455
	5.a.iii Soil water										
	5.b To other sources	109					35	144	113		257
	6. Total supply of water (=4 + 5)	835	81	6,590	0	0	118	7,624	389	81	8,094
	7. Consumption (=3–6)	7,087	20	32	0	0	5	7,144	18	–81	7,081
	7.a Losses from evaporation			32				32			32
	7.b Losses in distribution not because of leakages										

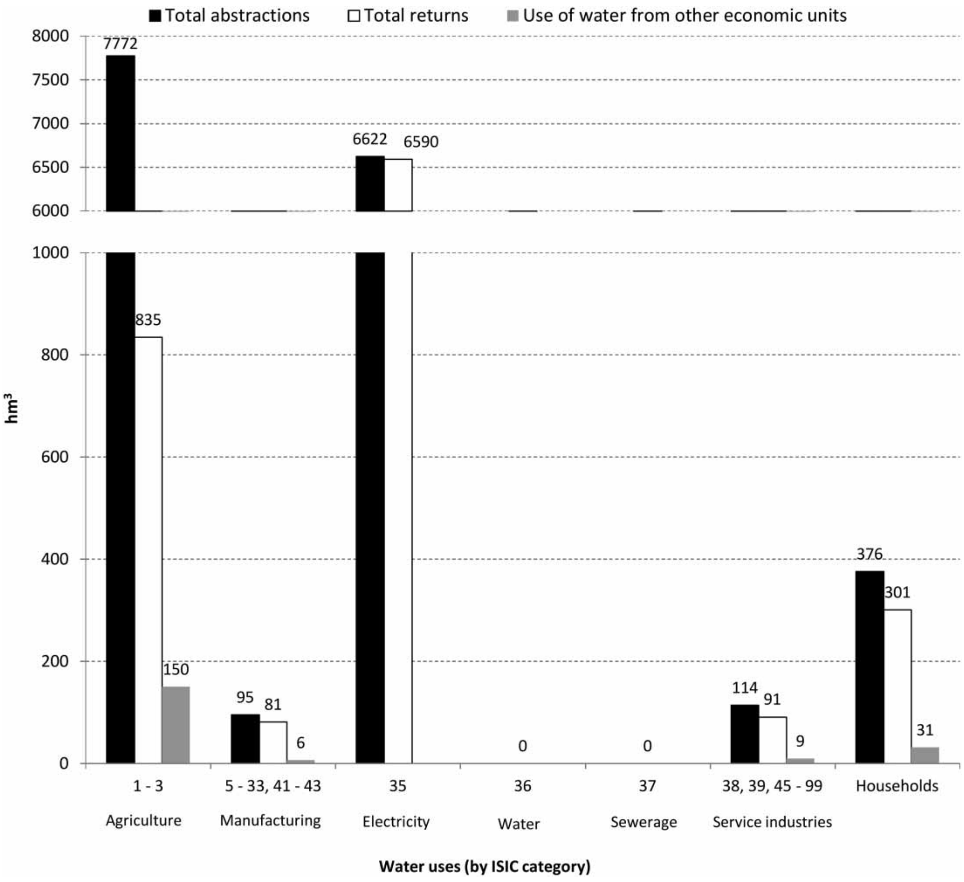


Figure 5 | Abstractions, returns and use of water from other economic units for the average year 1980/81–2011/12 (hm^3).

received from other economic units includes reused water and transfers from other territories.

As the figure shows, the major use is allocated for agrarian requirements (7,772 hm^3/year) and energy production (6,622 hm^3/year) followed at some distance by households (376 hm^3/year) and service industries (114 hm^3/year). On the other hand, according to the use of water received from other economic units, water transferred from other territories in conjunction with reused water plays an important role in the district, representing 81 and 115 hm^3/year respectively. Reused water is mainly used in agrarian and industrial supplies. In relation to the returns into the environment, the highest returns come from hydropower production, which are practically equal to its abstractions.

If we focus on hydropower production, these data could be difficult to understand, because the same volume of water goes through many hydropower installations. This fact has been highlighted by Dimova *et al.* (2014), as HPP in Vit River Basin are situated in cascade, thus the same volume of water is accounted several times. As we observe in the scheme of the hydropower production in Jucar River Basin presented in Figure 3, water flows through three HPPs with reservoirs upstream and downstream; and flows up and down in the pumping station, daily. This fact also may be considered as a weakness of the model, due to the models run at monthly scale and they do not reflect the issue of water moving through the pumped storage facility daily or even hourly.

In connection with hydropower abstractions, the values presented in the tables represent the result of a water allocation model, which might overestimate the hydropower production (which is 1,131 MW for the average year) as it considers that HPPs are operating 24 hours a day. Moreover, the values of hydropower abstractions mislead the main uses of water in the district. As remarked by

(Pedro-Monzonís *et al.* 2016b) this fact is noteworthy given that in stressed river basins the volume of water abstracted for hydropower generation depends on the water resources management and, in the case study, water resources are mainly managed for urban and agrarian uses. Similarly, agriculture abstractions are also masked due to rainfed agriculture, which traditionally has not been considered in water resources planning and management.

