Macroeconomics of Greening Turkish Agriculture

Ulaş Karakoç

Assistant Professor in Economics, Kadir Has University

ulas.karakoc@khas.edu.tr

Alp Erinç Yeldan

Professor in Economics, Kadir Has University

erinc.yeldan@khas.edu.tr

February 2025

99th Annual Conference of Agricultural Economics Society

University of Bordeaux

April 2025

Abstract

With the aid of an applied general equilibrium model, we study the macroeconomic effects of various policy alternatives to stimulate the implications of greening of Turkish agriculture. Our results suggest that the reduction in chemicals, fertilizers and oil at alternative rates of 30% and 50% would significantly reduce carbon emissions, but at the expense of adverse effects on agricultural output. In response, the negative effects on agricultural output can be reversed by a targeted investment programme that could facilitate technological change and a commensurate rationalization of the rural economy resulting in enhanced gains in agricultural productivity. We argue that the warranted funds towards such productivity enhancing investments can be earmarked by the introduction of a nation-wide carbon tax, and that they would boost not only agricultural output and rural incomes, but could also mitigate the adverse transition costs on GDP and social welfare.

Keywords: Sustainable Agriculture, European Green Deal, Green transition, CGE model, Turkish agriculture

JEL Codes: Q18, Q56

1. Introduction

Concerns over climate change, together with the observed upward trend in food prices and food-related health and environmental concerns, have recently positioned the rural economy at the front of environmental policy debates. The substantial contributions of the current farming systems to greenhouse gaseous emissions amalgamate these factors to reinforce a shift in food policy towards green transition. The EU's most recent *Farm to Fork* and *Biodiversity* strategies (*Strategies* hereafter) aim to decrease the use of pesticides, antimicrobials, mineral fertilizers, and fossil-fuels, and to increase biodiversity and organic areas (EC 2020a, EC2020b).

Understanding the effects of such major policy reorientations is immensely difficult, given the complexities due to the *global public good* characteristics of climate mitigation and the very insufficiency of the local, and often temporary, measures thereby advocated. Yet, using general and partial equilibrium models and relying on simplifying assumptions, researchers have attempted to explore the medium-long run economic impacts of transitioning to sustainable agriculture, as implied by the policy objectives of EU's *Strategies* (Beckman et al. 2020; Beckman et al. 2022; Barreiro-Hurle et al. 2021; Henning & Witzke 2021, Baquedano et al. 2023). These studies commonly indicate that this transition could reduce agricultural output and increase food prices, thus may reduce food security; though the magnitude of these effects varies based on model parameters, assumptions, and policy scenarios. Notably, most of this line of research has focused on the developed economies, with limited attention given to the auspices of the developing world. The unique challenges faced by the agricultural sectors of the developing economies —as characterized by smallholder farming, large rural populations, and low productivity— necessitate a closer examination of the implications of the input reductions in the context of development policy.

This article attempts to initiate such an investigation and studies the possible effects of green transition in Turkish agriculture on the macroeconomy at large with particular attention to agricultural output and formation of rural incomes and carbon emissions. We cast the problem within the discipline of general equilibrium analytics, and study two sets of green policy interventions (namely, (1) rationalization of input use in agriculture by reducing inputs of chemicals and fossil fuels; and (2) invigoration of a targeted rural investment programme to be financed by a nation-wide carbon tax) over Türkiye's rural economy with the aid of a computable general equilibrium (CGE) model.

The paper is organized as follows: Section 2 provides a general long-run assessment of agricultural output and employment, while discussing the current challenges in Turkish agriculture. Section 3 presents the details of our general equilibrium model and discusses the analytical results of the CGE simulations on agricultural output, GDP, farm incomes, GHG emissions, as well as other macro indicators. We investigate two complementary policy environments. First, our analysis suggest that a reduction in fertilizer and fossil fuel-based energy use (at alternative rates of 30% and 50%), would significantly reduce emissions, but also have adverse effects on the overall agricultural output. The overall effect on the farm incomes is, however, positive due to the improved terms of trade for agriculture. Furthermore, a commensurate rationalization of the sector, technical change, more efficient use of inputs and the resultant productivity increase would reverse such negative output effects. We argue that the warranted funds towards such productivity enhancing investments in the rural economy can be compensated by the introduction of a nation-wide polluter tax to be levied on the carbon-intensive energy resources. Section 4 discusses our results in relation to the existing literature on the economic effect of the EU's *Strategies,* and Section 5 concludes.

