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Assessing Sustainability: The Societal Metabolism of Water in Israel

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Abstract: Water management in Israel faces significant challenges in terms of physical scarcity and ecosystem stability, due to the increasing water demand for irrigation and drinking and the prominent role of water in environmental conflicts. Defining sustainability in this context requires an analytical framework that can handle non-equivalent descriptive domains, namely the social, economic and environmental dimensions, and multiple spatial and temporal scales of analysis. This paper provides an integrated assessment of bio-physical and socio-economic factors in order to generate a more holistic vision of societal metabolism and water use in Israel. Results show how the current metabolic pattern is sustained thanks to the generation of an economic surplus, which makes it possible to cope with water and land scarcity through imports. A set of indicators is used to show how the assessment of the feasibility, viability and desirability changes depending on the scale of analysis and on the values and beliefs considered.

Keywords: *Integrated assessment, sustainability, water, societal metabolism, MuSIASEM*

1. Introduction

Water management in Israel is a highly contested topic, which generates interest from a variety of perspectives. The Israeli government sees water as a scarce resource that is crucial to maintain living standards and ensure the well-being of the population [1; 2]. Water scarcity has prompted the adoption of probably the most efficient water systems in agriculture and an unparalleled level of innovation in the country, ranging from drip irrigation, grey water recycling in agriculture, all the way to the development of sea-water resistant crops [3; 4]. Water has been taken also as the explanatory factor for conflicts in the Middle East [5; 6] and within Israel and Palestine [7]. In this paper, we make use of an integrated assessment of biophysical and socio-economic factors to help generate a more holistic vision of the societal metabolism of water in Israel and of the challenges of defining sustainability in this context.

Societal metabolism is a concept borrowed from biology to describe the integrated set of processes expressed by human societies using materials and energy to reproduce themselves [8]. Extensive research shows that there is a strong correlation between the level of economic development of a society and the rate of energy and material consumption [8; 9]. As societies moved from hunter-gatherer to industrial economies, there was acceleration in the rates of energy and material consumption both in extensive terms (more population) and intensive terms (higher consumption per capita). One immediate consequence is that more developed societies are more dependent on material and energy throughputs in order to maintain their lifestyles. In this sense, it is crucial to relate the requirement of flows to resource availability in order to evaluate the

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sustainability of metabolic patterns both in terms of *feasibility* (*i.e.,* compatibility with external biophysical constraints) and of *viability* (*i.e.,* compatibility with internal societal constraints). Additionally, social factors determine the *desirability* (*i.e.,* compatibility with social and cultural values) of the metabolic pattern under study.

A developed metabolism implies also a higher water consumption rate. This fact is of particular interest in the case of Israel, where water scarcity poses significant limits to the feasibility of the current metabolic pattern. This paper analyses water flows across different economic sectors in order to reveal how and in which ways water is needed to sustain societal metabolism. The analysis contributes to the challenge of quantifying sustainability when looking at complex systems characterised by a hierarchical organisation across scales. Scientific knowledge should help assessing the viability and feasibility of the system under analysis as a means to support an informed debate with society at large over the definition of a desirable social organisation and over the handling of the definitions of feasibility and viability affected by heavy doses of uncertainty [10]. When facing this challenge an integrated set of indicators needs to be considered at each scale of analysis in order to avoid reductionism.

The paper uses the Multi-Scale Integrated Assessment of Societal and Ecosystem Metabolism (MuSIASEM) approach [8, 11]. The first section looks at water extraction in Israel and gives an assessment of the feasibility of the current water consumption rate with relation to ecosystem constraints (the external view of the metabolism of the society, seen as a black-box, in relation to the biophysical context). The second section relates water consumption rates to human activity and provides a quantitative description of the societal metabolism of water, characterising the viability of water use in relation to societal requirements (the internal view of the metabolism of the society, the utilization of water by the parts operating within the black-box). The third section links the quantitative characterisation to the different narratives found about water, showing how social values and perceptions produce a variety of different representations of the problem. This raises the question: which representation should be considered? Concluding remarks suggest that the debate over sustainability cannot be solved by science alone because it requires the discussion about the relevant scales, dimensions and social values to be taken into account.

