When Water Saving Limits Recycling: Modeling Cascading Water Use in a Computable General Equilibrium Framework

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Abstract

Due to water scarcity problems, the reclamation of wastewater is an increasingly important water source in many parts of the world. The use of reclaimed wastewater is often advocated, as a cheap and reliable form of water supply, which preserves water resources and is an economically efficient method for processing sewage. This study integrates wastewater recycling in a Computable General Equilibrium model. The novelty of the approach is that the quantity of reclaimed wastewater depends on water consumption by economic agents connected to a sewer system, such that a cascading water use can be modeled. An application to the case of Israel shows that not considering this linkage can lead to an overestimation of the potential of wastewater recycling, especially when economic agents engage in water saving.

Keywords:

Cascading water use; computable general equilibrium model; STAGE_W; wastewater recycling; wastewater reclamation; shadow price

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1 Introduction

Many countries in the world face increasing problems of water scarcity, caused by growing demand for water but also because of dwindling supplies. Furthermore, in many countries the quality of freshwater resources is deteriorating; water bodies and aquifers are increasingly polluted. This results in higher purification costs or, if these cannot be borne, a spread of water born diseases (*Jimenez & Asano*, 2008).

One way to ease the problem of water scarcity and at the same time to mitigate pollution problems arising from discharging wastewater into water bodies is the reclamation of wastewater. This wastewater can be used as a substitute for potable water in applications that do not require potable water quality, e.g., irrigation of non-food crops and cooling of industrial processes. Especially for the agricultural sector, being the largest water consumer in many countries, reclaimed wastewater presents a reliable and cheap form of water provision and thus is applied in more than 40 countries around the globe already (*Jimenez & Asano*, 2008). In many countries the ratio of reclaimed wastewater reuse to total water extraction is still very low, such that there is a high potential to further increase the usage of reclaimed wastewater. Other countries already reuse a considerable share of their total freshwater extraction, which can be as high as 35% in Kuwait and 18% in Israel (*Jimenez & Asano*, 2008). Usually only a limited share of the freshwater extracted can be recollected after usage; for example water used for irrigation is mostly lost due to evapotranspiration or percolates back into the groundwater. In many cases only municipal wastewater is collected in a central sewer system and thus potentially available for being reused. Therefore, with such high reclamation rates as specified for Kuwait and Israel, the availability of sewage to be treated can pose a limitation on the usage of treated wastewater. Under such conditions, water saving by water users connected to the sewer system will reduce wastewater supply and thus the potential for reclaimed water usage.

This mechanism has not been evaluated in Computable General Equilibrium (CGE) frameworks, but may have considerable effects. With freshwater resources getting scarce there is, on one hand, an incentive to recycle[1] more wastewater, while on the other hand, wastewater supply would decline with increasing potable water prices and reduced potable water use. This paper presents a general equilibrium approach to link the reclamation of wastewater and the quantity of reclaimed water available to potable water consumption. This results in a more realistic depiction of the potential of water reclamation. Furthermore, this approach allows approximating the shadow price of wastewater in the economy, which may inform pricing decisions. The proposed framework is generic; it can be applied in any country. In this paper the model is given empirical content for the case of Israel, which is a good example due to its high wastewater reclamation rate and availability of data.

The remainder of the paper is structured as follows. Section 2 gives a brief literature overview on existing approaches to model the reclamation of wastewater from an economic perspective. In Section 3 the STAGE_W model and its extension to link water consumption and wastewater reclamation are introduced. To demonstrate the functionality and the validity of the model, the following section presents an application to the Israeli economy (Section 4). In Section 5, the results of the Israeli simulation are discussed and put into general context. Finally Section 6 provides conclusions for the case of Israel as well as for the approach in general.

[1] In this paper recycled wastewater is wastewater which is treated and reused.

2 Literature overview

Although the literature on water models for economic policy analyses has developed in quality and scope in the last 25 years (*Booker et al.*, 2012), Feinerman et al. (2001) found that the economics of wastewater recycling had been little investigated and Lavee (2014) noted that economic implications are by far less studied in the field of wastewater recycling than the technological aspects. However, in recent years several authors analyzed the economics of wastewater reclamation in more detail. The literature has mainly focused on two aspects: the optimal reclamation quality, and the optimal distribution of recycling costs between wastewater producers and consumers. Very few papers aim at depicting the reclamation of wastewater in economy-wide models.

2.1 Reclamation quality

After finding that the use of reclaimed wastewater for irrigation generally yields a positive net benefit in Israel (*Haruvy*, 1997), Haruvy et al. (2008) develop an "integrated planning-hydrological-technological-economical model" for sustainable water management and find that reclaimed wastewater should be desalinated to stabilize chlorine concentration in the soil in the long run.

Lavee (2013) applies a cost benefit analysis to investigate whether a national quality standard for wastewater or differing local standards should be applied in Israel. While in case of a national uniform standard the upgrade of reclaimed wastewater to the highest sanitary and lowest salinity levels (including tertiary treatment) would be more beneficial and yield a higher net benefit than lower treatment levels, allowing some regions to apply a lower regional standard would double the countrywide average net benefit per m^3 of reclaimed wastewater compared to the uniform standard.

2.2 Reclamation costs

Feinerman et al. (2001) Investigate on how the costs of wastewater recycling could be shared most efficiently between wastewater producers (municipalities) and users of recycled wastewater (farmers). They describe that the reclamation of wastewater is a public good for the wastewater producers but a private good for the users of the reclaimed wastewater and deduct that for this reason, market failure exists and thus no optimal allocation will be achieved on a free market, which justifies policy intervention. The authors also find that the often applied polluter pays principle does not necessarily lead to an efficient allocation of reclaimed wastewater. They conclude that no general rules can be deducted for the optimal pricing of reclaimed wastewater. Thus Axelrad & Feinerman (2010) develop a regional model based on game theory to optimize the cost sharing between municipalities and two competing farmers associations for wastewater reclamation under symmetric and asymmetric information regarding the demand for reclaimed wastewater. They find that total gains are the highest in case of symmetric information, which supports the motivation for cooperation between economic entities and reaching regional agreements between cities and farmer associations about the allocation and price of water.

2.3 Wastewater recycling in simulation models

The first CGE model incorporating wastewater recycling was constructed by Rivers and Groves (2013). They investigate a potential water pricing scheme for Canada. Thereby they allow companies to internally recycle water which is not consumed e.g., incorporated in final products or evapotranspirated. Thus these firms can save on abstraction costs and wastewater discharge fees. Depending on relative costs of internal water recycling versus fresh water supply and discharge costs, in the extreme case all non-consumptive usage could be internally recycled infinitely. This is supported by Levine & Asano (2002), who find that through the investment in internal wastewater recycling, industries are able to reduce their freshwater intake by up to 95%.

However, the approach of Levine & Asano (2002) as well as the CGE analysis of Rivers & Groves (2013) do not capture the possibility of consecutive water use, i.e. wastewater being discharged by one entity, then recycled and finally used by another entity. Thus, recycled wastewater cannot be transferred to other sectors e.g., recycled household water to be used in agriculture.

This limitation is overcome by Roumasset & Wada (2011), who in their dynamic optimization model add recycled water as a substitute for fresh water which can be used in the agricultural sector. They find that under the assumption of constant marginal provision cost, the application of recycled wastewater becomes a backstop technology in the agricultural sector, whereas with increasing marginal cost it serves as a supplemental resource. In this model, however, the supply of reclaimed wastewater is not limited such that any quantity of reclaimed wastewater could be provided as a backstop technology. This can be a misleading assumption, especially when it comes to a drought as pointed out by Park et al. (2008).