This situation is further complicated when we try to build the hybrid tables, since there is a relevant difference depending on the type of HPP considered. In this sense, we distinguish between three types of stations.

1. Run-of-river stations: they extract the potential energy from water while water flows throw the river.
2. Reservoir stations: they need one reservoir in order to regulate water on an hourly scale allowing the station to concentrate the production in the best hours within the day.
3. Pumped storage stations: they consist of an upper and a lower reservoir with turbines, which can generate or store electricity by changing the turbines work between pumping and turbining.

Considering that fact, the economic value of hydropower production is proportional to the volume used and with different proportionality factors depending on the installation considered. The proposed classification of HPP, although it does not completely solve the problem, improves its description in the following aspects: the first type (run-of-river stations) represents an energy production derived directly from the passage of water managed for other purposes, therefore it is a net profit whose only cost is the environmental affection located in the river section affected; the second one (reservoir stations) does cause water losses in the system and therefore it can compete with other uses of water in the system; and thirdly, pumped storage stations move (theoretically) the same volume of water between two reservoirs, so that the volume of water resource used should be considered null, so in this case the proposal is to consider 0 the net water flowing as pure pumping (this decision has already been taken into account in the tables presented). As a result, run-of-river stations use the average of daily prices, reservoir stations consider approximately the maximum daily price and finally, the energy storage (pumping stations) needs to buy energy at a low price to pump it with a higher price. These energy prices are the result of market strategies (Monteiro *et al.* 2014).

On the other hand, there are some aspects of the SEEA-W tables that should be improved. One of them is the time scale of the analysis because from a hydropower point of view the approach should be designed for shorter time scales, not monthly. The weaknesses in hydropower representation are added to the ones previously noticed in environmental requirements (Pellicer-Martínez & Martínez-Paz 2016), being a critical issue in water stressed river basins. The consideration of environmental water stress and/or the damages on ecosystems caused by hydropower could be another turn of the screw towards the improvement of SEEA-W approach, as other water accounting approaches do, such as water footprint (Scherer & Pfister 2016). It is worth noting that the approach used in this research to obtain SEEA-W tables implies the use of DSSs, which are very powerful tools that enable improvement and extend the information presented by these tables. As noticed in previous works (Pedro-Monzonís *et al.* 2016a), improving water accounting approaches in order to include environmental needs represents a clear requirement.

CONCLUSIONS

The main target of this paper was to analyse hydropower generation in stressed river basins within the System of Environmental-Economic Accounting for Water approach. With this paper the authors have tried to demonstrate that filling the SEEA-W tables needs a significant degree of knowledge about the environment and the economy and the flows between them.

As we have seen, the SEEA-W approach exemplifies a powerful device for describing the water cycle, and improving transparency in water planning and management decisions (Dimova *et al.* 2014; Pedro-Monzonís *et al.* 2016a; Vicente *et al.* 2016). Note that in water planning the most appropriate use of water among several proposed alternatives must be selected. If we are able to simulate each alternative separately and obtain the corresponding SEEAW tables, it will be possible to understand at a glance conclusions about the advantages and costs of each option, favoring the correct decision-making.

In general, the most widely used approach for building SEEA-W tables is the use of hydrological and water management models, which are able to generate the huge amount of required data regarding the different components of the water cycle that cannot be obtained by monitoring and to include the numerous water management alternatives in a river basin.

Regarding hydropower production, there are some key issues that should be better considered. Firstly, the inclusion of water abstracted by the energy sector can distort water balances, since the volume abstracted is often larger than the rest of the uses in the river basin. This aspect is also remarkable when we analyse the abstraction of soil water for rainfed agriculture. Both values mask the level of stress suffered by the system, since reused water and transfers from other territories are unnoticed. Secondly, the volume of water used for energy production is accounted several times due to HPP being placed each one next to the other. Thirdly, depending on the type of hydropower station (run-of-river, reservoir or pumped storage station) the management of the system may be affected by the production of hydroelectricity. The fourth question is the time scale of the analysis, since it has been proved that the inclusion of hydropower production requires the use of daily or even hourly models. Finally, regarding the water scarcity conditions of the case study, it is required to emphasise the competition of hydropower production, not only with the rest of the users of the system, but also with environmental requirements, which are not considered in SEEA-W approach. This information is useful for decision makers to introduce these methodological decisions to guarantee consistency and comparability of the results.

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REFERENCES

Andreu, J., Capilla, J. & Sanchís, E. 1996 AQUATOOL, a generalized decision-support system for water-resources planning and operational management. *J. Hydrol.* **177**, 269–291.

