Water Resources Research®

RESEARCH ARTICLE
10.1029/2020WR028860

# Livestock Support and Water Depletion in Turkey

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**Key Points:**

- Removal of direct Turkish livestock support may not lead to large water savings but redirects irrigation water to higher value crops
- Removal of fodder subsidies shows the largest potential for water savings out of all scenarios
- Improvements to overall economic efficiency in Turkey's livestock sector lead to net economic gains without major effects on blue water use

**Supporting Information:**

Supporting Information may be found in the online version of this article.

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**Citation:**

Schuenemann, F., & Hess, S. (2023). Livestock support and water depletion in Turkey. *Water Resources Research*, *59*, e2020WR028860. https://doi.org/10.1029/2020WR028860

Received 17 SEP 2020
Accepted 31 OCT 2022

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**Abstract** Turkey serves as an important food hub for neighboring countries in the water-scarce Middle East and North African region, and self-sufficiency in agri-food production is one of the country's major policy objectives. The Turkish government had therefore introduced various support measures for its inefficient livestock sector, including payments for irrigated fodder crops, which are likely to increase water depletion. To simultaneously assess the economic and environmental effects of these policies, we link an economy-wide computable general equilibrium model of Turkey to a newly developed water footprint module. We find that removal of direct livestock support may not lead to large water savings, but may instead redirect irrigation water to higher value crops. Conversely, removal of fodder subsidies and overall efficiency improvements in livestock can lead to overall water savings and net economic gains.

**Plain Language Summary** Turkey is a major exporter of food for the dry Middle East and North African region, while the goal of the Turkish government is to become more independent of imported livestock products. The government therefore pays different subsidies to encourage production within Turkey's inefficient livestock sector. As part of this strategy, a subsidy is paid to fodder crops that are irrigated with an increasing amount of water, although water resources in Turkey are already under stress. We therefore develop a new methodology that combines an economic model of the Turkish economy with a new water footprint calculation tool. With this method, we assess how different types of subsidies affect water use in Turkey through economic linkages and livestock-related policies. Our model results show that removal of subsidies which are directly paid to livestock producers would not much reduce irrigation water use. However, the valuable irrigation water would increasingly be used to produce high value export crops such as vegetables, rather than low value fodder crops. Moreover, the abolishment of subsidies directly paid to fodder crop producers and technical measures that spur productivity in the livestock sector can achieve both, a reduction in irrigation water use and better economic outcomes.

## 1. Introduction

Turkey is a major agricultural producer and key food exporter to its net food-importing neighboring countries in the Middle East and North Africa region (FAO, 2016). The comparative advantage of the Turkish agri-food sector lies primarily in food processing and the production of high-value crops such as fruit and vegetables. With relatively limited pasture land and rain-fed areas that would be suitable for the competitive production of roughage, the opportunity cost of supplying Turkey's large and growing population primarily with domestic beef and milk seems to be high (Koc et al., 2012). This opportunity cost is exacerbated by a relatively small-scale livestock sector in Turkey, where the markets for beef and milk face high transaction costs and suffer from technical inefficiencies and low average productivity (Yolcu & Tan, 2008).

However, self-sufficiency in agri-food production is a major objective of the Turkish government, hence a range of support is given to livestock and livestock products. First, direct subsidies are paid to producers of meat and dairy products; second, import tariffs protect Turkey's unproductive livestock sector; and third, the livestock industry receives indirect support through subsidies paid in relation to inputs that are extensively used in livestock and dairy production. This is especially problematic in the case of maize produced as fodder on land irrigated with an increasing share of domestic water resources in irrigation water (FAO, 2016) because irrigation water is essentially a free resource in Turkey and the irrigation infrastructure is subsidized by the government (Cakmak, 2010; World Bank Group, 2016). While the absence of a market for irrigation water is highly likely to lead to inefficient allocations of water, additional livestock support measures could increase these misallocations by further encouraging forage crop production on irrigated land. This means that the livestock support measures are not only likely to distort economic welfare by allocating resources to unproductive sectors, but also to foster the depletion of water resources that in some regions are already under severe stress (FAO, 2016; World Bank

**Table 1**
*Water Footprints of Maize in Turkey*

| HS code | SITC code | Crop | Water footprint (m³/ton) | World average[a] | Turkey (2000)[a] | Turkey (2013)[b] |
|---|---|---|---|---|---|---|
| 1005 | 044 | Maize (corn) | Green | 947 | 646 | 168 |
| | | | Blue | 81 | 208 | 686 |
| | | | Gray | 194 | 277 | |
| | | Maize silage | Green | | | 24 |
| | | | Blue | | | 97 |
| | | | Gray | | | |

[a]Mekonnen and Hoekstra (2011). [b]The water footprints for the year 2013 are based on Muratoglu and Avanoz (2021).

Group, 2016). The role of livestock for irrigated maize can be seen in the large increase in the share of maize used as fodder from 29% to 63% between 2004 and 2014 (OECD, 2021). Our aim is to quantify the potential distortions that could be created by the support to Turkey's livestock sector, both in terms of economic losses and the potential degradation of domestic water resources, by combining an economy-wide computable general equilibrium (CGE) model with a water accounting module.

Economy-wide CGE models are a class of economic models that are widely used in the analysis of policy measures (Lofgren et al., 2002). CGE models depict a country's entire economy through the circular flow of income between producers, consumers and the government, and are thus valuable tools for understanding how a policy measure affects production and consumption linkages through product and factor markets. Given the focus on market interactions, however, the inclusion of natural resources, such as water, that originate outside of markets remains complex (see e.g., Luckmann et al., 2014). There have been numerous attempts to model the effect of Turkish policies on the Turkish economy within an economy-wide CGE framework (Atici, 2000; Bekmez, 2002; De Santis, 2000; Diao et al., 1998; Kat et al., 2018), and some have also focused on agricultural issues and the use of natural resources. Most recently, Dudu and Cakmak (2018) coupled a long-term CGE model of Turkey, which includes water as a production factor, with a crop model to capture the impact of climate change on crop yields. However, their study features an aggregated agricultural sector that cannot reflect competition for irrigation water within agriculture. To date there has been no economy-wide analysis of the effect of current Turkish agricultural support policies on irrigation water use. Our study will therefore close the research gap on how livestock support measures reinforce the inefficient allocation and depletion of blue water resources in Turkey. For this purpose, we develop an innovative methodology where we couple a CGE model with a new water footprint tool.

The paper is structured as follows: Section 2 reviews livestock support policies in Turkey in the context of water depletion; Section 3 describes our modeling framework and our scenarios; Section 4 discusses the results, and finally our study's conclusions are presented in Section 5.

## 2. Livestock Support and Water Policies in Turkey

### 2.1. Livestock Support Policies

FAO (2016) argues that Turkey's overall political priorities and strategic targets are laid out in the country's Development Plans, for example, the Tenth Plan 2014–2018 (Ministry of Development, 2013). That plan stated that livestock enterprises in Turkey were small scale and the productivity of livestock herds would generally be low based on international comparisons. The limited availability of pasture and other land suitable for the production of high quality roughage and the aim to support forage crop production are also mentioned in the Tenth and Eleventh Development Plan as a structural problem in the livestock sector, along with the need to overcome it through "… increased production and product diversification" (Ministry of Development, 2013, p. 102) and therefore "… the production of high quality forage production and forage crop production will be supported" (Presidency of Strategy and Budget, 2020, p. 97). However, the Tenth Development Plan also acknowledges that the design of agricultural support programs should take their impact on available water resources into account (Ministry of Development, 2013, p. 10). To boost farm incomes, the aim is to achieve productivity gains in beef, dairy and sheep production. As part of this, policymakers consider it appropriate to increase the supply of maize and alfalfa, for example, from irrigated areas (FAO, 2016). However, such political incentives may devote especially the slowly renewing ground water resources a part of irrigation water toward fodder and feed production, and thus away from either more efficient present use or future use options (World Bank Group, 2016).

Table 1 presents a comparison of different water footprints (WFPs) in m$^3$ per metric ton of maize produced in Turkey with the average global WFPs for maize. The first two WFP columns are from Mekonnen and Hoekstra (2011), who have calculated comprehensive global WFPs around the year 2000. A WFP (Hoekstra, 2003) is defined as

**Table 2**
*Output Subsidies for Cattle*

| Support subject | | Unit premium (2014) (TL/head) |
|---|---|---|
| Cattle for dairy and combined breeds and their hybrids | | 225 TL/head |
| Rootstock cattle for breeding | | 350 TL/head |
| Rootstock buffalo | | 400 TL/head |
| Addition to pedigree of cattle for dairy and combined breeds and their hybrids | | 70 TL/head |
| Production support for fattening material (cattle for fattening) | Rootstock | 350 |
| | Calf | 150 |

Source: FAO (2016); own translation of Ministry of Food, Agriculture and Livestock (2014); TL is Turkish Lira.

the total volume of freshwater used to produce the unit of goods in question and can be divided into three parts: the blue WFP, the green WFP, and the grey WFP. The blue WFP refers to the volume of surface and groundwater consumed during production. Consumption refers to the volume of freshwater used and then evaporated or incorporated into a product and also includes water abstracted from groundwater or surface water that does not return to the catchment from which it was withdrawn (FAO, 2016). The green WFP is only the volume of rainwater consumed during the production process. Finally, the grey WFP is an indicator of freshwater pollution that can be associated with the production of a product along its entire supply chain (FAO, 2016).

Table 1 shows that the average ton of maize produced in Turkey required about two to six times more blue water than required by the average ton of maize in the rest of the world, even though total water usage is lower. This can be explained by the fact that green water usage largely refers to rainfed maize, which is common in other regions. Turkey, relatively short of rainfed land for maize, instead substitutes rain with ground- and surface water used for irrigation. Data from the Turkish General Directorate of State Hydraulic Affairs (DSI, 2021) shows that from to 2000 to 2011 the share of maize that is irrigated increased from 36% to 51% of total maize area. Using more recent WFP data from Muratoglu and Avanoz (2021) for the period 2008–2019 confirms this increase in irrigation. The last column of Table 1 shows that the green WFP of maize has further decreased, but the blue WFP is now more than 7 times the world average. The last row of Table 1 also lists the WFP of maize silage. The maize silage yield per ha in Turkey is 6–5 times the maize grain yield, as silage has a much higher water content and includes the whole maize plant (TSI, 2022). Given the much higher weight of silage maize compared to corn maize, the WFP per ton of silage maize is much lower, but the blue WFP is still higher than the global average.

Table 2 presents recent levels of output subsidies for bovine animals in Turkey (FAO, 2016). It shows that, in line with the strategic goals of the Tenth Development Plan, there are incentives to adopt higher productivity genetic breeds (FAO, 2016). In addition, production support is also provided in terms of a direct premium per head. Given the objectives of the Tenth Development Plan, it would appear logical to subsidize beef production in this way. However, such policies typically distort market incentives and do not include any incentives to reduce the blue water footprint of beef in Turkey (FAO, 2016, p.152).