2. Water Resources – The Feasibility Check

Water resources can be classified as water available to human appropriation (surface and ground water, also defined as blue water) and water available to plants (soil water, also defined as green water), which can be used only in agriculture [12]. Blue water is appropriated by human activity, through water extraction and desalination, while green water can only be provided by the ecosystem, posing a severe constraint on the rate of water use (and water saving) in agriculture. Blue water can be further split according to its production cost into cheap water (*e.g.,* water extracted through wells) and expensive water (*e.g.,* desalinated seawater), which requires high technology, monetary and energy inputs. Blue water produced through expensive technologies is called economic water in this study. It adds to water appropriation but it implies an additional economic cost, and thus is not available to, say, a low income farming system.

Therefore, the supply of economic water is made possible by the availability of economic surplus, and depends on the level of economic development of each society. Wastewater produced by human activity and discharged into the ecosystem (grey water) is not accounted for in this study. A representation of water flows is given in the diagram below (Figure 1) following the grammar proposed by Madrid *et al*. [12]. The classification used allows mapping, in simplified terms, the interactions between the ecosystem and the societal system and the potential constraints to human appropriation of water resources. All figures refer to 2008.

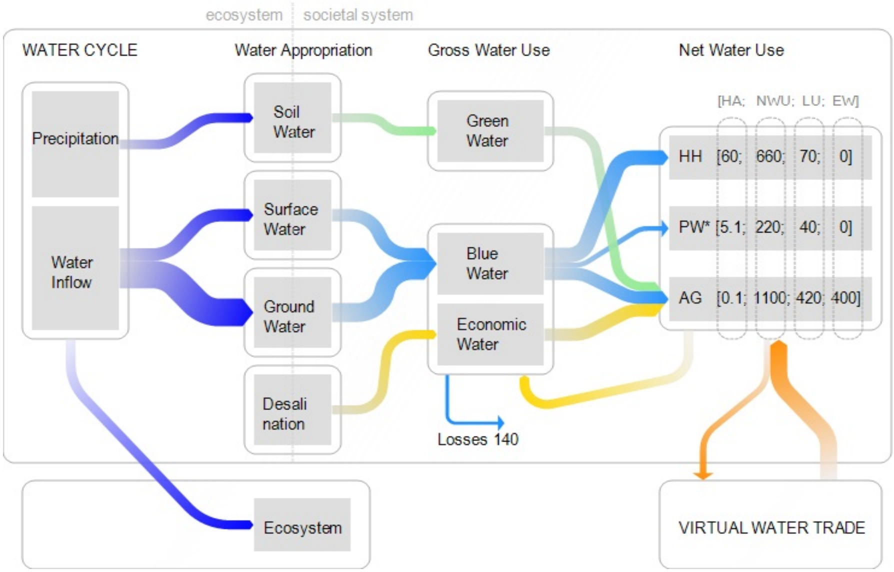

Figure 1: Water Grammar**.** Adapted from [12]. The economic compartments considered are Agriculture (AG), all other Paid Work activities (PW*) and Household/leisure and physiological overhead (HH). Values attributed to each compartment are Human Activity (HA), Net Water Use (NWU), Land Use (LU), and Economic Water (EW).

Israel is characterised by an arid climate and chronic water scarcity. Average yearly rainfall ranges from 400 to 800 mm, and the Negev desert, where precipitation is down to 25 mm/year, accounts for about 60% of the area of the country [13]. Water resources amount to 1.78 km^3/year [14] including surface water and groundwater sources. Annual fresh water withdrawal is estimated to be about 1.54 km^3/year [15], equivalent to 87% of total renewable water resources. The extraction rate of water resources is very high, in some cases threatening the stability of ecosystem. The main surface water source is the Kinneret Lake, situated in the North-Eastern border with Syria and Jordan, which supplies about 25% of the annual water consumption in the country with 560 hm^3/year [15]. Water levels in the Kinneret Lake are lowering due to over-extraction of water. Once water goes below 214 metres below sea level, ecosystem instability and deterioration of water quality are so high that pumps in the lake can no longer operate [2]. The limits imposed by the ecosystem are threatening the feasibility of the current water extraction rate.