2. Long-run trends in agriculture

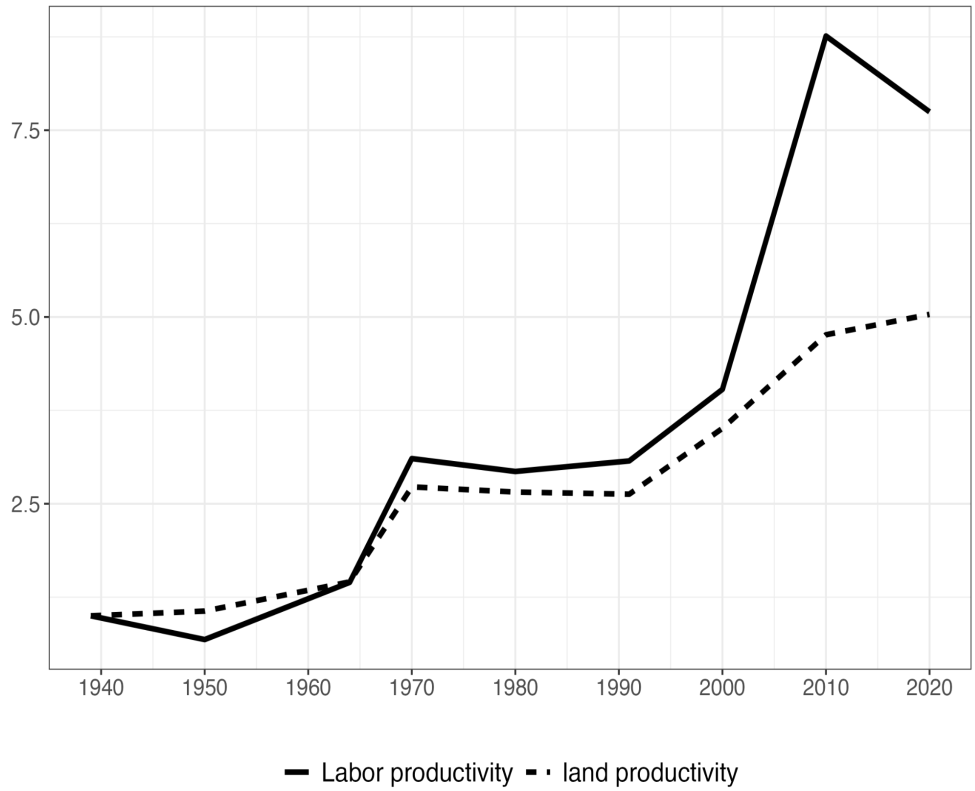
Türkiye is home to about two million small and medium-scale farmers. In 2021, agriculture, fishing and forestry were responsible for 6,3 percent of GDP and employed about 16 percent of the labor force. Despite the low labor productivity, the sector plays a prominent role in the national safety net, as it absorbs the labor surplus and provides direct access to food for poorer or low-income communities. Also, the country is in a geographical zone expected to face significant climate change, particularly the Mediterranean regions in the south.

Türkiye's total net greenhouse emissions in 2021 was 564.1 MtCO2, and 12.3 percent of it was due to the agricultural sector, almost equal to direct industrial production emissions. 19.23 MtCO2 of this sum was due enteric fermentation in animal husbandry, 5.14 MtCO2 by fertilizer consumption, 16.87 MtCO2 by the land use in farming (ÇŞB 2024). The ongoing policy initiatives aimed at enhancing agricultural efficiency and reducing carbon emissions are still very much in their infancy, and a comprehensive and well-structured policy framework has yet to be developed.

Türkiye has witnessed a profound structural change since the mid-twentieth century. The declining share of agriculture in both aggregate GDP and employment was evident and consistent over time. The output share decreased from 40 to 6.2 percent between 1939 and 2023, while the employment share declined even more dramatically from 81 to 14.8 percent. Behind this structural change lay, first, the rapid rural-urban migration that started in the 1950s and forcefully continued until the early 2000s. The relatively high wages in industry and services provided a decisive pull factor, while population growth in the countryside created a push effect. Second, the gains in land and labor productivity made it possible to keep up food production despite the population outflow (Figure 1). The intensified mechanization in the 1950s (*tractors)*, introduction of high-yielding wheat seeds in the 1960s, and the rise in public investment in irrigation after the 1980s all together led to the significant increase in land use intensity, multiple cropping, and large-scale use of chemical fertilizers and water, enabling higher land productivity.