In addition, specific output and input subsidies are provided by the Turkish government for the production of forage crops, such as specific subsidies for fertilizer use and fuel in forage crops (Ministry of Food, Agriculture and Livestock, 2014). These subsidies incentivize the use of irrigated land for fodder production, which is a fuel-intensive process, and constitute further distortions of the otherwise already heavily distorted (or partly non-existent) market for irrigation water in Turkey (FAO, 2016). A water market that is distorted in this way provides incentives to use more water than under water market prices that would reflect the true scarcity of water more appropriately for Turkey (World Bank Group, 2016). Additional policy-induced incentives to use irrigated land for fodder production may aggravate this set of distortions (FAO, 2016). Further support for the production of fodder on irrigated land may come from investment incentives such as government loan programs or deductions on interest rates for other loans. Such programs do exist, but their effect on water usage in the bovine sector is difficult to assess (FAO, 2016).

With regard to output subsidies for forage crops, FAO (2016) states that the official producer support estimate figures for corn (maize) in Turkey provided by the OECD would not include the so-called category C supports, which comprise direct subsidies per animal or per hectare, while category A (B) would refer to general price-based

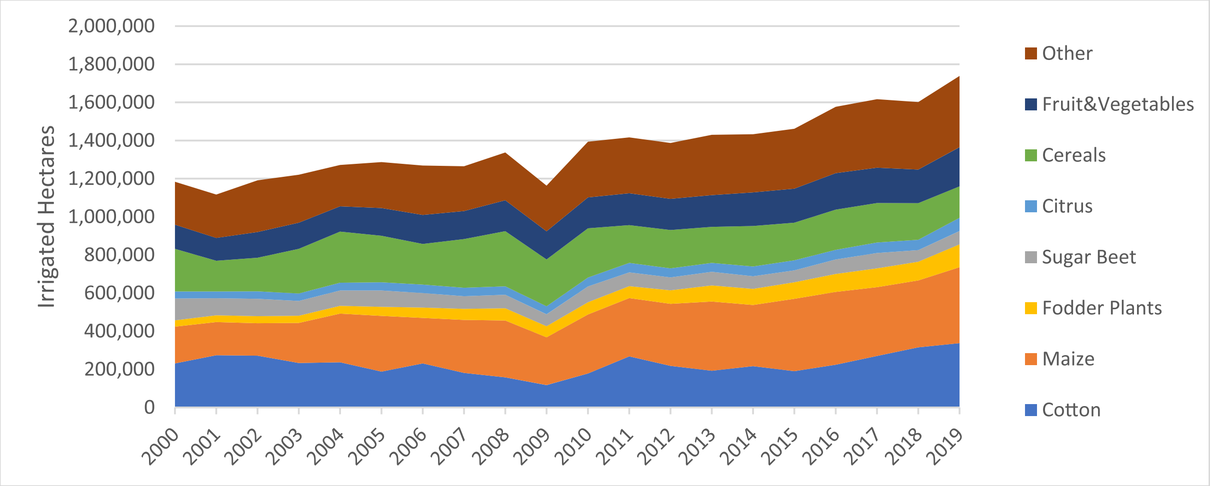

**Figure 1.** Share of main crops in total irrigated agricultural land in Turkey. Source: Own depiction based on data from DSI (2021).

output (input) subsidies. These additional category C supports are published in the Bulletin of the Turkish Ministry of Food, Agriculture and Livestock (Ministry of Food, Agriculture and Livestock, 2014), which gives 75 TL/da/year for maize for (irrigated) silage as a specific subsidy (FAO, 2016). Thus, if the farmer can document that a certain hectare is planted with maize for silage and this hectare receives irrigation, the farmer receives 750 Turkish Lira for this hectare once each calendar year that the planting is in place (in Turkish statistics da is used more often than hectare; 10 da = 1 ha). For irrigated maize, per hectare subsidies were substantially increased between 2012 and 2013 (by 36%) until they reached the range of annual EU single farm payments per hectare, and a similar level of support seems to apply to artificial meadows and pastures (FAO, 2016). The harvested area of maize in Turkey grew by 17% between 2004 and 2014, while the share of maize used for silage or being fed green increased in this total area from 29% to 63% in the same period. Total maize used for feed in Turkey as a share of total domestic consumption (including imports) increased in the same period from 64% to 76%. In particular, the share of irrigated maize and other fodder plants in total irrigated agricultural land in Turkey has increased considerably along with a substantial expansion of total irrigated area, as shown in Figure 1.

### 2.2. Water Pricing and Water Depletion in Turkey

Even though the Turkish government has transferred most of its public irrigation schemes to what are known as water user associations, water pricing by these associations is not related to the actual volumes of water used. Instead, farmers pay a lump sum fee per hectare and crop based on the annual expected costs of operation, maintenance and investment (FAO, 2016). This has led to the overuse of water in many areas of Turkey (Cakmak, 2010). Using a constrained optimization farm model for Turkey, Cakmak et al. (2008) found that the shadow price of water measured as the value of the marginal product of irrigation water is double the amount actually paid by farmers. In addition, 80% of irrigation projects are financed by the government which is reluctant to recuperate the public capital investments, effectively translating this into a subsidy to irrigating farmers. Nevertheless, farmers are also constrained in their water use through (a) lack of irrigation infrastructure, (b) lack of water available for use and limited water quality, and (c) other institutional constraints such as water quotas/allotments that are determined by the respective local water user association and through which irrigation water is allocated. In sum, even though Turkish farmers partly pay for their use of the irrigation infrastructure, there is no market for irrigation water in which the price of water would reflect its marginal scarcity whatsoever (Bierkens et al., 2019; World Bank Group, 2016).

While this lack of water markets has already led to an overuse of some aquifers (FAO, 2016), additional livestock support measures that encourage irrigated fodder crop production are likely to exacerbate water depletion in Turkey (FAO, 2016). Although there is a large regional variation to what extent different basins and aquifers are endangered, several basins are already critically overexploited in particularly dry regions, for example, the Konya basin in Central Anatolia (see Türker (2013) for the groundwater situation in different basins in Turkey).

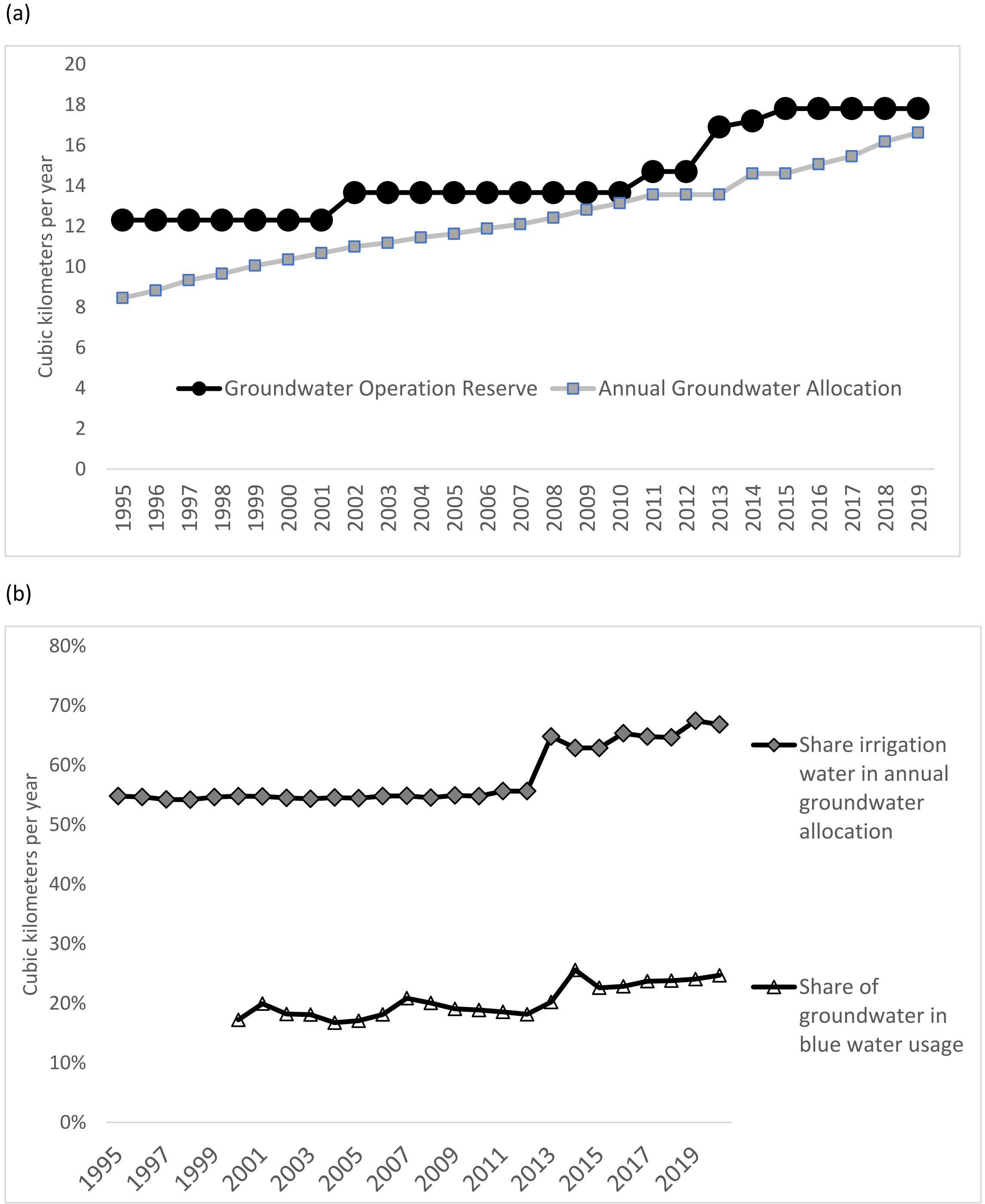

**Figure 2.** (a) Groundwater use in Turkey over time. (b) Groundwater and blue water use for irrigation in Turkey over time. Source: Own depiction based on data from DSI (2021).

Figure 2a also shows the narrowing gap between annual groundwater allocation for use (general and irrigation, respectively) in Turkey and official groundwater operation resources (DSI, 2021). Figure 2b shows the share of groundwater in irrigation (blue) and surface water used for irrigation, respectively.

The OECD (2017) identifies Turkey as a country among the potential future water risk hotspots, in range with other countries in the Mediterranean and Middle East. In their review of studies on future and present water risks

(OECD, 2017), Turkey was found to exhibit in ca. 35% of studies in the reviewed literature currently severe water risks, while a future severe water risk was found in ca. 40% of the studies.

## 3. Model and Methodology

Turkey's livestock support measures affect both production and consumption linkages as well as product and factor markets in the Turkish economy by influencing the prices of both livestock inputs and outputs. CGE models capture these linkages and market interactions within an economy and are thus valuable tools for analyzing the economy-wide impacts of policy measures on output, prices, welfare and trade. Since CGE models can only measure market interactions and water is essentially free and not traded at markets in Turkey, we link the CGE model to a newly developed water accounting module to measure both the economic and water-use impacts of Turkey's livestock support measures.