The Yarkon Basin, or Mountain Aquifer, is the main source of groundwater extending from the West Bank to the Mediterranean Sea, and has an annual supply of 360 hm^3. The Coastal Aquifer contributes 240-300 hm^3/year with an area of 1,800 km^2, which includes Gaza's strip [15]. The two aquifers together are the second most important source of water in the country. The state exerts a tight control over water extraction given that both aquifers extend beyond the borders of the state and into Palestinian territories.

Total water consumption, estimated at 2000 hm^3 in 2008, is considerably higher than what is provided by the ecosystem (1500 hm^3/year). This difference can be explained by three factors. Firstly, water desalination provides about 300 hm^3/year, from three plants:

Ashkelon, Hadera and Palmahim. Secondly, treated wastewater is re-used in agriculture, representing about 50% (530 hm^3) of water inputs in this sector [15], considerably reducing grey water production. Finally, in cases of extreme scarcity, fresh water has been imported from Turkey [16]. Desalination and reuse of treated municipal water can be considered economic substitutes for fresh water [17], that is, water produced thanks to economic surplus. The limits imposed by the ecosystem are thus overcome through economic means and energy intensive technological solutions. As a matter of fact, water pumping uses about 5% of total electricity consumption and desalination accounts for an additional 2% [18].

In response to growing water scarcity, the state has pursued active control over water consumption through a progressive tariff system, encouraging treated brackish water use for irrigation and limiting the use of high quality potable water; through subsidies for the adoption of water saving measures such as drip irrigation, water-efficient garden irrigation systems; and a highly centralised water and land management system, which are both considered public assets and allocated by quotas [15]. The Water Authority is responsible for establishing water quotas for the different economic sectors and agricultural practices. As a result, water consumption per capita has decreased but overall domestic water consumption in absolute terms has increased due to the nine-fold increase in population between 1948 and 2008 (Figure 2).

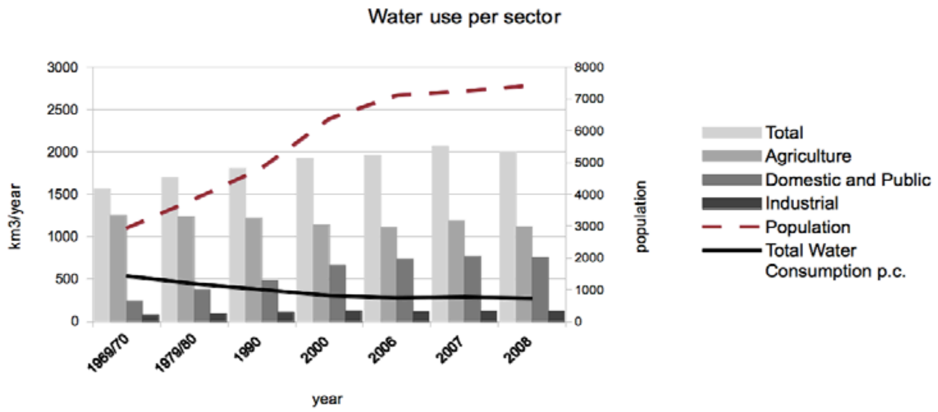

Figure 2: Water use per sector, Water Consumption per capita and Population. Data taken from [19], own elaboration.

Given that water use exceeds extraction, the current water consumption rate depends on water production external to the ecosystem. In terms of feasibility, *i.e.*, the compatibility of the societal system with the ecosystem in which it is embedded, Israel's water metabolism is unsustainable. Unfeasible water consumption patterns are sustained thanks to the monetary surplus generated by economic activity. Wealth can be seen as a water surrogate [20]. Israel represents a case of money for water, that is, societal overhead is invested in the production of water.