The energy-intensive technical change significantly progressed beyond 1990 until 2010s. However, these trends have very recently slowed down. First, the cropped land has noticeably fallen since 2000, a fact is in line with trends in the countries such as Italy, Spain and Poland with agricultural sectors of comparable size (Ağır et al. 2023). The decline in land use has been the result of land loss, especially in urban and semi-urban areas, and the land use choices in favor of increasing efficiency by fully exploiting the fertile and irrigated lands at the expense of low-quality lands. The second challenge is the unfavorable demographic transition. The rural communities, mostly consisting of small medium-scale family enterprises, are aging, getting fragmented and vulnerable, and while it is hard to pin down due to the data constraints, the actual number of farmers are decreasing.

Figure 1 Indices of land and labor productivity

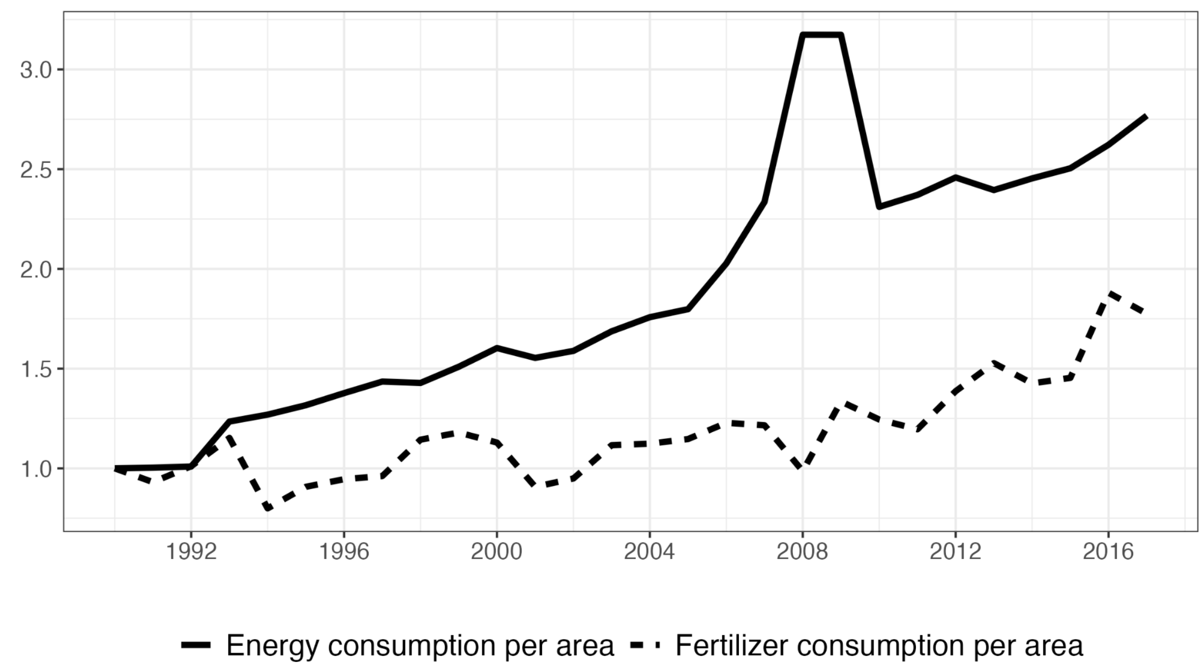


Under such circumstances, the bulk of farmers are under the strain of price and cost volatility, restricting the choices of inputs and technology to the short-term horizon. The urgency to keep debt service and sustain the immediate livelihood of the family along with the insufficient access to long-term credit and market opportunities, force farmers to switch to crops with higher immediate returns and to make excessive use of fertilizers and pesticides as tools to maximize their short-term yields, thereby largely ignoring considerations of sustainability.