### 3.1. Economy-Wide Modeling Approach

We use a comparative static CGE model of Turkey based on the single country IFPRI Standard CGE model described in Lofgren et al. (2002). The model comprises several economic agents in the form of producers, households, the government and the rest of the world. Producers maximize their profit subject to constant elasticity of substitution (CES) production functions that govern the substitution between production factors, while intermediate inputs enter the production technology subject to Leontief functions with fixed input-output shares. Households maximize their utility subject to a Stone-Geary utility function that gives rise to a linear expenditure system. Both input and output commodities are traded with the rest of the world under the Armington assumption of imperfect substitution between domestic and foreign commodities. A CES function determines the substitution between domestic and imported commodities. Likewise, a constant elasticity of transformation function governs the output quantities for export. Producers and consumers decide how much to export and import depending on the relative prices of commodities and considering taxes and transaction costs. World market prices are assumed to be exogenous. The equations can be found in Schuenemann et al. (2018).

We calibrate the model to a 2011 Turkey social accounting matrix (SAM) extracted from the GTAP9 (Global Trade Analysis project) database with 57 activities and commodities (Aguiar et al., 2016), including eight crop production activities and four animal husbandry sectors (e.g., outdoor livestock such as bovine cattle and indoor livestock such as poultry and pigs) and three livestock processing sectors (two types of meat and milk processing). A list and description of these sectors can be found in Table S1 in Supporting Information S1. It is important to note that a SAM lists inputs and outputs in terms of values and not physical quantities, so that we can only determine the value share of different fodder crops in the feed mix. As the fodder crops are intermediate inputs that enter the production with fixed input-output shares, the feed composition in all scenarios is fixed. Looking at the input-output shares in the SAM allows the identification of fodder crops, which include wheat, grains, oilseeds and a few other crops. The database also includes crop residues used as livestock feed within an aggregated other crop sector (“OCR”), while grazing is captured through the pasture land used in the outdoor livestock sectors. Table S2 in Supporting Information S1 lists the value shares of the different crop sectors and pasture land in the feed mix of the livestock sectors. Given that other existing SAMs of Turkey only feature an aggregate agricultural sector, the detailed disaggregation of agriculture in the GTAP data was preferred in this instance because it allows an analysis of the linkages between livestock and fodder crops. In addition, a comparison of the 2011 GTAP Input-Output Table with a recent Input-Output Table for Turkey for the year 2012 shows a very similar share of value-added in agriculture (60% vs. 63%) and a similar share of agriculture in total value added (8.3% vs. 7.8%). Several adjustments were required to enable the GTAP SAM to achieve the format needed for the single country CGE model and to better capture fodder crops and land use. In particular, GTAP SAMs feature the so-called regional household that functions as an intermediary collecting taxes and factor rents that are then distributed to a private household, the government and the savings-investment account (Corong et al., 2017). This intermediary was removed so that households directly pay taxes to the government and savings to the savings-investment account, while they directly receive returns from factors.

We added two more changes to the original GTAP9 database. The GTAP-SAM features an aggregated grain sector “GRON” that does not allow us to capture the maize sector separately. Therefore, we use the software

**Table 3**
*Types of Global Trade Analysis Project Agro-Ecological Zones (GTAP-AEZs) and Their Share of Land in Turkey*

| GTAP-AEZ class | Moisture regime (length of growing period [LGP]) | Climate zone | Share of total land |
|---|---|---|---|
| AEZ7 | Arid | Temperate | 0.00 |
| AEZ13 | (LGP 0–59 days) | Boreal | 0.00 |
| AEZ8 | Dry semi-arid | Temperate | 0.37 |
| AEZ14 | (LGP 60–119 days) | Boreal | 0.01 |
| AEZ9 | Moist semi-arid | Temperate | 0.39 |
| AEZ15 | (LGP 120–179 days) | Boreal | 0.00 |
| AEZ10 | Sub-humid (LGP 180–239 days) | Temperate | 0.20 |
| AEZ11 | Humid (LGP 240–299 days) | Temperate | 0.02 |
| AEZ12 | Humid; year-round growing season (>300 days) | Temperate | 0.00 |

Source: Based on Monfreda et al. (2009) and own calculations based on GTAP9 database.

SplitCom to disaggregate the maize sector using production data from FAOSTAT for 2011 to generate the necessary splitting weights (Horridge, 2005).

To capture the climatic and hydrological differences in Turkey, we disaggregate the production factor land used in agricultural, livestock and forest production into agro-ecological zones (AEZs) using the GTAP-AEZ approach that distinguishes 18 AEZs according to climate zone and moisture regime (Baldos, 2017). Table 3 shows the different types of AEZs in Turkey and their share of total land. More than 96% of land is distributed among AEZs 8–10, while the other AEZs play only a minor role. Of these, AEZ8 is the driest region in terms of rainfall covering Central and Eastern Anatolia and one of the most critically overexploited basins, the Konya basin (FAO, 2016). Yet almost 40% of maize is grown in this region. Other critically overexploited basins can be found in AEZ9 in the Marmama region such as the Susurluk, Marmara, Meriç-Ergene, and Kuzey Ege basins (Türker, 2013).

For our static model version, we assume that all factors (land, labor, and capital) are initially available at an exogenously fixed amount and fully employed (utilized), but mobile between sectors. Labor is furthermore disaggregated into skilled and unskilled labor. Thus, factor use in each sector is endogenously determined under a CES production technology that allows for imperfect substitution between factors. The degree of substitution that takes place within the model depends on relative prices and the exogenously specified elasticities of substitution in the CES function. This means that to a certain extent, the producer can substitute land for capital and labor and vice versa. The equations can be found in Supporting Information S1. The fixed land endowment is based on the land under cultivation in 2011 (the base year of our Social Account Matrix SAM) for which producers of crops and livestock compete. Full employment means that all land available is also used for agricultural production. Note that the SAM does not distinguish between irrigated and non-irrigated land. How much land is allocated to a certain crop or pasture depends on the relative profitability of each crop or livestock sector. Thus, land use in each scenario is an endogenous result of the decision making of the producers to maximize profits. For example, as we remove the subsidies for fodder crops, their prices increase, leading to a decrease in the demand for these crops. Producers of fodder crops consequently reduce production while this way setting free land and other resources. As this land becomes available, producers of more profitable export crops take up this land and increase their production. This is equivalent to fodder crop producers given up fodder crop production and taking up export crop production. As a result, we see an increased land use for export crops and a reduction for fodder crops. Within our model, these steps occur simultaneously during the solving process.

The representative household earns income from the production factors labor, land and capital. The household uses its factor incomes for the consumption of commodities, for savings and for the payment of direct taxes to the government. Consumption of commodities is governed by a linear expenditure system that is calibrated to income elasticities based on Hertel and van der Mensbrugghe (2016). Our SAM also features a detailed representation of six tax accounts to reflect the livestock support measures, with activity taxes paid by producers to the government based on output and factor taxes based on factor use. A negative value for these taxes reflects a subsidy. Direct taxes are paid by households on income, whereas sales taxes are incorporated in market prices and paid

**Table 4**
*Scenario Description*

| Scenario name | Description |
|---|---|
| *Base* | Baseline reflecting fodder and livestock subsidies in 2011 |
| *nolivsub* | Removal of livestock subsidies |
| *nofodsub* | Removal of fodder subsidies |
| *Livlib* | Liberalization of import tariffs on bovine cattle and beef |
| *Comb* | Combination of nolivsub, nofodsub, and livlib |
| *nofacsub* | Removal of factor subsidies received by producers of bovine cattle |
| *Livprod* | Technical progress of bovine cattle by 10% |

Source: Own compilation. Note that the modeled subsidies only include "market price support (MPS)" and "payments based on output (PO)" from the OECD producer support database (OECD, 2018).

by commodity accounts to the sales tax account. The same applies to export taxes and import tariffs. All six tax accounts pay their receipts to the government.

Finally, we choose a set of macroeconomic model closures. We choose a flexible exchange rate to reflect Turkey's floating exchange rate regime while receipts of foreign capital are fixed. In addition, we choose a savings-driven investment closure with a fixed private savings rate. In terms of the government closure, we fix tax rates exogenously and later simulate changes in our scenarios, while recurrent spending is flexible to balance government revenues and expenditure. The model's numeraire is given by the domestic price index. Since Turkey has been exhibiting unemployment of around 10% in the last two decades, we also run a sensitivity analysis with an unemployment closure. The results can be found in Supporting Information S1.

### 3.2. Simulating the Impact of Livestock Support Measures

We use our Turkey CGE model to run different scenarios with regard to the effects of direct and indirect livestock subsidies on various economic outcome indicators in relation to agricultural water use. Since the support measures captured within the GTAP SAM of Turkey do not fully account for the actual support measures paid by the Turkish government to producers of livestock products and fodder in 2011, our first step is to create a base reference that reflects the subsidies paid to producers of livestock and fodder crops around the year 2011. We use data from the OECD producer support estimate database with regard to output and input subsidies for livestock and fodder crops and shock our model with the respective subsidy rates (OECD, 2018). The database lists four types of subsidies for the Turkish livestock industry: payments based on output, market price support (MPS), payments based on input use and payments based on area/animal numbers. Here, we only focus on output payments and MPS, as the aggregated nature of our sectoral data does not allow to model the specific payments based on area for example, for silage maize. In general, the removal of payments based on area however would have the same qualitative affect as the removal of payments based on output. The former is implemented in the model as negative activity taxes and is partly already reflected in the GTAP data. The database shows that producer support was mainly paid in 2011 to producers of fodder crops including maize, barley, wheat and sunflower. MPS is paid to producers to keep the domestic market prices of agricultural goods above world market prices, but was not included in the GTAP data until now (Huang, 2009). As MPS is listed as "support paid based on commodity outputs," we also implement MPS as a negative activity tax. MPS is paid for both fodder crops such as maize, wheat and sunflower, and for livestock products such as milk, beef, poultry and sheep meat. Barley, an important feed grain for which we include subsidies in our model, is part of an aggregated sector "other grains/GRO" in our database. The sector includes barley, oats, rye, millet, triticale and mixed grains. Given that barley accounts for 92% of the aggregated grain sector according to FAO production data, we approximate the support policy scheme for the aggregated GTAP sector with the support paid to barley producers, even though some crops in this sector are non-subsidized. This implies that we might slightly overestimate subsidies for "other grains/GRO" in Turkey.