3. Societal Metabolism of Water – The Viability Check

We now turn to the internal view of society in order to understand how water resources are used and what determines total water demand. The concept of societal metabolism is used to explain how the system reproduces itself. This paper uses the MuSIASEM representation of societal metabolism, based on Georgescu-Roegen’s flow-fund model. Funds are defined as elements that enter and exit the process with their identity intact –

they remain “the same” in the chosen representation. In the study of economic processes, examples of funds are Ricardian land, capital and the work force. Flows are defined as elements that enter but do not exit, or exit without having entered, the production process. Examples of flows are: material inputs used in the production process, materials used for maintenance, output and waste [21]. The funds describe *what the system is* and the flows describe *what the system does* interacting with its context in the chosen representation [8].

The novelty introduced by the MuSIASEM approach is the explicit use of fund elements. The identity of the fund is a pre-analytical choice needed to make possible an analysis of flows, which are considered since the consumption (or production) of flows is aimed precisely at the reproduction of the fund. The flow-fund model is based on the consideration that the economic process “introduces qualitative change and is affected by the qualitative change of the environment into which it is anchored” [21]. The economic process can thus be characterised by intensity of resource use – *i.e.*, flows of energy, water and materials per unit of fund elements. An analysis of the trends in the evolution of metabolic pattern shows that an acceleration in the rate of consumption of resources results in a higher societal overhead, which makes it possible for a larger share of the population not to work, allows the establishment of a welfare system, the creation of a wide variety of leisure activities, and so on [8].

This analysis focuses on the fund element “human activity” measured in terms of hours per year. Thus Total Human Activity is calculated by multiplying the population by 8760, the number of hours in one year, and amounts to 65 million hours for the year 2008.

When considering the society as an organic whole (level n), its functioning cannot be described by disaggregating the whole into individuals on a per capita basis. In order to study the nested hierarchical structures that constitute society we have to identify specific structural and functional compartments [22]. At a lower level (n-1), human activity can be split between paid work (working activity in the conventional economic sectors) and non-productive activities (human activity outside the paid work sector). This split is determined by two facts: (i) only part of the population is economically active; (ii) those employed in the Paid Work sector work for only a limited amount of hours over the year.

The dependency ratio in Israel is 62%, which defines the fraction of the population that does not work, labelled as the Household sector in this study. This category includes: children, the elderly, the unemployed, students, the military, and ultra-orthodox Jews. It follows that 38% of the population working a limited amount of hours per year (less than 2,000) sustains the consumption of the society as a whole, *i.e.*, the non-working population and themselves. In fact, the average working load of the working population is of 35.4 hours/week [19]. Expressed in work hours per year, the human activity of the employed is approximately 5 million hours per year, representing 8% of Total Human Activity. This means that 92% of Total Human Activity in Israel is allocated outside the Paid Work sector.

Coming to the analysis of the metabolism of water, the flow-water corresponds to the total amount of human appropriated water, which includes only blue water in this study. Looking at the structural and functional compartments, the main consumer of water is the agricultural sector with about 54% of Net Water Use (Gross Water Use net of distribution losses). Israel's agricultural water consumption is markedly below the average for the Middle East (83%) and slightly below Mediterranean Europe (60%) [14]. This can be explained in terms of the advanced technology and high water efficiency that characterizes the agricultural sector in Israel. Thanks to the tight control over water use in agriculture and a switch to crops with higher yields [23], water demand by this sector in absolute terms has slightly diminished during the last 20 years. Imports of high water requirement crops also help reduce domestic water consumption by externalising production (and the water use associated with it).

Gross water use is allocated according to the use of the agricultural sector (52%), other Paid Work sector activities (10%), and the Household sector (31%), and accounts for water losses (7%) in distribution and handling. At this point, it is possible to compare the performance of the sectors considered in terms of metabolic rates, *i.e.,* water consumed per hour of human activity, and economic productivity of water, *i.e.,* dollars generated per m^3 of water used. The agricultural sector presents a metabolic rate of 11 m^3/hour, markedly above the remainder of the paid work sector (0.04 m^3/hr) and the Household sector (0.01 m^3/hour). This can be explained by the fact that agriculture requires more water than any other human activity and a very small portion of the work force is needed thanks to the high level of mechanisation of the sector. In terms of economic water productivity, the agricultural sector presents the lowest value added per m^3 of water (3 $/$m^3$), considerably below the average of the paid work sector (120 $/$m^3$). Agricultural exports perform slightly better (5 $/$m^3$) although this does not significantly add to overall Exports.