The effects of climate change on agriculture can be understood given this context. On the one hand, climate change brings about persistent, yet unpredictable, changes in temperature, rainfall, and precipitation patterns. Farmers face varying patterns in many areas, so adaptation to the new patterns requires better knowledge, new techniques, capabilities, and a supportive organization and institutional environment (TOB 2021). Therefore, the underlying structural problems and climate change reinforce challenges to switch to the reduction in inputs and adoption of sustainable practices (Sen et al. 2012, Vanli et al. 2019).

Figure 2 remarkably shows that the energy consumption and fertilizer per unit of land increased by three and two-folds, respectively, over the last three decades. Most of the rise in energy consumption has been realized between 1990 and 2010, while fertilizer use particularly expanded after 2010. International comparisons reveal that while fertilizer consumption in Türkiye is still lower than in France, Italy, and Poland, the gap is narrowing down since 2000, because while the consumption per unit of area is declining in those countries, it has substantially increased in Türkiye (Ağır et al. 2023). Yet, it is possible to decrease fertilizer use by increasing fertilizer efficiency, pushing precision agriculture, and a more widespread use of biological methods without risking the physical output.

Figure 2 Indices of energy and fertilizer use per unit of area, 1990-2020 (1990=1)



There are significant structural challenges in developing sustainable agriculture in Türkiye, with the underlying patterns of land and labor use and the widespread small-holder farming setting major barriers. The current attempts of sustainable agriculture remain as insignificant and isolated, though, still exemplary incidences. The ongoing climate change aggravates these difficulties by creating a fast-changing environment, where action towards adaptation and transformation becomes more urgent.

3. Macroeconomics of greening the agricultural sector

3.1 Modeling the effects of the green policy alternatives in agriculture

In this section we develop an applied, national, comparative-static Walrasian general equilibrium model of the computable general equilibrium (CGE) genre to investigate two complementary strategic policies towards designing an efficient and sustainable agriculture. The model is applied to the Turkish economy to assess the impact of a selected number of green policy instruments and public policy intervention mechanisms, including market-based incentives.

The study is based on the 2014 macroeconomic balances of the Turkish economy, with a detailed focus on carbon emissions from energy combustion in agriculture and industrial sectors, and the relevant market instruments of abatement. The data sources are based on the Global Trade Analysis Project[1] (GTAP) –with Türkiye-focused as a direct separate entity against the rest of the world's global system of accounts, and the TurkStat Input-Output 2012 data updated to 2014 given 2014 national income accounts and household labor force survey data from TurkStat[2].

The model encompasses thirty sectors, twenty-one of which consist of agricultural activities. Some sectors directly refer to crop production, such as production of cereals, fruits, vegetables, and animal products. Oil, coal, and their products, as well as chemical products, including fertilizers, comprise the second group of sectors. Finally, manufacturing and services are represented as the broader sectoral categories. Crucially, our model separates the "fossil fuel" energy sources exclusively and accommodates land, capital, and labor to produce sectoral output along given neoclassical production functions.[3]

---

[1] https://www.gtap.agecon.purdue.edu/databases/v10/index.aspx

[2] https://data.tuik.gov.tr/

[3] Agriculture sector includes: *pdr* (Paddy rice), *wht* (Wheat), *gro* (Cereal grains), *V_f* (Vegetables, fruit, nuts), *osd* (Oil seeds), *c_b* (Sugar cane, sugar beet), *pfb* (Plant-based fibers), and *ocr* (Crops nec). Animal products sector comprises: *ctl*(Bovine cattle, sheep, goats), *oap* (Animal products nec), *rmk* (Raw milk), and *wol* (Wool, silk-worm cocoons). Forestry sector has *frs* (Forestry), while Fishing sector includes *fsh* (Fishing). Energy sector consists of:

The model relies on the background works to the Rio+20 conference laid by Bouzaher et al. (2015) and the WWF-IPC 2015 Report that was submitted to the COP21 Paris meetings (Voyvoda & Yeldan 2015). Antecedents of the model rest on the seminal contributions of the CGE analysis of gaseous pollutants, energy utilization, and economics of climate change for Türkiye (Acar et al. 2018, Acar & Yeldan 2016, Kolsuz & Yeldan 2017). Among other innovations in the specification of the production technology and environmental pollution, a major distinguishing feature of our approach is its accommodation of a detailed agricultural sub-sectoral structure with explicit recognition of chemical and fossil fuel dependency in the agricultural economy.