Finally, Zhang et al. (2014) take quality as well as quantity and pricing issues into consideration as they apply a genetic algorithm, to solve a multi-objective optimization model for 31 Chinese regions. The objectives are to optimize: i) the quality, ii) the quantity and iii) the economic profit from recycling of wastewater. The results are little surprising: regions suffering from quantity related water scarcity should opt to maximize recycling quantity, regions suffering from quality related scarcity should minimize the pollutant content in the wastewater and all other regions should maximize profits from wastewater recycling.

The approach presented in this paper builds on Luckmann et al. (2014), which is the first one allowing for the transfer of recycled wastewater to other activities in a CGE framework. The model of Luckmann et al. (2014) is extended by taking up the suggestion for further research by Feinerman et al. (2001) to link the recycled wastewater production to potable water use and thus make it an endogenous variable in the model. Thus in our approach the consumption of potable water limits the quantity of reclaimed wastewater available, such that it cannot be considered an independent substitute, as in other approaches described above.

3 Model Description

This analysis is based on an extension of the STAGE_W model (*Luckmann & McDonald*, 2014). STAGE_W is a SAM based single country CGE model, which includes nonlinear as well as linear relationships governing the behavior of the model's agents. It can be implemented in a comparative static or recursive dynamic way. The water sector is depicted in detail: different types of water activities produce different water commodities from water resources or by-products. According to the country context and research question, the model is flexible to accommodate any number and composition of water activities, commodities and resources. With the help of various subsidy and tax instruments (production subsidy (TX_a), water commodity tax ($TWAT_c$), water user subsidy ($TWATA_{c,a}$)) the costs of water provision to the supplier as well as water fees charged from different consumer groups can be adjusted for each type of water (Figure 1). The production subsidy together with constrains on the use of water resources also allow for the simultaneous production of homogenous commodities by more than one activity, despite of different cost structures.

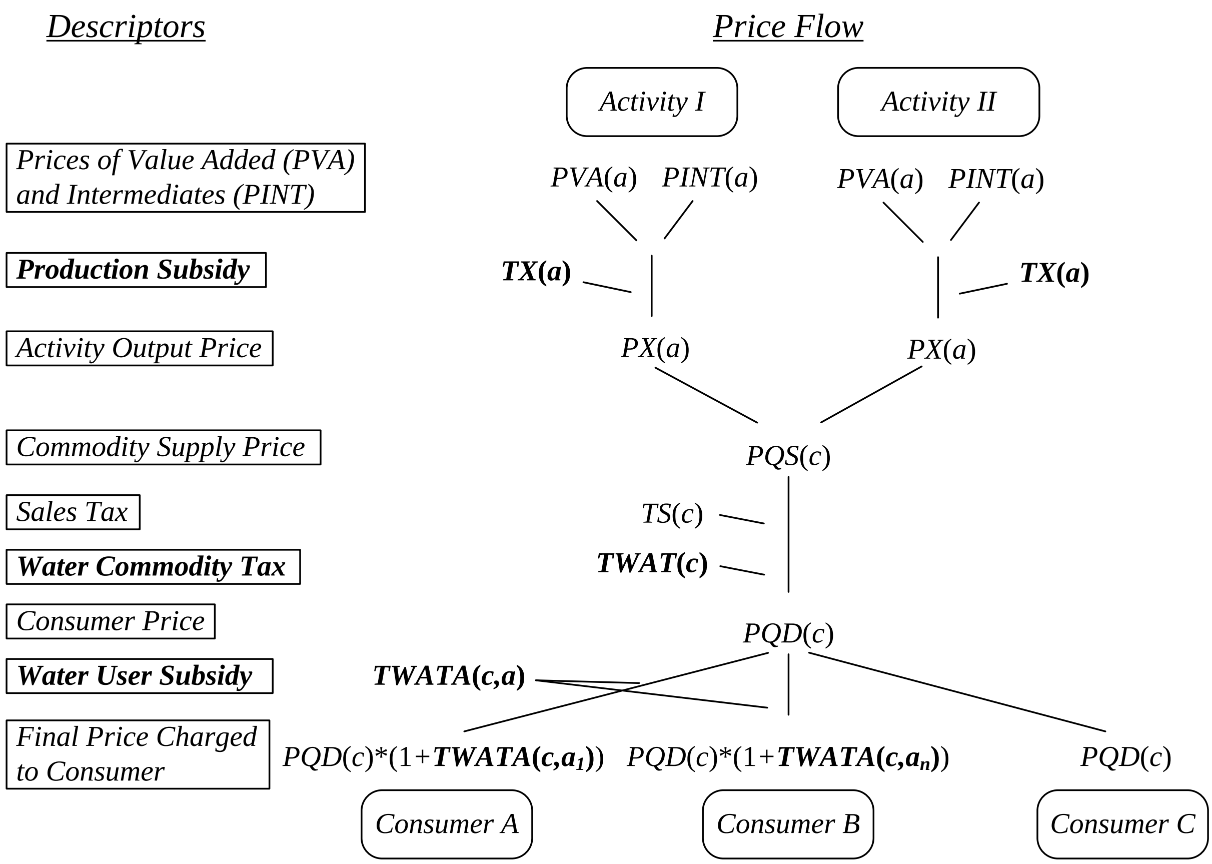

Figure 1: STAGE_W water pricing system

The production of commodities is governed by a series of nested production functions with elasticities of substitution between zero (Leontief) and less than infinity (CES), whereby water commodities, resources and by-products enter on the lowest nest. This allows for substituting between water commodities as well as between water aggregates and other inputs on higher levels. Figure 2 depicts an example of the generic production structure, which is fitted to the case of Israel described below.

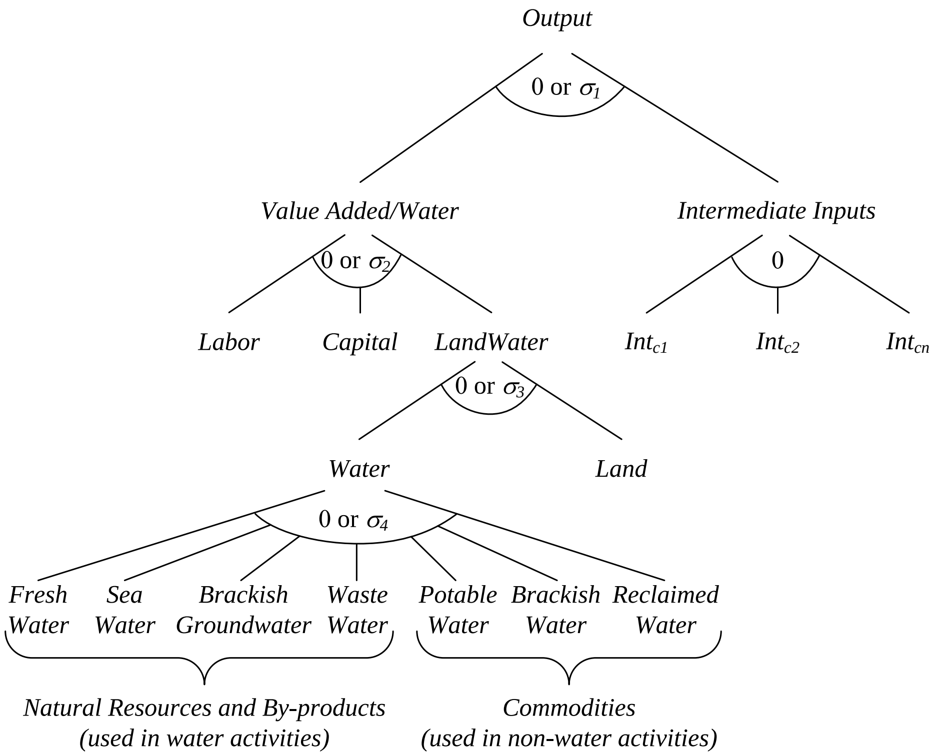

Figure 2: Production system for activities in STAGE_W.