The allocation of water resources is determined by the specific function absolved by different human activities in the reproduction of societal metabolism. Different structural and functional compartments mapping on to categories of human activities (Agriculture, Service and Government, Households) can be seen as different organs. Agriculture functions like the hearth, having a central role in the economic process because no other activity can provide food to society. Just like the hearth requires the highest flow of blood, in the analogy agriculture is the sector which uses the most water resources. Water is necessary because it is a compulsory input for irrigation and technological innovation cannot reduce the bio-physical water requirement of crops. For this reason, all agricultural sectors are heavily dependent on water resources regardless of the level of economic development or technological progress achieved. The concept of "strong" sustainability [24; 25] flags the impossibility of substitution of inputs made available by natural processes by capital and/or labour. The fact that agriculture contributes to a small share of GDP (about 2%) should not lead to the conclusion that society can reproduce itself without agriculture. At best, agriculture can be substituted by food imports.

Imports of agricultural products relieve the pressure on the country's agricultural water demand. Allan [17] termed the water savings derived from the import of crops as "virtual water" imports, in other words, the import of crops can be seen as the import of the water required to grow them. Israel imports 95% of its cereals, 80% of its fish, and half of its beef, oilseeds and nuts [19]. It should be noted that the own production of beef would imply a major boost in the demand for biomass production – an estimated 13 kg of grain are needed to produce 1 kg of beef [26] – and in a high consumption of water for running the beef lots. The water saving through trade does not mean that society requires less water to survive, but simply that its requirement of water is externalised to the producer.
Two alternative approaches are used to represent societal metabolism (Table 1).

(1) The Internal View – in the MuSIASEM approach, this view is used to categorise the end uses of funds and flows and characterise the organisation of society. The flows food and money and the fund land are introduced in the analysis. Food is measured in Peta joules in order to account for the nutritional value of what is consumed, allocated to the household sector, losses and exports. Israel has specialised in the export of high value added food products, such as citrus, avocado, and cherry tomatoes. Given that the nutritional value per ton of grains is quite different from that of fresh vegetables (mainly made up of water), we use joules to quantify the nutritional value of food flows. In terms of joules, the food self-sufficiency ratio[1] is of about 44%. Monetary flows represent Gross Value Added of each economic compartment, Taxes and Exports. Water is allocated according to end use and virtual water embedded in agricultural exports.

(2) The External View – in the MuSIASEM approach this view is used to show the dependence of the system on external inputs (imports or natural resources whose availability is outside human control). In this case, about 60% of food is imported from abroad, corresponding to 1700 hm^3 of virtual water imports, *i.e.*, the water required to produce the same amount of food domestically calculated using total water requirement of the current crop mix. Given that domestic production is specialised in crops with a low water requirement, virtual water imports are underestimated in this representation. Nevertheless, this second approach shows how food imports significantly reduce direct water use.

Table 1: Flows and funds of the system. The compartments considered are the Household sector (HH), the Paid Work sector (PW), the agricultural sector (AG) and other economic sectors within Paid Work (PW*).

END USE	FOOD (PJ)	WATER (hm3)	MONETARY FLOWS (million $)	HUMAN ACTIVITY (billion hr)	LAND USE (thousand ha)
HH	2.1	660		60	70
PW		1300	158000	5.2	460
AG		1100	3200	0.1	420
PW*		220	155000	5.1	40
LOSSES	0.7	140	47000[1]		
EXPORTS	0.3	280 (v)	82000 (40%)	2.1 (v)	110 (v)
TOTAL	**3.1**	**2100**	**205000**	**65**	**530**

SUPPLY	FOOD (PJ)	WATER (hm3)	MONETARY FLOWS (million $)	HUMAN ACTIVITY (billion hr)	LAND USE (thousand ha)
IMPORTS	1.9	1700 (v)	85000 (42%)	2.2 (v)	270 (v)
DOMESTIC SUPPLY	1.2	2100	205000	65	530

[1]Taxes
(v) virtual

On the other hand, “Israel's clever “techno-fix” for the water crisis, desalination, is not the solution, since it is hugely energy intensive” [28]. Fossil fuels make up 98% of Israel's primary energy sources [29] and come entirely from imports [30]. In monetary terms, Israel presents a negative trade balance, indicating that the viability of the system in biophysical terms depends on the generation of economic surplus not directly related to biophysically based economic activities. Finally, in terms of land use, food imports also relieve the constraint posed by the limited availability of fertile arable land.