We then run six sets of scenarios that we compare with the baseline. These are given in Table 4. In the first three scenarios, we reduce the livestock output subsidies to zero (a), reduce the fodder crop output subsidies to zero (b), and simulate a complete liberalization of import tariffs on bovine cattle and beef (c). These shocks are

**Table 5**
*Tax Rates in the Baseline and in the Scenarios*

| | Base | nolivsub | nofodsub | livlib | comb | nofacsub | livprod |
|---|---|---|---|---|---|---|---|
| *Tax/subsidy rates* | | | | | | | |
| Fodder crops | | | | | | | |
| Wheat | −0.23 | −0.23 | 0 | −0.23 | 0 | −0.23 | −0.23 |
| Maize | −0.18 | −0.18 | 0 | −0.18 | 0 | −0.18 | −0.18 |
| Barley | −0.16 | −0.11 | 0 | −0.16 | 0 | −0.16 | −0.16 |
| Oilseeds | −0.26 | −0.11 | 0 | −0.26 | 0 | −0.26 | −0.26 |
| Primary livestock sectors | | | | | | | |
| Outdoor livestock (Bovine cattle) | 0.00 | 0 | 0 | 0.00 | 0 | 0.00 | 0.00 |
| Indoor livestock | −0.30 | 0 | −0.30 | −0.30 | 0 | −0.30 | −0.30 |
| Raw milk | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Processed livestock products | | | | | | | |
| Cattle meat | −0.19 | 0 | −0.19 | −0.19 | 0 | −0.19 | −0.19 |
| Other meat | −0.10 | 0 | −0.10 | −0.10 | 0 | −0.10 | −0.10 |
| Milk | −0.16 | 0 | −0.16 | −0.16 | 0 | −0.16 | −0.16 |
| *Import tariffs* | | | | | | | |
| Primary livestock sectors | | | | | | | |
| Outdoor livestock (Bovine cattle) | 0.44 | 0.44 | 0.44 | 0 | 0 | 0.44 | 0.44 |
| Processed livestock products | | | | | | | |
| Cattle meat | 0.66 | 0.66 | 0.66 | 0 | 0 | 0.66 | 0.66 |
| Milk | 1.40 | 1.40 | 1.40 | 0 | 0 | 1.40 | 1.40 |
| *Change in capital cost* | | | | | | | |
| Primary livestock sectors | | | | | | | |
| Outdoor livestock (Bovine cattle) | – | – | – | – | – | 0.51 | – |
| Indoor livestock | – | – | – | – | – | 0.25 | – |
| *Productivity increase* | | | | | | | |
| Outdoor livestock (Bovine cattle) | – | – | – | – | – | – | 0.1 |

Source: Own compilation using data from the GTAP database (Aguiar et al., 2016) and the OECD producer support database (OECD, 2018). Note that these tax rates include "market price support (MPS)" and "payments based on output (PO)" and do not include any payments on in input use. Change in capital cost represents a reduction in the factor subsidies for capital.

implemented in the price equations of the CGE model, which link endogenous prices to other prices and quantity variables in the model (Lofgren et al., 2002). In the first two scenarios, we technically shock the producer tax rate $t_a$, which directly affects output quantities $\mathrm{QA}_a$ and prices $\mathrm{PA}_a$ in Equation 1, which states that output revenue must equal producer costs from factors ($\mathrm{PVA}_a \cdot \mathrm{QVA}_a$) and intermediate inputs ($\mathrm{PINTA}_a \cdot \mathrm{QINTA}_a$). In the third scenario, we shock the import tariff $\mathrm{tm}_c$ of commodity $c$, thereby affecting import prices $\mathrm{PM}_c$, as shown in Equation 2 where import prices are the sum of world market prices $\mathrm{pwm}_c$ multiplied by the exchange rate EXR and the second term that denotes the margins paid to trade and transport commodities $c'$. In a fourth scenario, we simulate the combined effect of the previous three scenarios. Table 5 shows the different tax rates in the baseline and the six scenarios with respect to activity and import taxes.

$$\mathrm{PA}_a \cdot (1 - t_a) \cdot \mathrm{QA}_a = \mathrm{PVA}_a \cdot \mathrm{QVA}_a + \mathrm{PINTA}_a \cdot \mathrm{QINTA}_a \tag{1}$$

$$\mathrm{PM}_c = \mathrm{pwm}_c \cdot (1 + \mathrm{tm}_c) \cdot \mathrm{EXR} + \sum\nolimits_{c'} \mathrm{PQ}_{c'} \cdot \mathrm{cm}_{c'c} \tag{2}$$

In a fifth scenario, we remove the factor subsidies on capital received by producers of cattle and raw milk, which corresponds to shocking $\mathrm{tva}_a$ in the factor demand equation (Equation S2 in Supporting Information S1). Bovine cattle producers receive US$ 834 million and raw milk producers US$ 368 million. Without this subsidy, capital costs would be 51% higher for bovine cattle producers and 25% higher for raw milk producers. We implement this cost increase by increasing the price for capital in the two sectors by 51% and 25%, respectively.

Finally, we run a scenario that reflects the combined various Turkish policies that target higher productivity and average technical efficiency in the livestock sector, as outlined under the Ninth, Tenth, and Eleventh Development Plan. We model the assumed macroeconomic outcome of these combined measures by introducing a positive productivity shock of 10% on bovine cattle, which corresponds roughly to the milk yield increase that would result from the targeted increase of more productive cattle breeds in Turkey's cattle herd (Ministry of Development, 2013). Technically, we increase the efficiency parameter and $\alpha_a^{va}$ in the value-added CES function (Equation S4 in Supporting Information S1) from 1 to 1.1. Since higher productivity implies in general improved feed efficiency (=higher feed conversion ratios) and thus more output from a given amount of water input, such a policy measure could reduce the virtual water embedded in each unit of output and thus decrease the water footprint of the livestock sector (FAO, 2016). This aggregate scenario abstracts away from potential second-best effects that may result from changes in the feed composition at higher average productivity levels. However, this scenario allows an analysis of the relative economic effect of improvements in productivity and technical efficiency in comparison with the effect of market liberalization in the Turkish livestock sector.

### 3.3. Water in CGE Models

The inclusion of water in CGE models remains challenging (see e.g., Luckmann et al., 2014) given that CGE models are based on market interactions and prices, whereas water supply originates as an ecosystem service provided by nature outside of any market and thus has an effective price of zero. Most water is either a constantly flowing resource, as in the case of rivers, or a seasonal resource, as in the case of rainfall (and groundwater recharge), whereas CGE models work with an annual time step. Since the activities of formal water distribution systems with volumetric water prices are usually reported in national supply use tables, the values of household and industry water demand are typically depicted in standard social accounting matrices such as GTAP as the supply of a water sector (Aguiar et al., 2016). This formal water sector, however, represents the service of water distribution and not water itself.

Most CGE models accounting for water focus on agriculture as the largest user of water from blue and green water resources (FAO, 2016). There are two broad approaches to capturing agricultural water in CGE models. The first is to include irrigation water as a factor of production in the model. Based on the assumption that the value of irrigation water is implicitly included in the land value-added, land is disaggregated into rain-fed land, irrigated land and water (Calzadilla et al., 2011). Taheripour et al. (2013), for example, disaggregate the rain-fed and irrigated agricultural sectors and determine the shadow value of water to be the difference between the respective returns to land in rain-fed and irrigated production (Taheripour et al., 2013). To account for the fact that water supply does not react to price signals, the availability of water is constrained to some exogenous level, and most studies then analyze the impact of changes in this exogenous water endowment on agriculture (e.g., Calzadilla et al., 2017; Liu et al., 2019). In general, including water as an economic production factor provides a proxy for the water shadow price in the form of its marginal productivity (Calzadilla et al., 2017). In reality, however, the marginal productivity of water is linked to the evapotranspiration of crops, which is influenced by climatological variables such as temperature, humidity and crop-specific physical and physiological features (Allen et al., 1998). Therefore, the other common approach has been to couple the CGE model with biophysical models to capture the effect of water variability, especially under climate change, on the productivity of crops. This can be done with a crop model that measures the impact of physical water availability on yields under different climate realizations and then by translating these changes into total factor productivity changes that are imposed on crop production functions in the CGE model (e.g., Dudu & Cakmak, 2018; Schuenemann et al., 2018).

Simultaneously depicting the natural water supply response and the hydrological cycle goes beyond pure economic modeling and requires integrated economic-biophysical approaches at more disaggregated levels. While CGE models usually have a global or national focus, water supply is given at the drainage basin level. The latter can only be assessed with hydrological models, especially with respect to groundwater availability that is influenced by recharge and possible pumping (Hertel & Liu, 2019). For example, Robinson and Gueneau (2013) sequentially couple a CGE model of Pakistan and a water basin model of the Indus to analyze the impact of varying river flows on water availability for irrigation and other uses in different regions.

**Table 6**
*Model Indices, Parameters, and Variables*

| | |
|---|---|
| Indices | |
| $a$ | Model crop sectors (aggregated) |
| fod $\in a$ | Fodder crop sectors (wheat, maize, barley, vegetables, and oilseeds) |
| live $\in a$ | Livestock sectors (bovine cattle, small livestock, and milk-producing livestock) |
| scen | Set of scenarios |
| FAO_crop | FAO crop sectors (disaggregated) |
| Parameters and variables | |
| $\mathrm{WFP}_{\mathrm{FAO}_{\mathrm{crop}},\mathrm{AEZ}}$ | Blue water footprint of FAO crops per ton per AEZ in 2011 |
| $\mathrm{WFP}_{a,\mathrm{AEZ}}$ | Blue water footprint of model crops per ton per AEZ in 2011 and in the baseline |
| $\mathrm{WFP}_{a,\mathrm{AEZ},\mathrm{scen}}$ | Blue water footprint of model crops per ton per AEZ in each scenario |
| $\mathrm{WFP}_{\mathrm{fod},\mathrm{AEZ},\mathrm{scen}}$ | Blue water footprint of fodder crops per ton per AEZ in each scenario |
| $\mathrm{WFP}_{\mathrm{live},\mathrm{AEZ},\mathrm{scen}}$ | Total blue water footprint of livestock sectors due to embedded water from fodder per AEZ in each scenario |
| $Q_{a,\mathrm{scen}}$ | Output of model crops in each scenario |
| $\Delta Q_{a,\mathrm{scen}}$ | Change in output of model crops in each scenario compared to baseline |
| $\mathrm{crp\_share}_{a,\mathrm{FA0\_crop}}$ | Output share of disaggregated FAO crops in aggregated model crops' output |
| $\mathrm{live\_shr}_{\mathrm{fod},\mathrm{live},\mathrm{scen}}$ | Share of livestock sectors' demand in total demand of fodder crops in each scenario |

Source: Own compilation.

Since both water supply and demand in agriculture are dependent on biophysical variables and cannot satisfactorily be assessed with an economic model, we refrain from explicitly including water as a production factor in our analysis. Like previous CGE analyses, the value of water is assumed to be implicitly included in the land rent. This assumption is not unrealistic as a market for agricultural water does not exist in Turkey (World Bank Group, 2016). While the absence of a market and public subsidies for irrigation water probably lead to inefficient allocations of water in any case, we are particularly interested in how the different livestock support measures reinforce such misallocations. Therefore, we develop a simple but robust water accounting module to measure agricultural water use as explained below.