In this study the basic model is developed further in order to link the quantity of sewage available for reclamation to the consumption of water by economic agents connected to a sewer system. Therefore an additional equation is introduced to the STAGE_W model.

$$FS_{sew} = E = SHSEWS * (1 - SHSEWL) * \left(\sum_{cwat,asew} QWAT2_{cwat,asew} * SHSEW_{cwat,asew} + \sum_{cwat,h} QCD_{cwat,h} * SHSEW_{cwat,h} \right) \quad (1)$$

This equation determines the supply of effective sewage[2] (FS_{sew}) available as a resource to the reclamation activity. The quantity of FS_{sew} depends on the quantity of water commodities consumed by households ($QCD_{cwat,h}$) and being used as an intermediate input in the production of activities connected to the sewer system ($QWAT2_{cwat,asew}$). Thereby the set *asew* can be specified flexibly. Not all water which is consumed by these agents also results in sewage. For example households might use some water for garden-irrigation, which then is either lost due to evapotranspiration or percolates into the groundwater. Therefore for each household group or activity an individual water-commodity-conversion rate can be specified ($SHSEW_{cwat,h}$ and $SHSEW_{cwat,asew}$) determining the volume of sewage produced per m³ of water consumed. The total volume of sewage available is calculated as the sum of sewage accruing at all entities. As not all this is collected in a central sewer system to be transported to a reclamation plant, the ratio of sewage collection is determined by the variable *SHSEWS*. Finally also during the processing of the sewage some losses occur which is considered by the loss share variable *SHSEWL*.

[2] Effective sewage refers to the water content of sewage, excluding everything which is added to the water by primary usage and filtered out again in the wastewater treatment process.

All of the effective sewage is treated and converted into a reclaimed wastewater commodity (*cwatrec*). Reclaimed wastewater which is not recycled (used in economic activities) but for example discharged to rivers for natural conservation and to improve river flow is flowing out of the economy, as for this no economic transactions occur. This water quantity is incorporated in the model as government consumption. Thereby the government consumption of reclaimed wastewater is formulated as a mixed complementary problem (2), with a lower bound being the base quantity but an unlimited upper bound (3).

$$QCD_{cwatrec} = G = QGDWADJ * comgovconst_{cwatrec} \quad (2)$$

$$QCD.LO_{cwatrec} = comgovconst_{cwatrec} \quad (3)$$

Thereby $QCD_{cwatrec}$ is the quantity of reclaimed wastewater consumed by the government which is calculated as the base government demand $comgovconst_{cwatrec}$ multiplied by a scaling factor *QGDWADJ.* This formulation gives flexibility to the model, as depending on the simulation, it allows for more reclaimed wastewater to be discharged into the environment.

4 The case of Israel

4.1 Wastewater recycling in Israel

Israel is a country in which water scarcity is very severe. The annual fresh water supply is less than 250 m^3 per capita, which is 50% below the threshold of severe water scarcity according to the Falkenmark indicator (*Tal*, 2006). The Israeli water law of 1959 states that all water in Israel belongs to the state. This includes sewer and wastewater (*Kislev*, 2011). The law also obliges the authorities to treat municipal sewage (*Inbar*, 2010). Therefore, over the last years the capacity for wastewater treatment has been increased continuously. Today 94% of the sewage produced is collected in a central sewer system and 91% is treated (*Lavee*, 2013). About 75% (355 million m^3) of the sewage is recycled and mostly used in agriculture. The remainder is discharged into rivers after treatment, to improve water quality and river flow, (*Inbar*, 2010; *Lavee & Ash*, 2013) (Figure 3). The Israeli wastewater recycling rate[3] is considered to be among the highest in the world (*Lavee & Ash*, 2013). Reclaimed wastewater constitutes about one third of total irrigation water. The reclaimed wastewater is distributed via an extended separate network, such that in many localities farmers can decide to either use potable water or reclaimed wastewater for irrigation. However, due to sanitary restrictions the irrigation with recycled wastewater is limited to crops which are either not for human consumption, e.g., cotton, fodder crops, or to plants of which the consumed parts are not touching the water directly, e.g., orchards (*Inbar*, 2010).

[3] The wastewater recycling rate is the share of recycled wastewater over total wastewater produced.

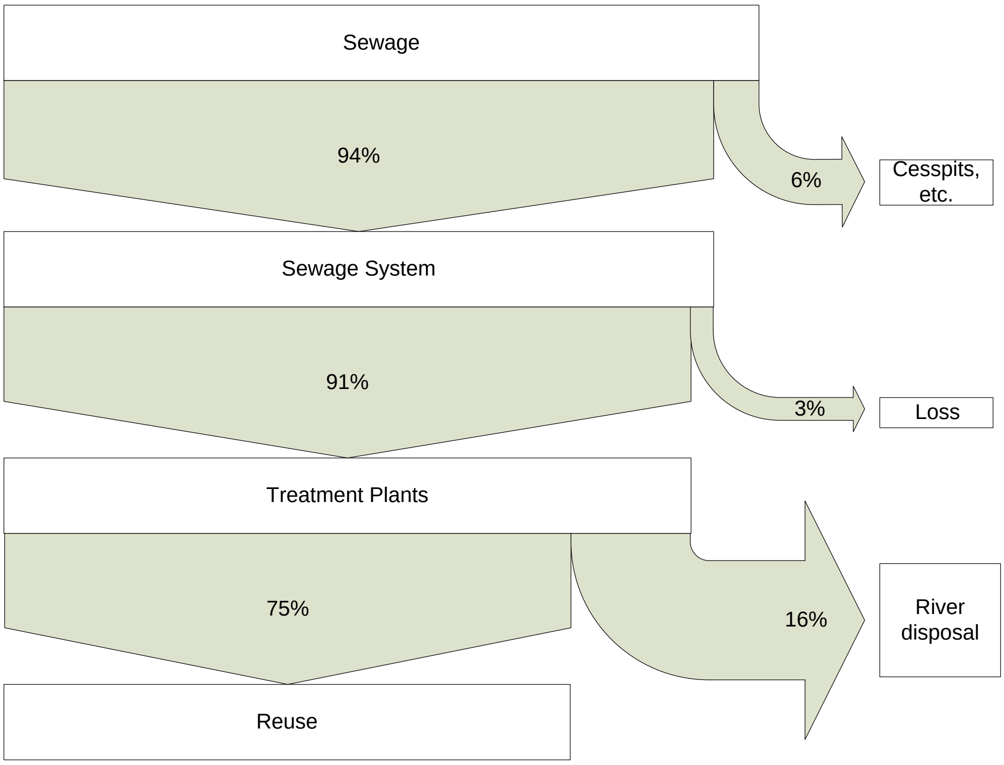

Figure 3: Sewage disposal system in Israel.

The Israeli Water Authority (IWA) has been appointed to manage the water sector and supervise all companies which are involved in the provision of water of all qualities. The biggest of those companies is Mekorot Ltd., a state owned enterprise, which provides and distributes around 70% of the national water supply (*FAO*, 2009) and accounts for about 50% of the current wastewater reclamation capacities (*IWA*, 2012).