CEDEX (Centro de Estudios y Experimentación de Obras Públicas) 2005 *Caracterización de los tipos de río y lago*. Available from: http://eflus.com/index.php?option=com_docman&task=doc_view&gid=196&Itemid=109.

Dimova, G., Tzanov, E., Ninov, P., Ribarova, I. & Kossida, M. 2014 Complementary use of the WEAP model to underpin the development of SEEAW physical water use and supply tables. In: *12th International Conference on Computing and Control for the Water Industry, CCWI2013*. *Procedia Engineering* **70**, 563–572. https://doi.org/10.1016/j.proeng.2014.02.062.

Dincer, I. 2000 Energy and sustainable development: a crucial review. *Renew. Sustain. Energy Rev.* **4**, 157–175.

El Periódico de la Energía 2016 *Las 10 mayores centrales hidroeléctricas de España* [Online]. Available from: http://elperiodicodelaenergia.com/las-10-mayores-centrales-hidroelectricas-de-espana/ (accessed 11 April 2016).

EP (European Parliament) 2000 Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy. *Off. J. Eur. Parliam.* **L327**, 1–82.

Estrela, T., Pérez-Martín, M. A. & Vargas, E. 2012 Impacts of climate change on water resources in Spain. *Hydrol. Sci. J.* **57**, 1154–1167.

European Commission 2016 *SEEA-Water* [WWW Document]. Available from: www.seeawater.eu/index.php/es/seea (accessed 16 July 2016).

IEA 2015 *Energy Policies of IEA Countries – Spain 2015 Review*. International Energy Agency. Available from: www.iea.org/publications/freepublications/publication/IDR_Spain2015.pdf.

Lehner, B., Czisch, G. & Vassolo, S. 2005 The impact of global change on the hydropower potential of Europe: a model-based analysis. *Energy Pol.* **33**, 839–855.

MAGRAMA (Ministerio de Agricultura Alimentación y Medio Ambiente) 2008 Instrucción de Planificación Hidrológica. ORDEN ARM/2656/2008, de 10 de septiembre, por la que se aprueba la instrucción de planificación hidrológica. *BOE* **229**, 38472–38582. Available from: www.boe.es/buscar/doc.php?id=BOE-A-2008-15340.

Molden, D. & Sakthivadivel, R. 1999 Water accounting to assess use and productivity of water. *Int. J. Water Resour. Dev.* **15**, 55–71.

Monteiro, C., Ramirez-Rosado, I. J. & Fernandez-Jimenez, L. A. 2014 Short-term forecasting model for aggregated regional hydropower generation. *Energy Convers. Manag.* **88**, 231–238.

Pedro-Monzonís, M., Jiménez-Fernández, P., Solera, A. & Jiménez-Gavilán, P. 2016a The use of AQUATOOL DSS applied to the system of environmental-economic accounting for water (SEEAW). *J. Hydrol.* **533**, 1–14.

Pedro-Monzonís, M., Solera, A., Ferrer, J., Andreu, J. & Estrela, T. 2016b Water accounting for stressed river basins based on water resources management models. *Sci. Total Environ.* **565**, 181–190.

Pellicer-Martínez, F. & Martínez-Paz, J. M. 2016 Grey water footprint assessment at the river basin level: accounting method and case study in the Segura River Basin, Spain. *Ecol. Indic.* **60**, 1173–1183.

Pereira-Cardenal, S. J., Madsen, H., Arnbjerg-Nielsen, K., Riegels, N., Jensen, R., Mo, B., Wangensteen, I. & Bauer-Gottwein, P. 2014 Assessing climate change impacts on the Iberian power system using a coupled water-power model. *Clim. Change* **126**, 351–364.

Pérez-Martín, M. A., Estrela, T. & del Amo, P. 2012 Definition of environmental objectives in relation with nitrate pollution in the aquifers of Spain. Simulation model and scenarios used. In: *International Congress on Environmental Modelling and Software (iEMSs2012)*, Leipzig.

Pérez-Martín, M. A., Estrela, T., Andreu, J. & Ferrer, J. 2014 Modeling water resources and river-aquifer interaction in the Júcar River Basin, Spain. *Water Resour. Manag.* **28**, 4337–4358.

Scherer, L. & Pfister, S. 2016 Global water footprint assessment of hydropower. *Renew. Energy* **99**, 711–720.

UN (United Nations) 2008 *International Standard Industrial Classification of All Economic Activities (ISIC)*. United Nations Publication, Sales No. E.08.XVII.25, New York.

UNDS (United Nations Statistic Division) 2012 *SEEA-Water System of Environmental-Economic Accounting for Water.* United Nations Publication, Sales No. E.11.XVII.12, New York.

Vicente, D. J., Rodríguez-Sinobas, L., Garrote, L. & Sánchez, R. 2016 Application of the system of environmental economic accounting for water SEEAW to the Spanish part of the Duero basin: lessons learned. *Sci. Total Environ.* **563–564**, 611–622.

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