### 3.4. Water Accounting Module

While the CGE model can capture policy impacts on various economic variables such as output, GDP and welfare, water is an essentially free (and subsidized) resource in Turkey, thus irrigation water use is independent of prices and markets. We therefore develop a water accounting tool that translates changes in the output of crops and livestock sectors to changes in WFPs per unit of output and for Turkish agriculture as a whole. Table 6 shows the indices, parameters and variables used in the module. Note that this WFP specifically measures the blue, green and gray water use of Turkish livestock sectors based on feed from fodder crops and not the water consumed through non-feed water usage. While non-feed water use (i.e., drinking, service and feed-mixing water) only accounts for 2% of the total water footprint (Mekonnen & Hoekstra, 2012), on average about 90% of the total WFP of livestock products comes from green water (Mekonnen & Hoekstra, 2010). Yet, in industrial livestock production systems in Turkey, the blue water footprint is more than double the amount than for grazing systems (316 vs. 650 $\mathrm{m}^3$/ton; Mekonnen & Hoekstra, 2010), emphasizing the increasing importance of blue water in Turkey's livestock sector. It is important to note that the water used by crop residues is implicitly included in the WFP of crops. The global standard WFP calculations after Hoekstra et al. (2011) focus on the final crop product, such as the wheat grain. To calculate the WFP per ton of product, they assign all water applied to the field to this final product so that the water used by the rest of plant is already included in the WFP of the final product. Both indoor and outdoor livestock are fed with the final product grain, so the WFPs of any additional crop residues of the respective crop that is also fed to the animals are accounted for and included in our calculations. Assigning all water to crops (and nothing to residues) leads to an overestimation of WFPs for poultry, that is, indoor livestock that is not fed with residues, and to an underestimation of WFPs for ruminants, that is, outdoor livestock.

However, this is not a problem with our more detailed WFPs for maize that specifically distinguish between WFP for maize grain and maize silage and therefore capture maize residue WFPs, as we explain hereafter.

We use two different water footprint data sets for crops in Turkey that both have advantages and disadvantages. The first data set by Mekonnen and Hoekstra (2011) includes the most widely used and in many respects most detailed WFPs and list the water footprint in terms of blue, green and gray water per ton of production for 76 Turkish provinces. We map these provinces to the seven Turkish regions which are then mapped to the AEZs shown in Table 3 to get distinctive WFPs per crop in each AEZ. We then multiply these footprints by crop production data in tons from FAOSTAT for the year 2011 in Turkey which we distribute over the AEZs according to land use shares. Since crop sectors in our model are more aggregated than the standard FAOSTAT crops due to the structure of the social accounting matrix, the water footprint of FAO crops $\mathrm{WFP}_{\mathrm{FAO\_crop}}$ is summed and multiplied by the output share of these crops in our model crop sectors $\mathrm{crp\_share}_{a,\mathrm{FA0\_crop}}$, as shown in Equation 3. This provides the water footprint of Turkish agriculture for each AEZ in the baseline $\mathrm{WFP}_{a,\mathrm{AEZ}}$:

$$\mathrm{WFP}_{a,\mathrm{AEZ}} = \sum\nolimits_{\mathrm{FAO\_crop}} \mathrm{WFP}_{\mathrm{FAO}_{\mathrm{crop}},\mathrm{AEZ}} \times \mathrm{crp\_share}_{a,\mathrm{FA0\_crop}} \tag{3}$$

We then proceed to link the CGE model to the water accounting module by passing down the change in crop production quantities in each scenario $\Delta\mathrm{QA}_{a,\mathrm{scen}}$ from the economic model to the water module. To calculate the WFPs in each scenario $\mathrm{WFP}_{a,\mathrm{AEZ},\mathrm{scen}}$, we multiply the water footprint in the baseline by the change in output for each crop sector in each scenario (Equation 4):

$$\mathrm{WFP}_{a,\mathrm{AEZ},\mathrm{scen}} = \mathrm{WFP}_{a,\mathrm{AEZ}} \times (1 + \Delta\mathrm{QA}_{a,\mathrm{scen}}) \tag{4}$$

It is important to note that the output changes for each crop are the same for each AEZ in our CGE model. This is on the one hand because we have one national production sector for each (aggregate) crop that uses land from different AEZs as factor input, so that we do not have distinct outputs per crop and AEZ. On the other hand, although we know how much output of each crop is produced in each AEZ originally, we find that there is little variation in the land use shares of each AEZ in the production of each crop in the simulations so that we cannot weigh national output with relative changes in the AEZ input. This is because there is little substitution between production factors in the production technology of crops, because the productivity of different production factors in crop production does not change in our scenarios.

Finally, to calculate the blue water footprint of the Turkish livestock sectors in each scenario, the blue water footprint of fodder crops is summed and multiplied by the share of each livestock sector's demand in the total demand of fodder crops in each scenario (Equation 5):

$$\mathrm{WFP}_{\mathrm{blue},\mathrm{live},\mathrm{AEZ},\mathrm{scen}} = \sum\nolimits_{\mathrm{fod}} \mathrm{live\_shr}_{\mathrm{fod},\mathrm{live},\mathrm{scen}} \times \mathrm{WFP}_{\mathrm{blue},\mathrm{fod},\mathrm{AEZ},\mathrm{scen}} \tag{5}$$

The detailed Mekonnen and Hoekstra (2011) data allow to calculate distinct WFPs for each AEZ but have two disadvantages: first, the data provides average WFPs around the year 2000. Since then however, yields of most fodder crops have increased according to FAO data as well as irrigation area. This means we might over- or underestimate the WFPs for our model base year 2011. Second, the Mekonnen and Hoekstra (2011) WFPs for maize do not specifically account for maize silage, the most important forage crop in Turkey where both the grain and most of the plant are fed to ruminants. Like for wheat or other crops, the water applied to the whole field and thus water used both by the grain and the lignocellulosic part of the plant are accounted for in the WFP of maize grain. But Mekonnen and Hoekstra (2011) only provide the WFP/ton of the final product maize grain, at which they presumably arrive by dividing the WFP/ha by the yield of maize grain (ton/ha). If we apply this WFP/ton to silage maize, we should overestimate the total WFP of silage maize because of the much higher yield and thus production of silage maize (6–5 times the corn maize yield; TSI, 2022).

Therefore, the second data set we use originates from Muratoglu and Avanoz (2021), who have calculated green and blue WFPs for Turkish crops for the years 2008–2019. While their data is only available on national level, it accounts for increased yields and irrigation and provides total WFP per crop. Using data with respect to area and production of maize grain and silage maize from TSI (2022), we can divide the total WFP of maize between grain and silage. As shown in Table 1, we arrived at distinctive WFPs/ton for silage maize, which are much lower compared to grain. We will thus also calibrate our water accounting tool to the Muratoglu and Avanoz (2021) data

**Table 7**
*Economic Impacts*

| | Initial share 2011 | Change in GDP at factor cost in % | | | | | |
|---|---|---|---|---|---|---|---|
| | | nolivsub | nofodsub | livlib | comb | nofacsub | livprod |
| Total GDP | 100.00 | 0.00 | 0.00 | 0.00 | 0.0 | 0.00 | 0.09 |
| Agriculture | 7.13 | −3.35 | −2.62 | −1.65 | −7.75 | −0.54 | 0.69 |
| Fodder crops | 1.10 | −2.68 | −17.67 | −0.58 | −21.18 | −0.33 | 0.60 |
| Export crops | 4.26 | −1.01 | 0.35 | 0.18 | −0.47 | −0.07 | 0.30 |
| Livestock | 1.27 | −13.54 | −1.25 | −9.83 | −25.24 | −2.55 | 2.21 |
| Industry | 30.31 | 0.94 | 0.67 | 0.14 | 1.70 | 0.06 | 0.05 |
| Meat and dairy production | 1.52 | −13.77 | −0.71 | −12.22 | −20.94 | −0.91 | 0.92 |
| Services | 62.56 | −0.07 | −0.02 | 0.12 | 0.07 | 0.03 | 0.04 |

Source: Results from the Turkey CGE model. Fodder crops include: wheat, maize, barley, oats, rye, millet, triticale, and mixed grains and oilseeds; Export crops include: vegetables and fruits, sugarbeet, seedcotton, and the other crop sector, which consists of tea (52%), vetches (25%), tobacco (11%), okra (9%), and carobs (3%).

at national level. In our results section we will present and discuss water use results of our scenarios according to both water footprint data sets after each other. We will abbreviate the Mekonnen and Hoekstra (2011) WFPs with “MH” and the Muratoglu and Avanoz (2021) WFPs with “MA.”

The combination of the CGE model and the water accounting tool allows the measurement of the economic and biophysical impacts of different livestock support measures in Turkey, as discussed in the next section. While our CGE model database does not distinguish between irrigated and non-irrigated land, the water accounting tool will show how blue and green WFPs of crop sectors change in the scenarios to assess how the blue water intensity of Turkish agriculture changes.

## 4. Results and Discussion

We simulate the above described scenarios by removing different livestock support measures in the Turkey CGE model and comparing them with the baseline that captures the structure of the Turkish economy in 2011, as shown in the first column of Table 7. Services dominate the Turkish economy, producing 62% of GDP, while the agricultural sector accounts for just 7% of Turkey's total GDP. In addition, meat and dairy processing represents only a small share of Turkish industrial production. This means that any policy shock to agriculture is likely to have small repercussions on the rest of the economy. However, products of animal origin should account for an important and increasing share of household food expenditure and therefore relevant GE effects cannot a priori be ruled out. In the GTAP9 data, most of agriculture's GDP share is generated by export crops and less so by livestock production, indicating the relatively low productivity of livestock production in Turkey. The way in which subsidies could change the composition of Turkish agriculture and its water use is discussed below.

### 4.1. Scenario 1: Removal of Livestock Subsidies

In the first scenario, we remove the subsidies paid directly to Turkish livestock producers per unit of output. The economic impacts can be seen in the second column of Table 7. As expected, the output of all livestock sectors decreases. Both primary livestock and meat and dairy processing fall by almost 14%. This also affects other sectors that are used as inputs in the livestock industry, mainly fodder crops but also trade services. Even though demand for fodder crops decreases, the negative effects on this sector are much smaller than on the livestock industry because additional land becomes available to fodder crops that was formerly used for pasture. There are also very small negative effects on export crops. While most of vegetables, fruits and other crops are exported, some of them are also fed to livestock and therefore exhibit a small decrease in output.

Total industry benefits and grows slightly as the contraction of the livestock sector sets free labor that migrates to other industrial sectors. Total GDP effects are negligible, which is plausible given the relatively small size of agriculture in GDP. The reduction in the livestock sector is mainly felt by households and less so by producers, as shown in the household effects in the second column of Table 8. As livestock output decreases, prices for

**Table 8**
*Household Impacts*

| | Initial 2011 in billion US$ or % | Change compared to baseline | | | | | |
|---|---|---|---|---|---|---|---|
| | | nolivsub | nofodsub | livlib | comb | nofacsub | livprod |
| Real consumption in % | 586.31 | −1.03 | −0.37 | 0.28 | −1.04 | −0.03 | 0.10 |
| Equivalent variation in 2011 billion US$ | 584.38 | 1.32 | 0.34 | −0.67 | 0.76 | 0.14 | −0.18 |
| Share of expenditure in % | 100.00 | 0.23 | 0.06 | −0.12 | 0.13 | 0.02 | −0.03 |
| Total subsidies paid in 2011 billion US$ | 10.24 | −6.15 | −4.09 | 0.00 | −10.24 | −1.2 | 0.00 |

Source: Results from the Turkey CGE model.

livestock products increase, leading to a one percent lower real consumption compared to the baseline. Similarly, the value for equivalent variation shows that households would have to be paid 1.3 billion US$ after the policy shock and price change to be as well off as before. However, the subsidy payments the government could save from removing livestock support amount to more than 6 billion US$ (last row of Table 8) and could more than compensate consumers for their welfare loss.