The IWA plans to increase the share of wastewater reuse from the current 75% to up to 95% over the next few years to have more potable water available for municipal usage (*Lavee & Ash*, 2013). With the development of further reclamation facilities and intensive efforts to connect most of the municipal water users to treatment plants, along with an assumed doubling of urban potable water consumption, by 2050 as much as 900 million m³ recycled wastewater shall be supplied annually (*IWA*, 2012). Furthermore, it is planned to upgrade the quality of recycled wastewater to allow for a wider use in agriculture (*IWA*, 2012).

The recycling of wastewater is heavily subsidized by the Israeli government because of perceived benefits. There is financial assistance for farmers who decide to switch to the use of reclaimed wastewater, as well as for upgrading the quality of reclaimed wastewater to a level being in line with current regulations. Total investment committed by the IWA for wastewater recovery projects amounted to 4.6 billion New Israeli Shekel (NIS) (~1.34 billion USD) in the last decade. Private recovery facilities receive a subsidy of 15-60% of their construction costs and inter-facility infrastructure has been fully government funded. The annual subsidy was estimated at about 170 million NIS (~50 million USD), which is cross-financed by domestic consumers through higher potable water prices and sewage fees (*Lavee & Ash*, 2013). At the same time quotas for the use of potable water in the agricultural sector have been cut drastically since the 1980s (*Zhou*, 2006).

The subsidized provision of reclaimed wastewater in the agricultural sector, along with the cut in potable water provision, results in a situation in which demand by the agricultural sector exceeds supply. Demand will even grow further, when the official plans are implemented to upgrade all Israeli wastewater reclamation facilities such that 100% of the wastewater is treated to a level that allows for unrestricted irrigation (*Inbar*, 2010). On the other hand, supply is limited in the short run by the infrastructure in place to collect and treat wastewater, while in the long run after additional investments, the available quantity is constrained by the quantity of wastewater entering the sewer-systems, which is a function of the consumption of water by municipalities. Accordingly, it is quite important to consider the link between potable water consumption and reclamation potential, especially in countries with already high reclamation rates such as Israel.

4.2 Model setup and Database

The setup of the model for this study is similar to Luckmann et al., (2014). Four water activities (freshwater purification, desalination, reclamation of wastewater, pumping of brackish groundwater) employ three water resources (freshwater, seawater and brackish groundwater) and one by-product(wastewater) to produce three water commodities (potable water, reclaimed wastewater, brackish water) (Figure 2). Thereby the water activities employ fixed proportions of capital, labour, and intermediates, which holds their costs structures constant as suggested by Tirado *et al*., (2006), i.e., the substitution elasticities are set to zero at all levels.

All non-water activities are modelled with more flexibility. Agricultural activities, which allow for the consumption of all three different water commodities, can substitute these water commodities with a medium to low substitution elasticity (σ_4) of 0.8 (*Sadoulet & de Janvry*, 1995). This rather low substitutability reflects the fact that not all components of the aggregated activities can use marginal[4] water qualities and that the option to use marginal water does not exist in all localities, although there is an extended supply network for recycled wastewater in Israel. On the third level of the production function, water and land form a CES-aggregate, whereby the substitution elasticity (σ_3) is 0.3 following Faust *et al*.'s, (2012) estimates of irrigation-land substitutability for Switzerland. The land-water aggregate is then combined with labour and capital at the second level of the production function: given the prevalence of drip irrigation systems in Israel (*Saleth & Dinar*, 1999), the substitution elasticity (σ_2) is set at 0.8 (*Berck et al.*, 1991). The top-level combines the value added and water aggregate with aggregate intermediate inputs with an elasticity (σ_1) of 0.5.

The STAGE_W model is adjusted to an Israeli SAM based on Siddig et al. (2011) which has been extended regarding the water sector as described in Luckmann et al. (2014) using data provided by the IWA (in *Zaide,* 2009), FAO (2009) and the Israeli Central Bureau of Statistics (*CBS*, 2009 and 2011). The base year of the SAM is 2004, which can be considered a normal year in a period of growth, after a recession due to the Second Intifada and before the world financial crisis in 2009 (*CBS*, 2013). Therefore results can be considered as representative also for more recent years.

The SAM incorporates 46 activities which produce 45 commodities, including 3 water commodities (potable water, brackish water and reclaimed wastewater) whereby potable water is produced by a freshwater purification activity and a desalination activity. Furthermore the SAM consists of 41 production factors and 25 tax categories (two of which are implemented especially for the water pricing regime). Finally the SAM allows for the analysis of welfare implications and distributional effects, as it differentiates 10 household groups classified according to ethnic background (Jewish

[4] In this paper the term marginal water refers to reclaimed wastewater and brackish water.

and non-Jewish) and income (five quintiles). An aggregated version of the SAM can be found in *Luckmann & McDonald* (2014).

For this analysis the SAM is further adjusted: Firstly effective sewage is introduced as a production factor. As in Israel sewage is not considered an economic good, there is no compensation for it, thus it is included in the SAM with a very low value. Similar to the freshwater resource, this factor is owned by the government as the government is in charge of the sewer system. Wastewater reclamation is the only activity which uses this factor in its production nesting. As described above the Leontief-setup in the production structure of the wastewater reclamation activity guarantees that sewage cannot be substituted by other inputs or production factors, such that 1 m^3 of effective sewage potentially yields 1 m^3 of reclaimed wastewater, whereby losses within the sewer system (Figure 3)are considered by the variable *SHSEWL*.
In this study only municipal wastewater is considered, which includes sewage produced by households, utilities and the service sector except for construction services. The wastewater treatment activity in this application represents primary and secondary treatment which is the most widespread treatment level in Israel and after which the reclaimed water can be recycled by irrigation of non-food crops (such as cotton) and crops for which lower sanitary restrictions apply, since they can be irrigated without the water being in direct contact with the harvested parts, e.g., olive and citrus trees.

4.3 Scenarios and Closures

4.3.1 Scenarios

Since several years, a main goal in the Israeli water economy was to reduce freshwater uptake from aquifers. This was mainly triggered by a row of drought years, in which aquifer replenishment rates fell to as little as 63% of the multiannual average (*Shachar*, 2009). Thus, to avoid overexploitation of aquifers Israel has to reduce freshwater consumption. On the other hand the population is growing and the economy is expanding and thus the demand for water is increasing, which is why alternative water sources such as reclaimed wastewater have been fostered. It is the declared aim to fulfill the water demand of the irrigation sector to a large extent with reclaimed wastewater in the future.

In this analysis it is shown that this aim might not be easily achieved under the conditions described, when the implications of the linkage between potable water consumption and wastewater recycling are considered. In preparatory simulations, the decrease of aquifer offtake was simulated by a stepwise reduction of the output of the freshwater activity in 10% steps till a decline of up to 80%, where the model hit binding constraints. However, for reduction rates between 10% and 70% the patterns of the results were consistent.[5] For this paper, a 50% rate of reduction was chosen as an exogenous shock to the model, as it would reflect a sustainable usage of fresh water resources, even under the above mentioned drought conditions as experienced in recent years (*Shachar*, 2009). Furthermore, the quantity of desalinated water is held constant, as increasing the quantity would require the construction of further desalination plants. Therefore the reduced output of the fresh water activity directly results in a reduced quantity of potable water available to the economy.