4. Social Values and Narratives – The Desirability Check

Is Israel water scarce or a water abundant country? This may seem like an odd question given the aridity of the region. Nevertheless, in the early years of the State, “the country's annual water potential was a hotly contested category. Prior to Israel's establishment, the water potential of Palestine played an important role in determining the annual “appropriate” level of Jewish immigration” [32]. Zionist water experts argued that water resources were abundant in order to encourage open immigration of Jews into the country.

[1]Calculated according to the guidelines of FAO’s [27] “Food Balance Sheet – A Handbook” as:

SSR = production / (production + imports – exports) *100

This debate introduces a new context to the question of defining the sustainable level of water use, namely social and cultural values. In order to assess the desirability of such a system, an in-depth participatory evaluation should be carried out with interested stakeholders. Different countries evaluate different problems differently, so that no general assessment of what is sustainable is possible in abstraction from the social and cultural values in which the assessment is embedded. The very concept of sustainability needs to be carefully defined according to the context. As a consequence, no conclusions can be drawn from the overview provided in this paper. What follows is a tentative approximation to some of the possible relevant criteria for evaluating the sustainability of water use in Israel.

The appraisal of the system as sustainable or unsustainable changes according to the indicators used (*e.g.*, efficient water use at the level of the agricultural sector versus aquifer recharge rate at the ecosystem level), which in turn depend on the analyst's choice of representing a specific object in a certain way based on their goals and beliefs (*e.g.*, encouraging immigration versus maintaining ecosystem stability). The desirability of the system can thus be discussed by mapping the different indicators and relevant narratives found in the literature about water in Israel according to the temporal and spatial scales which they refer to. Narratives are defined as tools used to establish causality and assign meaning and are necessary to create a shared experience [33]. Figure 3 offers an example of different sets of indicators that can be used to assess the three dimensions of sustainability (economic, social and environmental) at different spatial scales (ecosystem, society and a specific economic compartment) and temporal scales – the "snapshot time" (t_1) at which the system is observed (static indicators) and the time differential (dt) used to simulate the dynamics of the system (performance indicators) [34].

The narrative of water scarcity, largely endorsed by the government, uses indicators such as water withdrawal rates, water quality [1] and biodiversity loss [2] as well as the increasing water demand for the rehabilitation of aquifers [15], which map onto the ecosystem level in our representation. The "water crisis" narrative has been used as an argument to support centralised control of water and land [32].

At the level of society, different narratives can be identified regarding the current situation (time t): the capacity to produce water to meet society's demand is seen as a great achievement [18], population density on the contrary is seen as a threat adding pressure to existing resources [7, 29], and dependence on imports is perceived as a menace to energy and food security [28; 30]. Regarding the desirability of observed trends (time *dt*), growing water demand and growing population [15] are seen as threats to sustainability, while GDP growth is considered as desirable [35].

At the level of the agricultural sector (zooming in), the system seems to perform very well in terms of water efficiency (measured as water use per hectare [3; 4]) and GDP per capita, which locates Israel in the high income countries category, as classified by the World Bank [35]. Due to the high level of mechanisation, the agricultural sector absorbs only 2% of the economically active population, a characteristic trait of more developed economies [22].