Even though there is a small reduction in crop output, the land use results in the second column of Table 9 show a clear reallocation of pasture land to export crop land, which is most pronounced in AEZ8, indicating a more profitable use of land especially in Turkey's driest region. Some fodder crops also benefit from the land that is set free by pasture. As the demand for fodder crops from the livestock sector decreases, especially wheat and oilseeds become cheaper leading to higher demand on the world market. As a consequence, farmers substitute pasture land for crop land to satisfy this export demand. Land use of other fodder crops however decreases, as the demand from the livestock sectors has contracted. Favorable outcomes are also evident when looking at the blue water use impacts according to the MH WFPs in Table 10. Water use in the livestock sector is calculated as the virtual water

**Table 9**
*Land Use Impacts*

| | Inital land (million ha) | Change in land use in % | | | | | |
|---|---|---|---|---|---|---|---|
| | | nolivsub | nofodsub | livlib | comb | nofacsub | livprod |
| *Total land allocation (all AEZs)* | | | | | | | |
| Fodder crop land area | 12.55 | 1.89 | −4.97 | 3.41 | −5.04 | 2.51 | 3.53 |
| Export crop land area | 5.47 | 6.16 | 8.29 | 7.01 | 11.07 | 5.47 | 6.12 |
| Pasture land area | 14.62 | −5.25 | 2.98 | −10.81 | −17.48 | 0.84 | −4.89 |
| *Land allocation in major AEZs* | | | | | | | |
| AEZ8 | | | | | | | |
| Fodder crop land area | 4.77 | 0.38 | −10.50 | 2.20 | −11.19 | 1.28 | 2.55 |
| Export crop land area | 2.18 | 7.57 | 9.42 | 8.46 | 12.79 | 6.65 | 7.41 |
| Pasture land area | 6.23 | −4.77 | 3.18 | −10.37 | −16.68 | 1.01 | −4.65 |
| AEZ9 | | | | | | | |
| Fodder crop land area | 4.18 | −0.44 | −11.85 | 1.42 | −13.67 | 1.02 | 2.15 |
| Export crop land area | 2.04 | 5.03 | 6.92 | 5.94 | 8.96 | 4.64 | 5.26 |
| Pasture land area | 5.20 | −5.79 | 2.24 | −11.26 | −18.79 | 0.65 | −5.12 |
| AEZ10 | | | | | | | |
| Fodder crop land area | 3.15 | 0.44 | −10.53 | 2.19 | −11.71 | 1.55 | 2.68 |
| Export crop land area | 1.10 | 5.30 | 8.40 | 6.04 | 11.49 | 4.47 | 5.07 |
| Pasture land area | 2.97 | −5.35 | 3.91 | −10.97 | −16.88 | 0.79 | −4.99 |

Source: Results from the Turkey CGE model. Fodder crops include: wheat, maize, barley, oats, rye, millet, triticale, and mixed grains and oilseeds; Export crops include: vegetables and fruits, sugarbeet, seedcotton, and the other crop sector, which consists of tea (52%), vetches (25%), tobacco (11%), okra (9%), and carobs (3%).

**Table 10**
*Water Use Impacts (Agro-Ecological Zones [AEZ] With Water Footprints After Mekonnen and Hoekstra (2011))*

| | | Change compared to baseline | | | | | |
|---|---|---|---|---|---|---|---|
| | Initial 2011 | nolivsub | nofodsub | livlib | comb | nofacsub | livprod |
| *All crops* | | | | | | | |
| Total water use in million m$^3$ (all AEZs)[a] | 109,452.45 | −3,544.20 | −11,503.27 | −1,136.86 | −16,123.92 | −420.02 | 597.91 |
| Blue water use in million m$^3$ (all AEZs) | 17,910.24 | −488.89 | −955.96 | −131.67 | −1,570.84 | −58.45 | 88.27 |
| *Livestock* | | | | | | | |
| Total water use in million m$^3$ (all AEZs)[a] | 13,860.18 | −2,016.18 | −189.10 | −1,251.43 | −3,527.02 | −329.92 | 289.50 |
| Blue water use in million m$^3$ (all AEZs) | 2,442.20 | −355.10 | −33.30 | −220.61 | −621.43 | −58.15 | 51.03 |
| Outdoor livestock for beef | 727.06 | −86.84 | −6.31 | −181.32 | −281.44 | −42.39 | 28.61 |
| Outdoor livestock for milk | 936.17 | − 51.11 | −5.38 | −47.29 | −115.91 | −13.68 | 18.11 |
| Indoor livestock | 739.79 | −216.89 | −20.83 | 7.61 | −223.04 | −2.02 | 4.16 |
| Blue water use in % (all AEZs) | 100.00 | −14.55 | −1.37 | −9.02 | −25.45 | −2.38 | 2.09 |
| Outdoor livestock for beef | 100.00 | −11.89 | −0.87 | −24.94 | −38.71 | −5.83 | 3.94 |
| Outdoor livestock for milk | 100.00 | −5.46 | −0.57 | −5.05 | −12.38 | −1.46 | 1.93 |
| Indoor livestock | 100.00 | −29.32 | −2.82 | 1.03 | −30.15 | −0.27 | 0.56 |
| *Water intensity of total agriculture* | | | | | | | |
| Per ton in m$^3$ (blue water) | 144.16 | 143.93 | 143.01 | 144.14 | 142.81 | 144.09 | 144.27 |
| Per unit of value added in m$^3$ (blue water) | 489,543.08 | 482,693.23 | 479,278.05 | 485,794.56 | 468,505.26 | 488,559.21 | 490,184.82 |
| Per unit of value added in % (blue water) | 100.00 | −1.40 | −2.10 | −0.77 | −4.30 | −0.20 | 0.13 |
| Per unit of value added in % (total water[a]) | 100.00 | −1.91 | −7.45 | −1.07 | −10.55 | −0.26 | 0.18 |

Source: Results from the Turkey CGE model and water accounting module. Note: The table shows the water footprints from crop water use.
[a]Blue and green.

entering livestock production through inputs in the form of the virtual water embedded in the fodder crops (see Section 3.3). We only report the percentage changes for blue water use over all AEZs as the percentage changes are exactly the same in all AEZs by design of the water accounting module. By removing the livestock subsidies, blue water use is reduced by almost 500 million m$^3$ or 15% over all AEZs compared to the baseline. The effects are most pronounced for indoor livestock such as poultry that have a higher share of fodder crop input compared to cattle that are partly kept grazing on pasture land (note that the pig sector in Turkey is neglectable). Detailed results for each AEZ can be found in Table S3 in Supporting Information S1. As a result the blue water intensity of total Turkish agriculture measured as the blue water used per unit of value-added decreases by 1.40%. Similarly, the total water intensity (blue, green, gray) of Turkish agriculture decreases by 1.91% because of the overall reduction of agricultural production.

Results with respect to the blue and green WFPs differ when we calibrate our water module to the WFPs from the Muratoglu and Avanoz (2021) as shown in Table 11. The first column shows that the more recent data exhibits a lower total water use due to the higher yields, but the blue water use of Turkish crops is almost two times as large given the large increase in irrigation area. Blue WFPs of the livestock sector are in fact almost double as those based on the MH data, emphasizing the importance of irrigation for forage crops, so that the absolute changes in water in scenario 1 are thus also almost twice as high. The percentage reductions in water use are exactly the same as for MH WFP data and are therefore not reported in Table 11. This is because to arrive at the WFP changes in each scenario, our water accounting module multiplies the WFP in the baseline by the change in production for each crop sector in each scenario.

Thus, the relative WFP changes in each scenario correspond to the relative output changes. Since the changes in production in each scenario are an output of the CGE model, they stay the same in the water accounting module no matter which WFP data we calibrate the module to. Interestingly, the reductions in the water intensity of Turkish agriculture are smaller for the more recent WFP data. Both total and blue water intensity decrease by 1.3%

**Table 11**
*Water Use Impacts (Water Footprints After Muratoglu and Avanoz (2021))*

| | | Change compared to baseline | | | | | |
|---|---|---|---|---|---|---|---|
| | Initial 2011 | nolivsub | nofodsub | livlib | comb | nofacsub | livprod |
| *All crops* | | | | | | | |
| Total water use in million m$^3$ (all AEZs)[a] | 70,493.35 | −1,888.90 | −8,365.52 | −486.38 | −10,729.26 | −215.96 | 354.60 |
| Blue water use in million m$^3$ (all AEZs) | 35,339.41 | −933.32 | −3,890.29 | −232.16 | −5,068.20 | −108.16 | 178.26 |
| *Livestock* | | | | | | | |
| Total water use in million m$^3$ (all AEZs)[a] | 8,607.72 | −1,252.57 | −117.48 | −776.87 | −2,190.55 | −204.83 | 179.74 |
| Blue water use in million m$^3$ (all AEZs) | 4,415.24 | −642.44 | −60.26 | −398.53 | −1123.61 | −105.07 | 92.20 |
| Outdoor livestock for beef | 1,313.59 | −156.24 | −11.40 | −327.59 | −508.48 | −76.60 | 51.69 |
| Outdoor livestock for milk | 1,690.93 | −92.32 | −9.71 | −85.42 | −209.37 | −24.71 | 32.72 |
| Indoor livestock | 1,339.64 | −392.75 | −37.72 | 13.78 | −403.89 | −3.65 | 7.53 |
| *Water intensity of total agriculture* | | | | | | | |
| Per ton in m$^3$ | 332.01 | 329.64 | 309.02 | 331.00 | 304.91 | 331.61 | 332.52 |
| Per unit of value added in m$^3$ | 965,937.28 | 953,289.74 | 889,030.84 | 959,296.25 | 867,977.15 | 964,192.42 | 967,315.10 |
| Per unit of value added in % (blue water) | 100.00 | −1.31 | −7.96 | −0.69 | −10.14 | −0.18 | 0.14 |
| Per unit of value added in % (total water[a]) | 100.00 | −1.35 | −8.85 | −0.72 | −11.06 | −0.18 | 0.14 |

Source: Results from the Turkey CGE model and water accounting module. Note: The table shows the water footprints from crop water use.
[a] Blue and green.

similar to the blue water intensity of the MH WFPs. These results further emphasize the increased importance of blue water use in the Turkish livestock sector in recent years.

Overall, the removal of livestock subsidies reduces livestock output and hurts households by increasing prices. At the same time, a reduction in direct subsidies to the livestock industry reduces the excessive blue water use in Turkish agriculture, even though we see a reallocation of land to more profitable and more water intensive export crops.