To show the importance of linking wastewater recycling to the consumption of water in such a case of reduced fresh water availability, the effects on the economy of the 50% shock in fresh water

[5] The full set of results is available from the contact author on request.

resources are demonstrated in two scenarios. The only distinction between the two scenarios is the link between fresh water consumption and sewage supply:

1) *Scenario "no-link": Reduced fresh water resource with unlimited sewage availability.* In this scenario, equation (1) is taken out of the model equations. To keep the variable and equation balance the implicit tax-rate on reclaimed water ($TWAT_c$) is fixed. This means that in this scenario supply of sewage (FS_f) is unlimited at a constant very low price. Thus, also any quantity of reclaimed wastewater can be produced, only depending on demand and the prices of other production factors and intermediate inputs.

2) *Scenario "link": Reduced fresh water resource with limited sewage availability.* For this scenario, the model is set up to include equation (1). Thus, a reduction in water consumption by municipalities leads to a reduced quantity of reclaimed wastewater available for the agricultural sector. This however, creates a mismatch between reclaimed wastewater produced and demanded. As described above, the water sector in Israel is largely government driven, such that the consumer price cannot freely adjust to balance supply. In this situation, the government can regulate demand by either implementing quotas or by introducing a tax which drives up the consumer price. In this application the latter is applied, which has the additional advantage that the tax rate can be considered as an estimate for the marginal value of the sewage. To allow for this adjustment the implicit water commodity tax ($TWAT_{c,}$; Figure 1) for reclaimed wastewater is made variable.

The technical variables determining the share of water being collected in the sewer system (*SHSEWS*) and the losses during the reclamation process (*SHSEWL*) as well as the ratio by which municipal entities convert water into sewage (*SHSEW*) are kept constant to ease comparison between the two scenarios. As the water consumption by municipalities is an endogenous variable, depending on relative prices of potable water and substitutes, this setup makes the quantity of wastewater available a dependant on the cost of potable water[6].

The results of the 50% shock in fresh water resources under both scenarios is compared to the model base, such that the relevance of modeling the link between potable water consumption and water reclamation can be assessed.

4.3.2 Market Clearing and Macroeconomic Closure

Through the reduction of the freshwater resource and with a fixed desalination capacity less potable water is available to the economy, creating an excess demand. As water prices are politically determined, as explained above for reclaimed wastewater, to balance demand and supply the implicit water commodity tax for potable water ($TWAT_c$) is made variable such that it can increase the consumer price (PQD_c). Also the production subsidy (TX_a) to the desalination activity is flexible to guarantee that despite of different price changes in production costs due to the shock, the quantity of water desalinated remains constant. (This mirrors the long term contracts of the Israeli government with the private operators of desalination plants, which guarantees the take-up of a fixed quantity of water for a certain period and at a certain price). Finally also the household income

[6] If the technical variables are adjusted to simulate that additional households are connected to the sewer system and less sewage is lost within the system the values of all result-variables lie in between the two described scenarios.

tax is adjusted multiplicatively to guarantee the government account to balance, despite of the changes in water taxes caused by the shock. All other tax rates remain constant.

Capital, land and labor factors are assumed to be fully employed and mobile between activities. This reflects the long term perspective of this analysis, showing the effects after adjustments have taken place. Water factors on the other hand are only used by one respective water activity and thus not mobile. Also the unit value is fixed as their prices, if they are not zero anyways, are politically determined. Therefore the quantity used of these factors is flexible, which allows the output of water activities to vary.

With respect to macroeconomic closure, Israel is assumed to be a small country: world market prices are fixed. The current account balance is fixed, such that the external account is cleared by a variable exchange rate. Regarding the government balance, consumption quantity and household transfers are fixed, as well as investment volume and government savings. On the other hand, the savings rate of households and enterprises is flexible. Under this closure, all household welfare changes are realized in the period investigated and there is no utility trade off with future generations.

4.4 Results

4.4.1 Water prices

As depicted in Figure 4, prices municipalities are charged for potable water triple in both scenarios compared to the model base, due to the reduction of potable water available to the economy, whereby the increase is slightly less strong in the no-link scenario. The agricultural and manufacturing sectors are affected in the same way, as the water user subsidy rate ($TWATA_{cwatpot,a}$) is kept constant in relative terms. Thus, in these sectors potable water prices increase from 0.24 USD/m³ to about 0.74 USD/m³ and from 0.48USD/m³ to about 1.47 USD/m³, respectively in the no-link scenario. In the link scenario the prices rise by an additional 0.01 USD/m³.

The mechanism behind this is that the mismatch between the reduced supply and the unchanged demand is balanced by an increase in the implicit water commodity tax ($TWAT_{cwatpot}$), which is an endogenous variable in this analysis. By this the consumer price of potable water is lifted and thus demand reduced, although the costs of water provision drop slightly.

Brackish water, on the other hand, becomes slightly cheaper, as the implicit commodity tax on this water quality is not altered and provision costs decrease as well. This is due to second round effects of a general decrease in domestic production, which results in falling factor and intermediate input prices (production prices of all industrial commodities decrease by between 5% and 6%, see further below). On the other hand brackish water can only be used in few agricultural activities, which is why demand is only slightly increasing (Table 1) and thus the price effect is still negative. The most drastic difference between the two scenarios can be observed in the price development of reclaimed wastewater. In the no-link scenario, it is sinking quite similarly to brackish water for the same reasons. However, with limited sewage supply (link) an increase in the implicit tax rate for reclaimed wastewater ($TWAT_{cwatrec}$) causes the consumer price to double. The differences in the potable and brackish water price changes between the two scenarios can also be explained by the limited sewage supply: In the link-scenario the total quantity of water available to the economy is lower in comparison to the no-link scenario (Table 1), thus $TWAT_{cwatpot}$ needs to be raised more to balance demand. For brackish water the commodity tax remains constant, however due to the few activities which can make use of this water commodity, again the second round effects from the downturn of the economy, which are stronger in the link-scenario, trigger the slightly stronger price decrease of this water commodity.