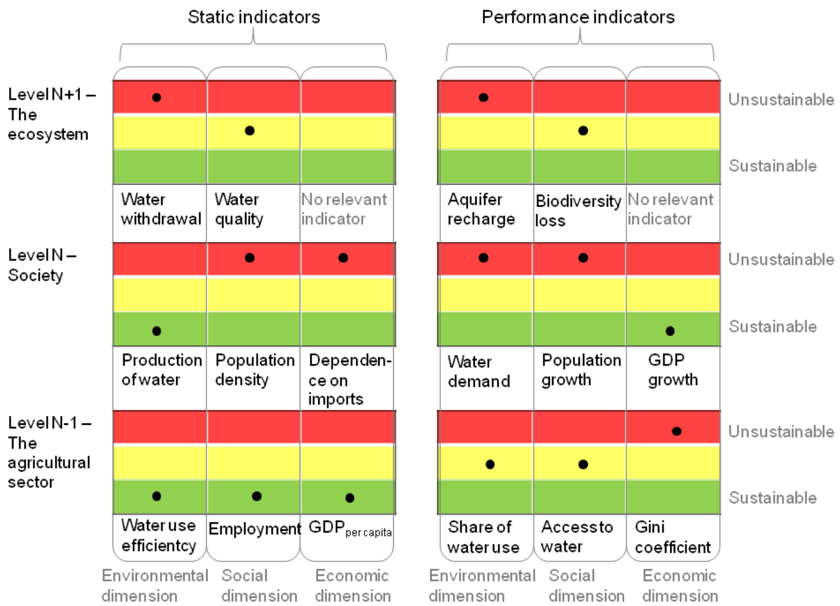

Figure 3: Sustainability Indicators at Different Spatial and Temporal Scales.

In a development perspective (adopting a higher temporal scale), the maintenance of the rural-agricultural sector is seen as a policy priority [1]. Concerns are raised over the unequal distribution of, or access to, water and income inequality. The Bedouin community in particular, whose settlements are not legally recognized, does not receive public services such as running water provision or sewage disposal [36]. The Gini coefficient, a measure if income inequality, is very high (0.38) compared to other developed countries [19].

In general terms, we can say that as a result of growing water scarcity, high living standards can only be maintained through a continuous increase of imports and the specialisation of the working population in high value added activities, such as services, high-tech start-ups and so on. A large economic surplus will be needed to guarantee water provision or to externalise resource-intensive production through imports. Our study shows that the current metabolic pattern of Israel is only feasible in the context of resource abundance abroad. In the context of peak oil, defined as the upper limit to the production of oil [37; 38], such dependence on external inputs, and particularly on fossil fuels, may become soon highly unsustainable. The peak oil scenario threatens the very survival of socio-economic systems heavily dependent on oil imports.

The problem of defining sustainability resides in the fact that changes in identity of the system can be seen only by maintaining the same level of analysis over time, that is, the same description based on the same choice of relevant variables. As discussed by Allen *et al*. [20] the analysis of the evolution of socio-economic systems should address the unavoidable change of strategy used by this system in order to cope with changing boundary conditions. In the first phase, when the system establishes itself it follows a strategy of “high gain” – flows are perceived to be abundant and used to improve the stability of the system (in this example, using water to boost food self-sufficiency, increasing the population). As the system matures and becomes more complex through the creation of new activities and a more hierarchical organization of human activities, it expands in its context by using more resources.

When resources become scarce, structural organisation has to adapt to resource availability. In this second phase the system has to adopt a “low gain” strategy looking for congruence between external and internal constraints (*e.g.*, the implications of water scarcity and demographic variables) and adjust the functional and structural compartments. According to this narrative the identity of Israel changed because its economy got more organised in terms of functional and structural compartments compared to its early stages. This requires that the definition of what we mean by sustainability should also change along with the evolution of the system, for example from soft (there are economic substitutes for water) to strong sustainability (there is an absolute scarcity of water). Sustainability should be seen as a moving target [39].

5. Conclusion

This paper suggests that the assessment of sustainability has to be carried out according to different spatial and temporal scales of analysis. The focal point (the level n) is the society. Desirability is defined at this level by looking at how social and cultural values shape the different narratives present in society and how those narratives determine the relevant attributes to be observed (what are the characteristics that matter?). Feasibility looks at the compatibility of the system with the external constraints. External constraints can only be observed by adopting a larger scale of analysis (the level n+1), a scale capable of studying the processes guaranteeing the stability of ecosystems. Viability looks at the compatibility with the internal constraints, that can only be observed by adopting a smaller scale of analysis (the level n-1), where we can observe specific social structures and organisations.