### 4.2. Scenario 2: Removal of Fodder Subsidies

In the second scenario, we only remove the subsidies paid to producers of fodder crops, which leads to a decline in fodder crop production of almost 18%, as shown in the third column of Table 7. Given the dominance of crop production in Turkish agricultural GDP, the removal of fodder crop production subsidies has a greater effect on Turkish agriculture than the removal of livestock subsidies. Livestock producers, however, are only marginally affected and their output decreases by around one percent. This is because as the output of domestic fodder crops decreases and their prices increase, livestock producers compensate for most of the lower domestic production of fodder crops through cheaper imports of fodder.

Similarly, land use of fodder crops is reduced by 5% (third column of Table 9), which is taken up mainly by export crops and converted into pasture land. Again, AEZ8 has the largest reallocation of land to profitable export crops. Export crop production increases slightly. Impacts on household consumption are also less pronounced than in the previous scenario (third column of Table 8). However, given the increase in prices of fodder crops such as wheat, maize and barley, which are also consumed by households, the equivalent variation shows that households would still have to receive almost 0.34 billion US$ to be as well off as they were before the price changes.

The third column of Table 10 shows the impacts on water use of removing fodder crop subsidies according to the MH WFPs. As domestically produced fodder crops are replaced with imported fodder crops, the water use in the Turkish livestock industry decreases by very little, around 1% overall. Note that for simplicity the imported fodder crops are assumed to contain the same amount of virtual blue water as domestic fodder crops. What is most striking is that due to the large reduction in (irrigated) fodder crop production, we find a reduction of the blue water intensity per unit of value added by more than 2%. The reduction in blue water intensity is even larger (8%)

and similar to the total footprints using the more recent data in Table 11. Overall, removing the distorting fodder subsidies would thus decrease the blue water intensity while having limited negative impacts on the livestock sector and households. Moreover, even though the blue water intensity of Turkish agriculture is reduced, more profitable export crops are produced.

### 4.3. Scenario 3: Liberalization of Import Tariffs on Bovine Cattle and Beef

Turkish livestock producers are not only subsidized directly, but also indirectly through import tariffs. In our third scenario, we remove the import tariffs for outdoor livestock (bovine and dairy cattle) as well as their processed products to capture their impacts on the economy and water use. This leads to large reductions in the production of both primary and processed livestock commodities, as shown in the fourth column of Table 7. Meat and dairy production decreases by 12%, and livestock production by just 10% on average. This is because import tariffs for processed livestock products are much higher than for cattle, as shown in Table 5. While cattle now has to compete with cheaper imports, indoor livestock products (mainly poultry) become relatively more competitive leading to an increase in their output by 3% (not shown in Table 7). The indoor livestock sector also benefits from the fodder crops that become available as the outdoor livestock sector contracts. This is because poultry feed is based primarily on cereals and maize grains, while our outdoor livestock sector consumes both grass from pasture land, maize for silage and compound feed. The latter may contain maize grains and other cereals etc. However, ruminants require minimum intakes of grass or silage-maize (“roughage”), while they can digest only limited quantities of compound feed in relation to the amount of their roughage intake. This is reflected in our model through fixed feed composition shares.

As both direct livestock subsidies as well as indirect fodder crop subsidies are still in place, the fodder crop sector can absorb more land from pasture as well as the labor that has previously been employed in livestock processing, so that negative impacts on fodder crops remain small. However, it is the export crop sector that benefits the most and can increase its land area by 7% (fourth column of Table 9). The largest increase in export crop land can be found in AEZ8. This is because the reduction in import tariffs leads to a depreciation of the exchange rate, making Turkish exports more competitive on the world market and increasing exports, especially in the crop sector. Households very much benefit from the lower prices of livestock products and their real consumption increases slightly (fourth column of Table 8). In addition, they also have higher utility and would have to give up income of 0.67 billion US$ to be as well off as they were before the price changes.

The large reduction in bovine cattle output translates into a 9% reduction in water use from the livestock sectors according to the MH WFPs, as shown in the fourth column of Table 10. Other livestock like poultry and sheep on the other hand increases its blue water use due to its increase in output. Together with the increase in export crop production, the blue water intensity of Turkish agriculture decreases only slightly compared to the baseline for both MH and MA WFP (fourth column of Tables 10 and 11). The total water intensity is a bit lower than in the baseline for both WFP data sets (−0.5%, fourth column of Table 10; −0.72 fourth column of Table 11), considering the small production decrease in agriculture (Table 7). The liberalization of import tariffs mainly benefits consumers and generally increases the competitiveness of the Turkish economy. Since the subsidies paid to livestock and fodder crop producers are still in place, blue water savings and the protection of (ground)water resources are limited.

### 4.4. Scenario 4: Combination of Scenarios 1–3

In the fourth scenario, we combine all the previous scenarios to measure the impact of domestic and international liberalization of the livestock industry in Turkey. As expected, both fodder crop and livestock production decreases considerably once all the subsidies are removed and respective imports enter the markets (fifth column of Table 7). Primary livestock production decreases by more than 25%, and meat and dairy production by 21%. Together with the enormous reduction in fodder crops (21%), this leads to a contraction of the agricultural sector by almost 8%. Even export crop production decreases slightly as some are also fed to livestock, which now exhibits lower demand. Given the loss of producer subsidies, especially the MPS, both fodder crop and livestock producers are unable to compete with world market prices and exports contract. Trade services are only marginally affected as the service sector can absorb some of the workers from agriculture.

In addition, industry has grown by 1.7% as workers migrate from livestock processing into more productive industrial sectors. Households, however, are the losers of combined subsidy and tariff liberalization (fifth column of Table 8) since they have previously benefited much more from lower prices through subsidies compared to the effect of an alternative removal of import tariffs. The prices of meat and dairy products in particular increase greatly, leading to a reduction in real consumption of 1%. In addition, they would have to be paid 0.76 billion US$ to be as well off as when there were subsidies and tariffs. On the other hand, the Turkish government could more than offset these losses as it would save 10 billion US$ worth of subsidies.

The main winner is the export crop sector, that takes up all the rainfed and irrigated land released by the fodder crop and livestock sectors and increases its land area by 11%, mainly in AEZ8 and AEZ10 (fifth column of Table 9). As all fodder and livestock subsidies are removed, fodder crop and livestock prices increase, leading to a reduction in demand for both types of products. Fodder crop and livestock producers cannot sell their products anymore and redistribute their land to more profitable crops, that is, export crops.

Due to the quite pronounced reduction in livestock production, water use by the livestock industry decreases by more than 25% (fifth column of Table 10). Together with the enormous reduction in irrigated fodder crop production, blue water use in total agriculture decreases by 1,570 million $m^3$ for the MH WFPs and by 5,000 million $m^3$ according to the more recent MA WFPs. Under the MH WFPs and under the MA WFPs, the blue water intensity of Turkish agriculture decreases by 4% (Table 10) and 10% (Table 11), respectively, while land is now used more productively in the export crop sector. Not surprisingly, total water intensity decreases by even more than 10% due to the contraction of agriculture (both for the MH WFP data and the MA WFP data).

Importantly, this combined scenario shows that the protection of the livestock industry has two effects: first, consumers of livestock commodities pay lower prices leading to more welfare; second, the subsidies and tariffs partly protect an inefficient and water-intensive agricultural sector, whose resources in terms of land and labor could be better employed in export crops and other industrial sectors. This is because for example, export crops generate a higher value added on the world market per unit of blue water than output of the bovine sector would do.

### 4.5. Scenario 5: Removal of Factor Subsidies Received by Producers of Bovine Cattle

Another livestock support measure that is supposed to reduce production costs but does not directly affect the use of blue water, like fodder subsidies, are factor subsidies on capital. These are predominantly paid to producers of cattle and raw milk and amount to up to 50% of capital costs. Once we remove these subsidies, a 2.5% reduction is seen in the output of primary livestock, but the reduction is smaller for processed meat and milk production (sixth column of Table 7). Given that the factor subsidies are only paid to producers of bovine cattle, the effects on the total livestock sector are small as other livestock such as poultry and sheep are not affected. Similarly, household real consumption in the seventh column of Table 8 decreases only marginally due to a slight rise in beef and milk prices. These results are also mirrored in terms of water use (sixth column of Table 10). Water use in beef production decreases by 6%, but the blue water intensity of Turkish agriculture remains essentially unchanged (sixth column of Tables 10 and 11). Overall, the capital subsidies paid to producers of bovine cattle do not play a large role in the Turkish economy and water use.

### 4.6. Scenario 6: Productivity Increase of Bovine Cattle

As mentioned above, one of the aims of Turkey's Tenth Development Plan is to increase productivity and average efficiency in the livestock sector. The plan aims at an increase in the share of “Pure Bred Cattle to Total Cattle stock” from 26% to 42% as target for the agricultural sector between 2006 and 2012. Azak and Çelik (2019) report average milk yield for culture (= pure) bred cattle and native cattle at 2,693 and 1,312 kg/year, respectively. After weighting by the respective shares of pure bred in Turkey's total cattle herd, this amounts to an increase in average milk yield of around 13% between 2006 and 2013. Given that we do not have information about the share of cross-bred cattle in Turkey's total herd, and assuming that beef production is less affected by the type of breed, we cautiously assume an average gain in productivity of the bovine sector at 10%. Therefore, we run a final scenario where we increase the productivity of bovine cattle by 10%. The economic impacts can be found in the last column of Table 7. As would be expected after a positive productivity shock, livestock output increases by 2.2%, whereas meat and dairy production is 1% higher than in the baseline, increasing the demand for fodder crops. As cattle production becomes more productive, land and labor are set free and available for fodder and export crops (last column of Table 9). Overall, the agricultural sector grows by 0.7% and total GDP grows by 0.09%. The growth in the agricultural sector triggers general equilibrium effects, leading to a higher demand for services. Industry grows due to the growth in meat and dairy processing. These favorable economic effects also influence household welfare. Household real consumption increases by 0.1% and the equivalent variation is negative, thus consumers gain 0.18 billionUS$. As prices for livestock products decrease, the additional output is taken up by the elastic domestic demand, while some livestock products are also exported.

The productivity increase also has interesting effects in land use (last column of Table 9). As outdoor livestock becomes more productive, it requires less feed (both crop-based and grass) per unit of output, so that pasture land and certain fodder crop land, mainly that for maize silage, is set free by the livestock sector and taken up by other sectors. This becomes available to other fodder and especially export crops, which can increase their land by 6%, similar to the scenario where livestock subsidies are removed.

Interestingly, this scenario shows very small effects related to water for both WFP data sets (last column of Tables 10 and 11). Both the absolute and blue water intensity of Turkish agriculture increase by 0.13%–0.18% due to higher absolute agricultural output for both WFP data sets (last column of Tables 10 and 11). The more productive livestock has an improved feed efficiency and requires less (irrigated) feed per unit of output. This means that livestock water use is lower in relative terms, even though we see an increase in absolute livestock water use due to the absolute output increase. The increase in the blue water intensity is very small, although all distorting support policies are still in place. This means that increasing the overall productivity of the Turkish livestock sector through for example, accelerated structural change, high-yield cattle varieties and improved management practices has potential to increase welfare and economic growth without large impacts on blue water use. If some of the distorting policies are removed, this could even reduce both the blue water intensity of Turkish agriculture and—depending on the size and direction of absolute changes—perhaps also to some extent the pressure on groundwater resources.