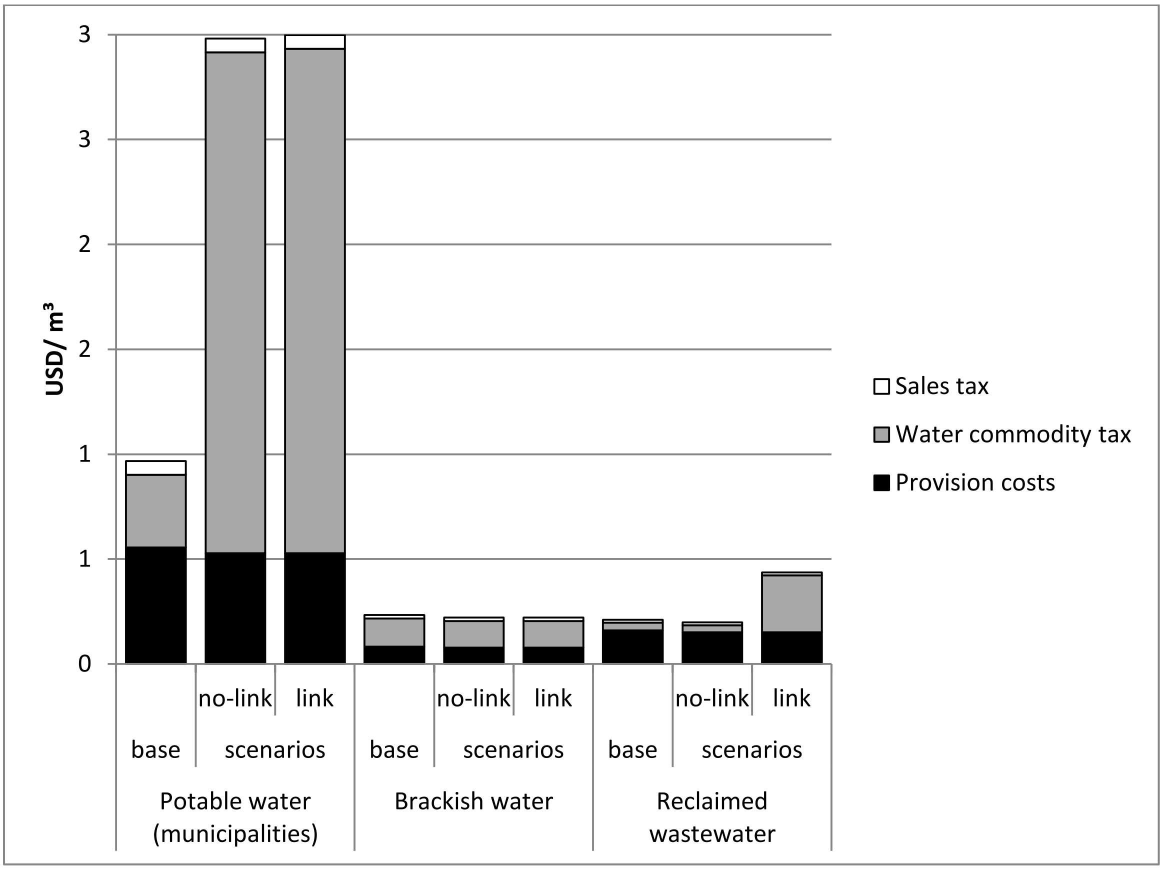

Figure 4: Provision costs and taxation of water commodities.

4.4.2 Water consumption

The price increase of potable water results in a drop of consumption by all user groups (Table 1). Thereby the reduction is pretty similar for all three economic sectors (agriculture, manufacturing and services). Only households reduce consumption to a considerable lesser extent. This is due to the share of subsistence consumption and the lower substitution elasticities in household demand functions compared to production functions of activities.

For the agricultural sector, one would expect that due to the higher price of potable water, it would be substituted by marginal water. This, however is only true to some degree for brackish water and for reclaimed water in the no-link scenario as substitution possibilities are limited, which is reflected by a relatively low substitution elasticity differing from zero only for a few activities of irrigated agriculture (see above).

In the link-scenario the reduction of water consumption by municipalities leads to a decrease in sewage availability. As the technical parameters of wastewater reclamation are fixed, the recycling rate which is the total quantity of reclaimed water consumed by the agricultural sector and used for river discharge over the total municipal water consumption remains constant at 72% in this scenario. Here the importance of considering this connection becomes obvious, as in the no-link scenario the reclamation share would reach an impossible 111% (Table 1).

The additional reclaimed wastewater which is available in the no-link scenario partly substitutes the declining potable water quantity in the agricultural sector. Thus total water consumption of the agricultural sector only sinks by 27% in comparison to 43% as in the link scenario. Due to the higher amount of reclaimed wastewater available, slightly less additional brackish water is produced, which has less good substitution possibilities, as it can be consumed only in two activities, whereas reclaimed wastewater is consumed by three agricultural activities.

The quantity changes of all non-agricultural water users (which do not allow for the usage of marginal water) are quite similar in both scenarios, as also price changes do not differ much. As for the price changes, also the quantity changes in the no-link scenario, are only slightly less severe than in the link scenario, due to the additional quantity of sewage and thus reclaimed wastewater which is available in the no-link scenario.

Table 1: Changes in water quantities consumed.

		Water quantity [million m³]			Change compared to base [%]	
Water quality	Sector	base	no-link	link	no-link	link
Potable	Agriculture	565	233	234	-58.7	-58.6
	Manufacturing	123	48	47	-61.5	-61.7
	Municipalities	702	476	475	-32.2	-32.3
	Services	218	84	84	-61.3	-61.5
	Households	483	391	391	-19.1	-19.1
Brackish	Agriculture	185	195	197	5.6	6.7
Reclaimed	Agriculture	379	401	216	5.7	-43.0
	Environment	126	126	126	0.0	0.0
	Total	**1954**	**1352**	**1170**	**-30.8**	**-40.1**
Reclamation rate [% of municipal water consumption]		72.0	110.8	72.0		

4.4.3 Domestic production and prices

Due to the price increase in both scenarios, potable water is partially substituted by other production factors and intermediate inputs, which become relatively cheaper. Furthermore, the production of most activities is reduced in both scenarios. This affects the agricultural sector the most, as in agricultural activities water has the highest share in production costs (up to 7.5%). Especially in the production of “other cereals”, “other crops” and “vegetables and fruit” this share is high (7.5%, 6.6% and 6.2%, respectively). Therefore, the output of these activities is reduced most drastically (Figure 5). The reason for the production of “vegetables and fruit” to drop less severe lies in the relatively lower integration in the international market of this activity and thus the lower dependence on the fixed world market prices: As commodities produced by this activity are exported to a lower extent and cannot be substituted with imports that easily, the increased production costs can be passed on to domestic consumers to a higher degree.

The downturn of domestic production decreases the demand for labour and other factors of production and as the total supply of labour is assumed to be fixed, wages fall by about 6.1% and 6.3% in the no-link and link scenarios respectively. This leads to decreasing production costs, especially for commodities with low water intensity. The only exception is the production of “other cereals”, for which costs rise by about 4.5% in both scenarios. This is caused by the high water intensity of this activity, and the inability to substitute with marginal water commodities. However, cheaper imports, due to an appreciation of the Israeli currency (see below), result in lower consumer prices as for almost all commodities.

When comparing the two scenarios, it becomes clear that especially activities which allow for a substitution of potable water with marginal water commodities (vegetables and fruit, other crops and mixed farming) and a high share of water in the production costs, the conditions under the link scenario result in a stronger decrease in production. For activities in which water makes up for only a small share of production costs the stronger decrease of wages and intermediate input costs in the link-scenario can partly compensate the more severe increase of water prices.

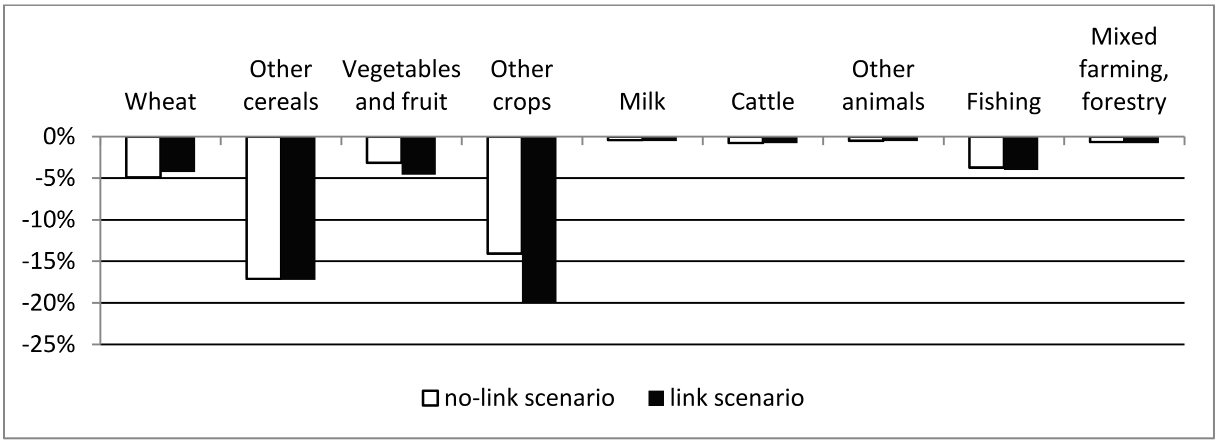

Figure 5: Changes in domestic production of agricultural activities.