Under this perspective of sustainability, the water metabolism of a society is sustainable if the desired distribution of human activity and allocation of water resources are feasible and viable. Defining what is desirable entails two challenges: on one hand, the ability to deal with non-equivalent descriptive domains and, on the other hand, the unavoidable existence of non-equivalent perceptions. The use of non-equivalent descriptive domains requires an integrated assessment, that is, the combined use different knowledge claims in order to generate a more complete representation that cannot be derived from a single discipline [40]. In the case study presented, the societal metabolism view highlights the importance of the agricultural sector for the reproduction of society, the economic view reveals the role of monetary surplus in compensating the bottlenecks imposed by bio-physical constraints while the ecological view flags the growing pressure on ecosystem stability due to water extraction. The challenge posed by the existence of a plurality of non-equivalent perspectives is out of the scope of this paper, we just point out that different narratives result in different choices of relevant attributes used to evaluate sustainability.

In conclusion, different knowledge claims have to be considered in order to check the quality of the scientific information (based on a specific choice of scale and dimension) used to inform policy. With this goal in mind, we should avoid oversimplifications in the representation of the system and handle the uncertainties faced carefully. In the case of Israel, many different issues emerge resulting in multiple contrasting definitions of sustainability, including the overexploitation of aquifers and of the Kinneret Lake, the goal of food self-sufficiency, the dependence on imports of fossil fuels, the growing population and income inequality, *et cetera*. The approach presented in this study seems to represent a step in the right direction away from the trap of reductionism in the direction of an open acknowledgment of the challenges posed by complexity.

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Appendix

The figures used for the characterisation of human activity are taken from the table K/3 “Average number of weekly work hours per employed person (incl. those temporarily absent from work), by industry” and table K/2 “Employed persons, by industry” [20]. Both tables report figures for the years 2008, 2009 and 2010. Figures for 2008 are considered.

Weekly work hours and employed persons are presented in quarterly figures, *i.e.*, as averages of three months each. Weekly work hours vary from one quarter to the next because national holidays are taken into account.

Since holidays are included in the accounting, it is considered that there are 52 work weeks per year. Employed persons vary in some industries because of seasonal work.

Yearly human activity of a given sector is calculated as:

HA_i = 13 weeks * (weekly hours * thousand people)$_{1st\ quarter}$ + 13 weeks * (weekly hours * thousand people)$_{2nd\ quarter}$ + 13 weeks * (weekly hours * thousand people)$_{3rd\ quarter}$ + 13 weeks * (weekly hours * thousand people)$_{4th\ quarter}$ Eq. (B.1)

According to the compartments considered in this analysis, the sectors have been aggregated as follows:

MuSIASEM categories	**National Statistics Categories**
AG	Agriculture
PW*	Manufacturing; Electricity and Water; Construction (building, civil and engineering projects); Wholesale and retail trade, and repairs; Accommodation services and restaurants; Transport, storage and communications; Banking, insurance and other official institutions; Real estate, renting and business activities; Public administration; Education; Health services and welfare and social work; Community, social and personal and other services; Services for households by domestic personnel; Extra-territorial organisations and bodies; Not known

Data on water consumption is taken from table st21.05 “Water production and consumption” [20]. The table reports figures for 1969/70, 1979/80, 1990, 2000, 2006, 2007 and 2008. Figures for 2008 are considered. Figures for consumption are divided in “Agricultural”, “Domestic and public” and “Industrial”. In order to disaggregate water consumption of the public sector and domestic users, Table “t06 Physical flows of water corresponding to economic uses recorded in Table 2, 2006” [20] was used as reference. Water consumption figures were classified according to the categories chosen for HA.

Data on land use for Israel is taken from table st19.2 “Agricultural crop areas” [20]. Data for 2008 is considered. Total agricultural land is calculated as the sum of the areas dedicated to the different types of plantations listed. Data on monetary flows is taken from table st18.1 “Gross Domestic Product of the business sector, by industry” and st14.2 “Gross Domestic Product and uses of resources, in the years 1995-2009” [20]. Data on food is taken from table st19.23 “Food supply balance sheet” [20]. Calories are calculated according to the conversion coefficients provided in “Food Composition Tables” [28].

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