### 4.7. Discussion

The results of our water module have emphasized the importance of taking potential negative environmental externalities of economic policies into account, as the real costs of distorting policies might not only be of economic nature. When resources are not priced as in the case of irrigation water in Turkey, this is only possible through combining economic models that analyze the economic costs of policies with biophysical models that capture the ecological consequences. Linking these two types of models is in our view an innovative and promising contribution to the methodological toolkit around the water-agricultural policy nexus, since it allows us to simulate farmers' decision making given their available resources with respect to labor, capital and land and the subsequent water use impacts. Our rigorous economic model depicts the endogenous land use and production decisions of the agricultural producer based on economic considerations in the form of demand, supply and prices. In the case of Turkey, these economic considerations are heavily distorted through subsidies and as irrigation water is not priced, it is not part of the farmers' land use and production decision. As we employ an economy-wide model, we can measure the costs and benefits of policy measures with respect to economic welfare as shown above. However, we require our newly developed water accounting module to translate the changes in production into changes in water use, thereby exposing the environmental cost of distorting policies.

From a general perspective, one could either develop a model that is very explicit at the level of AEZs and WFP for each crop, while it would have to assume that the rest of the economy remains largely constant. Here one would start explicitly with a disaggregated modeling of crops, water and livestock within each AEZ, while most likely having to accept a much more simplistic representation of the surrounding economy and the policies in question. Alternatively, one could try to model the surrounding economic effects from policies, markets, trade and consumption explicitly, while having to accept less detail at the level of each specific crop. The modeling approach that we present in this manuscript follows the latter approach by trying to extend a model of the Turkish economy through the addition of a water module. The linking of the economic model with the water module is an approximation of the complex interactions of physical production systems with the related monetary streams. Our economic model has more aggregated crop sectors compared to the 93 individual crops for which we have detailed WFP data. To precisely capture the changes in the WFP for each individual crop in each scenario, our economic model would have to include 93 crop production activities each with its individual production technology. We are not aware that such detailed input-output tables for crop production activities exist for Turkey and therefore rely on the aggregated GTAP production technologies. While it is an interesting avenue for further research, building input-output tables for 93 crops is beyond the scope of our current study. This means that for most individual crops, we weight their WFP according to their output share to calculate the WFPs of the aggregated model crop sectors as explained in Section 3.4. If the output shares of individual crops in the aggregated model sectors would change in the scenarios, this has to be taken into account: To avoid any potential imprecisions for the most important Turkish fodder crop maize, we disaggregate the production technology of grains to get a distinct maize production activity as explained in Section 3.1. This allows us to capture the precise changes to production and the WFP of maize in livestock feed, which is the main focus of our study. For the remaining crops, the output shares had been assumed to remain constant within each aggregated crop. In the future, the class of CGE models we use would benefit from better integration of biophysical interactions with respect to water and soil. This highlights the need for combining hydrological models with plant growth models and economic models, because otherwise either the hydrological effects or the impacting incentives from markets and policies would necessarily have to remain as stylized representations in either modeling approach. We think that our analysis presents a step in exactly this direction of better integrated modeling frameworks.

Our results also show how using different WFP data sets to look at water use can lead to rather different results with respect to water intensity of the livestock sector, given different evapotranspiration calculation methods and assumptions on yields and irrigated area. One of the reasons for these differences is that since the base year of the MH WFPs 2005, Turkish agriculture has undergone dramatic changes through large increases in yields on the one hand and large expansion of irrigation, especially for fodder crops, on the other hand due to the above mentioned policies (We are grateful to our reviewers for pointing various aspects in this respect out to us.). These two changes should have opposing effects on the water intensity of Turkish agriculture. While higher yields reduce both the green and blue WFP per ton of crops, increased irrigation will always increase the blue WFP per ton. To understand the impact of each of these changes on WFPs in turn, we conduct a sensitivity analysis and calibrate our water accounting module to WFP data from Tamea et al. (2021). Using the fast-track method, Tamea et al. (2021) scale the MH WFPs with the change in yields to estimate Turkish WFPs for the year 2011. The disadvantage of these more recent WFPs is that they are only available for the sum of blue and green WFPs for each type of crops. Table S4 in Supporting Information S1 shows the results. To better compare, we also report the total (blue and green) water use of Turkish agriculture and the livestock sector in Table 10 according to the MH WFPs and Table 11 according to MA WFPs. As expected, both for Turkish agriculture as a whole (MH: 109,000 vs. Tamea: 59,000 million $m^3$) and the livestock sector (MH: 14,00 vs. Tamea: 6,000 million $m^3$), WFPs are higher for the older MH WFPs compared to the Tamea et al. (2021) WFPs that account for the increases in yields. Comparing the Tamea et al. (2021) WFPs to the most recent MA WFPs that account for the increased irrigation area, we see an increase in the WFP of the Turkish agriculture (70,000 million $m^3$) and even a higher WFP of the Turkish livestock sector (8,600 million $m^3$) than with MH WFPs. Our results thus emphasize the importance of sensitivity analyses when using data sets from different periods based on different assumptions. The MA WFPs lead to the largest water use results in the livestock sector as they assume a large increase in irrigation and capture the silage maize production in Turkey, but do not have the regional detail like the MH WFPs. While both data sets have their advantages and disadvantages, the MA WFPs are more realistic with respect to maize grain and maize silage. This is also evident in our scenario analysis where a large share of the increased blue water use in Turkey is due to the distorting direct and indirect livestock support policies.

We find further limitations of the MH WFPs when it comes to the WFPs of livestock feed with respect to crop residues as explained above. This is because typically other parts of the plant apart from grain are also fed to animals. The fact that the MH WFPs are reported per ton of product and focus only on the final product grain means that WFPs of maize silage are greatly overestimated if they are based on maize grain. This is because maize silage still has a very high water content and weighs 6–5 times the maize grain. Theoretically, this means that using the MH WFP data, we should overestimate the WFP of maize fed to livestock. The MA WFP data on the other hand distinguish between the high WFP of maize grain and the low WFP of maize silage. Even though they thus account for maize silage, we find that the total WFP of the Turkish livestock sector has increased nevertheless due to the large increases in irrigation.

Finally, we conduct a sensitivity analysis with respect to the economic structure of Turkey. Since Turkey has been suffering from relatively high unemployment, we run all of the scenarios again with an unemployment closure. The method and results are explained in detail in Supporting Information S1. Our key findings do not change: All economic, household and water effects in the subsidy removal scenarios are very similar compared to full employment, but the negative effects on households, agriculture and the service sector are greater and the positive effects on industry are smaller (Tables S5–S7 in Supporting Information S1). This is because in the case of an unemployment closure, wages have to be held constant in the model and a negative shock on the economy leads to larger unemployment. Conversely, in the scenario of increased productivity in the bovine cattle sector, the constant wages increase economic growth by providing relatively cheap labor (given that wages are assumed to not increase along with growth in the economy under the unemployment closure). Thus, we still find that productivity increases in the livestock sector are a win-win situation from an economic, social and water perspective.

## 5. Conclusions

The Turkish livestock sector is heavily protected by a large number of direct and indirect subsidies, including direct producer and MPS based on output as well as import tariffs on processed livestock commodities. Most importantly, however, during the years of focus in this study, producers of livestock receive indirect subsidies through subsidized irrigated fodder crops that are exploiting blue water which contains a non negligible share of Turkey's groundwater resources. This study aims at analyzing the effects of different subsidies on blue water intensity, agricultural land use and economic welfare within the Turkish economy. For this purpose, we couple a CGE model of Turkey with a water accounting module to measure both the economic and ecological impacts of livestock support measures, irrigated crop production, sectoral productivity and trade policies.

Our study shows that Turkey is paying a relatively high price for its present support to the livestock sector, both in economic terms and also in terms of the depletion of blue water resources. Direct subsidies paid to livestock producers make the livestock sector artificially more competitive and allocate additional water to livestock products that could be used more efficiently in agricultural products for which Turkey has a comparative advantage. Given that beef, dairy products and even roughage feed could be imported from the world market under relatively favorable conditions, the question arises as to whether policymakers should pay more attention to the full opportunity cost of current livestock sector support policies. However, as long as the political goals of higher national self sufficiency rates in beef and milk production remain important, there might be little room for a reduction in output-enhancing policy incentives.

Yet, our simulations show that without the subsidies paid to fodder crops, livestock producers would import feed from abroad while barely reducing livestock output levels. This means that domestic blue water resources could be spared and, assuming that imported fodder has a smaller blue water footprint than domestically produced fodder, the water footprint of Turkish livestock products would decline.

Moreover, we find that the removal of import tariffs on livestock products does not only benefit the welfare of consumers, but also increases the overall competitiveness of the Turkish economy. While a complete liberalization of the markets related to beef and milk products would increase prices and negatively affect welfare of consumers, irrigated agricultural land would be redirected toward the production of high value crops, for which Turkey is internationally more competitive, both in terms of the economic cost of production and its blue water footprint.

Our simulation results show that alternative policy options that aim at supporting modernization and technical efficiency improvements in the sector are an efficient way to increase livestock sector output while benefiting consumers and stimulating economic growth without major effects on the blue WFPs per unit of livestock sector output.

For policymakers, our analysis bears the conclusion that output- or input related agricultural policies may very well exhibit water-related effects even when irrigation or water use may not directly be the target by these policies. Policy makers may therefore increasingly have to consider not only direct effects of agricultural policies on domestic water use, but also potential indirect effects.

Finally, our analysis reveals the problems of using aged water footprint data that does not account for technical changes in agricultural production. Turkish agriculture has undergone both large increases in crop yields but also substantial irrigation expansion in recent years. We find that the increase in irrigation area dominates WFPs of Turkish agriculture leading to an enormous increase in the blue water use in the livestock sector due to the distorting direct and indirect livestock support policies.

## Data Availability Statement

The Economic data set for this research is available in these in-text data citation references: Aguiar et al. (2016), and can be purchased for a fee at: https://www.gtap.agecon.purdue.edu/databases/v9/default.asp. Detailed water footprint data is available in these in-text data citation references: Mekonnen and Hoekstra (2011), and can be downloaded for free at: https://waterfootprint.org/en/resources/waterstat/product-water-footprint-statistics/. Most recent water footprint data can be found in Muratoglu and Avanoz (2021) and we were kindly provided with the data by the authors. Other water footprint data is available in these in-text data citation references: Tamea et al. (2021), and can be downloaded for free at: https://www.watertofood.org/download/. The CGE model we use for our analysis is the IFPRI Standard CGE model, whose code is published here: https://www.ifpri.org/publication/standard-computable-general-equilibrium-cge-model-gams-0. Our newly developed water module (GAMS file) and the relevant input data (excel file) are publicly available here: Schuenemann (2022), https://doi.org/10.6084/m9.figshare.19486772.v1.

**Acknowledgments**
The authors would like to thank the editor, associate editor, and three anonymous reviewers for their constructive comments, which helped us to improve the paper. Open Access funding enabled and organized by Projekt DEAL.

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