4.4.4 Household Welfare

As the water sector is comparably small in the Israeli economy and also the share of water in the consumption of households makes up for less than 1% of total household expenditure, shocks in this sector have only a limited effect on overall welfare. Nevertheless, overall welfare is decreasing for most households in both scenarios, whereby in the no-link scenario the effects are slightly less severe as part of the shock is mitigated through the increased availability of reclaimed water. Only the lowest jewish income quintile (hj1) is positively affected in both scenarios (Figure 6).

The explanation for the generally negative effect on household welfare can be found in the general downturn of the Israeli economy due to the reduced freshwater availability in both scenarios. Generally a reduction of production factors such as the freshwater resource leads to a shrinking of an economy: As described above the reduced factor availability is not fully compensated by substitution with other inputs, such that output is decreasing. The resulting reduction in wage-rates reduces household income by between 3.2% and 5.6%, whereby richer households are more negatively affected. The effects are slightly stronger in the link scenario.

Even though the consumer prices for most commodities also fall, the total effect on households is still negative in most cases. Only for the poorest Jewish households (hj1) this balance is positive as they receive a relatively high income share (close to 20%) from social enterprises and pensions. These social transfers are assumed to remain constant in the scenarios, while all other sources of income are declining. Therefore for this household group the benefits of lower consumer prices outweigh the losses in income.

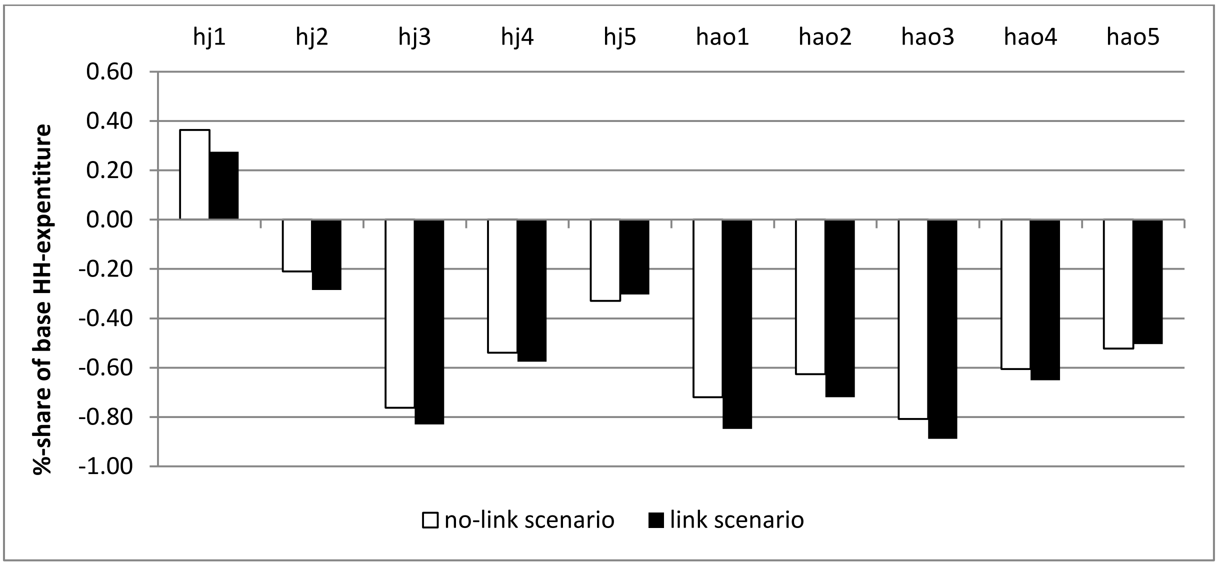

Figure 6: Household welfare measured in equivalent variation as percentage share of household expenditure. hj: Jewish households; hao: Arab and other households; 1–5: income quintiles poor to rich.

4.4.5 Trade

The lower domestic production costs for most commodities, together with a lower domestic demand results in an increased export potential and a falling demand for imports. This leads to an appreciation of the Israeli currency by 5.6% and 5.8% in the no-link and link scenarios respectively. Thus, imports become cheaper by that percentage expressed in domestic currency, whereas exports loose competitiveness on the world market. Regarding the composition of trade, especially water intensive products are imported more and exported less.

4.4.6 Government and Macroeconomic effects

The implicit water commodity tax rate on potable water is raised from 0.35 USD/m³ to 2.39 USD/m³ and 2.40 USD/m³in the no-link and link scenarios respectively. Additionally in the link scenario the implicit tax on reclaimed wastewater is increasing from 0.04 USD/m³ to 0.27 USD/m³. On the other hand, the expenditure for the water user subsidy increases by 26.0% and 27.2% in the no-link and link scenarios respectively, as it is paid as a share of the increasing potable water price. Still the income to the government from the water sector is increasing. However, this positive outcome is compensated by the negative indirect effects from reduced domestic production, resulting in a decrease of government income from factor, factor income and sales taxes, as well as factor income to the government. The income tax rate, which is formulated as a variable in order to ensure a fixed real income of the government falls by 2.8% as domestic prices fall.

The shrinking Israeli economy is also reflected in a decline of real GDP[7] by about 0.21% in the no-link scenario and 0.24% in the link scenario. This would translate into a difference of 31 million USD, by which the effects of the reduction in freshwater availability would be underestimated annually in case the linkage between water consumption and wastewater reclamation would not be considered. If all households would be connected to the sewer system and the losses within the system could be halved such that an additional 27 million m³ of reclaimed wastewater could be produced, this would translate in an additional GDP of about 8 Million USD annually.

[7] Measured by expenditure.

5 Discussion and Conclusions

For Israel, the 50% reduction in fresh water resources leads to an increased demand for reclaimed wastewater, and thus a much higher willingness to pay. In the link scenario, this is captured by the implicit water tax, which is used to balance the limited supply with the increasing demand. Thus, this tax can be considered a measure to estimate the marginal value of unpurified sewage in the Israeli economy in case of a reduction of available freshwater resources. This positive shadow price speaks against subsiding farmers for the disposal of wastewater as suggested by Haruvy (1997). The government revenue from the increased recycled wastewater price could for example be used to expand the infrastructure for water reclamation, to connect more households, or to upgrade facilities to purify the wastewater to a higher degree, which would allow for a wider usage, which would be in line with the plans of the IWA (*IWA*, 2012).

Regarding the treatment of wastewater reclamation in simulation models, this study develops and validates an approach to link the reclamation of wastewater to the consumption of potable water by a variable set of economic entities, making it the first CGE approach which allows to capture cascading water use involving different economic agents. Generally, the model can be applied to a wide range of different situations, countries and simulations, due to its generic formulation.

The case study shows that not considering the linkage between potable water consumption and wastewater generation can have significant effects on model-outcomes: it leads to a significant underestimation of the negative economic effects of a reduction in fresh water resources. Although the usage of reclaimed wastewater is restricted to few agricultural activities only for the case at hand, the losses to the Israeli economy in terms of GDP are considerably lower when the linkage is not considered. If reclaimed wastewater was used in a wider range of activities e.g., industrial cooling, and would be available in more locations (expressed by a larger substitution elasticity), as it is aimed at by the Israeli government, these effects would have been even more pronounced.

Moreover one can see that the dependence of the wastewater reclamation sector on the sewage-input makes water saving in the municipal sector the less efficient, the higher the reclamation rates are, because water saving implicitly reduces sewage and thus reclaimed water available. Furthermore, this study shows that wastewater reclamation does not necessarily serve as a backstop technology as claimed by Roumasset & Wada (2011).

In general, the case study on Israel proofs the relevance of the model for countries in which a cascade usage of water is applied to a considerable extend. In those cases it is advisable to apply an integrative water model, not considering water activities as independent but as closely connected. Additionally this model provides a measure to estimate the shadow price of wastewater, which could be used to inform the pricing decision in this sector.

5.1 References

Axelrad, G. & E. Feinerman, 2010. Allocation of treated wastewater among competitive farmers under asymmetric information. *Water Resources Research,* 46(1), W01502, doi: 10.1029/2008WR007687

Berck, P., S. Robinson & G.E. Goldman, 1991. The use of computable general equilibrium models to assess water policies. In: A. Dinar, D. Zilberman (eds.), The Economics and Management of Water and Drainage in Agriculture, Boston: Kluwer Academic Publisher, Ch. 25, 489-509.

Booker, J.F., R.E. Howitt, A.M. Michelsen & R.A. Young, 2012. Economics and the modeling of water resources and policies. *Natural Resource Modeling,* 25(1), 168-218, doi: 10.1111/j.1939-7445.2011.00105.x.

CBS, 2010. *Statistical Abstract of Israel 2010.* The Israeli Central Bureau of Statistics (CBS). Jerusalem, Israel.

CBS, 2011. *Satellite Account of Water in Israel 2006*. The Israeli Central Bureau of Statistics (CBS). Jerusalem, Israel.

CBS, 2013. *The Israeli Economy 1995-2011*. Statistilite. The Israeli Central Bureau of Statistics (CBS). Jersualem, Israel.

FAO, 2009. *Irrigation in the Middle East region in figures AQUASTAT Survey – 2008*. Food and Agricultural Organization of the United Nations (FAO), Rome, Italy.

Faust, A.-K., C. Gonseth & M. Vielle, 2012. *The economic impact of climate driven changes in water availability in Switzerland*. working paper, École Polytechnique Fédérale de Lausanne, Switzerland.

Feinerman, E., Y. Plessner & D.M. DiSegni Eshel, 2001. Recycled effluent: Should the polluter pay? *American Journal of Agricultural Economics,* 83(4), 958-971.

Haruvy, N., 1997. Agricultural reuse of wastewater: Nation-wide cost-benefit analysis. *Agriculture, Ecosystems and Environment,* 66(2), 113-119.

Haruvy, N., S. Shalhevet & Y. Bachmat, 2008. A model for integrated water resources management in water-scarce regions: Irrigation with wastewater combined with desalination processes. *International Journal of Water,* 4(1-2), 25-40, doi: 10.1504/IJW.2008.018145.

Inbar, Y., 2010. Wastewater Treatment and Reuse in Israel. In: A. Tal, A.A. Rabbo (eds.), Water Wisdom: Preparing the Groundwork for Cooperative and Sustainable Water Management in the Middle East, Rutgers University Press, 183-88.

IWA, 2012. *Long-Term Master Plan for the National Water Sector*. Policy Document. Israeli Water Authority, Tel-Aviv, Israel.

Jimenez, B. & T. Asano, 2008. Water reclamation and reuse around the world.In: B. Jimenez, T. Asano (eds.), Water Reuse An International Survey of current practice, issues and needs. IWA Publishing, London, UK, 3-26.

Kislev, Y., 2011. *The Water Economy of Israel*. Policy Program Paper. TAUB CENTER for Social Policy Studies in Israel. Jerusalem, Israel.

Lavee, D., 2013. National versus location-specific environmental standards: A cost-benefit analysis of wastewater treatment standards in Israel. *International Journal of Sustainable Development and World Ecology,* 20(4), 369-383, doi: 10.1080/13504509.2013.785987.

Lavee, D., 2014. Is the upgrading of wastewater treatment facilities to meet more stringent standards economically justified: The case of Israel. *Water Resources,* 41(5), 564-573, doi: 10.1134/S0097807814050042.

Lavee, D. & T. Ash, 2013. Wastewater Supply Management. In: N. Becker (ed.), Water Policy in Israel: Context, Issues and Options. Springer-Publishing, Dordrecht, Netherlands, 83-99.

Levine, A.D. & T. Asano, 2002. Water reclamation, recycling and reuse in industry. In: P. Lens, L. Hulshoff Pol, P. Wilderer, T. Asano (eds.), Water Recycling and Resource Recovery in Industry: Analysis, Technologies and Implementation. IWA Publishing, London, UK, 29-52.

Luckmann, J., H. Grethe, S. McDonald, A. Orlov & K. Siddig, 2014. An integrated economic model of multiple types and uses of water. *Water Resources Research,* 50(5), 3875-3892, doi: 10.1002/2013WR014750.

Luckmann, J. & S. McDonald, 2014. *STAGE_W : an applied general equilibrium model with multiple types of water; technical documentation*. Working Paper, Institute of Agricultural Policy and Agricultural Markets, University of Hohenheim, Germany.

Park, L., B. Bennett, S. Tellinghuisen & C.a.W.R. Smith, 2008. The Role of Recycled Water in Energy Efficiency and Greenhouse Gas Reduction, California Sustainability Alliance, San Francisco, USA.

Rivers, N. & S. Groves, 2013. The Welfare Impact of Self-supplied Water Pricing in Canada: A Computable General Equilibrium Assessment. *Environmental and Resource Economics,* 1-27, doi: 10.1007/s10640-013-9633-3.

Roumasset, J. & C.A. Wada, 2011. Ordering renewable resources: Groundwater, recycling, and desalination. *B.E. Journal of Economic Analysis and Policy,* 11(1).

Sadoulet, E. & A. de Janvry, 1995. *Quantitative Development Policy Analysis*. The Johns Hopkins University Press Baltimore, USA and London, UK.

Saleth, R.M. & A. Dinar, 1999. *Water Challenge and Institutional Response (A Cross-Country Perspective)*. Policy Resarch Working Paper, The World Bank Development Research Group, Rural Development Department, Washington DC, USA.

Shachar, G., 2009. *Domestic and Regional Water Crisis*. Global Agricultural Information Network Report. United States Department of Agriculture Foreign Agricultural Service, Tel Aviv, Israel.

Siddig, K., D. Flaig, J. Luckmann & H. Grethe, 2011. *A 2004 Social Accounting Matrix for Israel Documentation of an Economy-Wide Database with a Focus on Agriculture, the Labour Market, and Income Distribution*. Working Paper. Institute of Agricultural Policy and Agricultural Markets University of Hohenheim, Germany.

Tal, A., 2006. Seeking sustainability: Israel's evolving water management strategy. *Science,* 313(5790), 1081-1084, doi: 10.1126/science.1126011.

Tirado, D., C.M. Gómez & J. Lozano, 2006. Efficiency improvements and water policy in the Balearic Islands: A general equilibrium approach. *Investigaciones Economicas,* 30(3), 441-463.

Zaide, M., 2009. *Drought and arid land water management.* UN Department of Economic and Social Affairs, Division for Sustainable Development. New York, USA.

Zhang, W., C. Wang, Y. Li, P. Wang, Q. Wang & D. Wang, 2014. Seeking sustainability: Multiobjective evolutionary optimization for urban wastewater reuse in China. *Environmental Science and Technology,* 48(2), 1094-1102, doi: 10.1021/es404082f.

Zhou, G., 2006. *Water Resources Management in an Arid Environment The Case of Israel*. Background Paper. The World Bank, Environment and Social Development Department, East Asia and Pacific Region, Washington DC, USA.