We distinguish labor, capital, and a composite of energy inputs (electricity, petroleum gas, and coal), together with other intermediate inputs, as the main factors of production. Emissions arising from production and consumption activities are modeled within the specification of the economic sectors. The basic model features are discussed in more detail below.

The *production structure* in each sector is specified using a nested production technology. At the top stage, gross output is produced through an augmented Cobb-Douglas technology capturing capital (K), labor (L), and intermediate inputs, along with fossil-fuel-based primary energy composite (ENG) as factors of production. In addition, the model accommodates land aggregate as an additional composite factor of production in agriculture. The aggregate agricultural land is further decomposed as a constant elasticity of substitution (CES) aggregation of irrigated and rain-fed land. This decomposition is responsive to rental rates of the type of land respectively, where the model endogenously solves the relative land use.

The *energy composite* is a separate CES aggregation of *renewables* and *fossil fuel products*. The latter is further decomposed into a CES aggregation of three energy inputs: petroleum, gas, and coal. This specification is designed to ensure utmost sensitivity to input price dfferentials and to accommodate fiscal interventions in the form of carbon pricing.

We distinguish mainly *gaseous emissions* from energy combustion (regarding CO2 equivalents) for environmental pollution and climate change indicators. The model calculates indicators for the

---

coa (Coal), *oil* (Oil), *gas*(Gas), and *P_c* (Petroleum, coal products). Food processing sector encompasses: *meat* (Meat products), *vol* (Vegetable oils and fats), *mil* (Dairy products), *pcr* (Processed rice), *Sgr* (Sugar), *Ofd* (Food products nec), and *B_t* (Beverages and tobacco products). The remaining sectors are: Chemicals with *Chm* (Chemical products), Electricity with *ely* (Electricity), Gas sector with *gdt* (Gas manufacture, distribution), Manufacturing with *Manuf* (Manufacturing), and Services sector with *ser* (Services).

agricultural (non-CO2) GHG emissions in the form of nitrous oxide, methane, and CO2 emissions. Indicators for non-CO2 emissions are based on input use and outputs from production activities.

For resolution of *income generation and consumption*, the private sector is aggregated as one representative household. Given her preferences and the household budget constraint, the representative household is assumed to choose a bundle of consumption goods that maximizes her utility. Household income comprises returns to labor input (net of social security taxes for formal labor), land rental income, and remittances of profits from the enterprise sector, including the payments to renewables used for electricity production.

In its account of the *government accounts*, the model closely follows fiscal budget constraints. We regard the government transfer items to the households, enterprises, and social security system as fixed ratios to government revenues net of interest payments. Then, under an assumed primary surplus/GDP ratio, public investment demand is settled as a residual variable to close the general fiscal accounts.

In terms of the components of *environmental policy*, we assume that a pollutant tax serves as one of the instruments and is introduced per tons of carbon dioxide emitted on production, intermediate input usage, and consumption, respectively. The revenues are directed into the revenue pool of the government budget, to be disseminated in turn, towards green investments in agriculture along the policy scenario analysis with the model.

Finally, the overall model is brought into *equilibrium* through endogenous adjustments of product prices and the *real* exchange rate to clear the commodity markets and balance the payment accounts. The spot exchange rate (spot conversion ratio of the world to domestic price indexes) serves as the *numéraire* of the system.

We utilize the latest 2012 I/O table produced by the Turkish Statistical Institute (Turkstat) as the basis for constructing and expanding our data set with the GTAP I/O database. The base year of the model economy is 2014, against which the comparative static policy scenarios are conducted. This consistent dataset of the 'base year' is further utilized to 'calibrate' the analytical model's sectoral and macroeconomic balances to the existing data. In doing so, we obtain values of structural parameters and exogenous variables of our algebraic equations.

For the base year, we derive GHG emissions (in CO2 equivalent terms) from sectoral production activities and fossil fuel input demand. Nationwide, a total of 451 million tons of CO2e is reported by TurkStat for 2014. This aggregate contains emissions due to energy combustion (260.1 million tons). Agriculture as a whole is responsible for a total of 50.6 mill tons of CO2 emissions. A standard Input/Output analysis reveals that of this sum, 47.6 mill tons are observed to be due to *direct production activities* (*scope 1*); and 1.05 mill tons is due to the usage of electricity in agricultural production (*scope 2*); with the rest 1.9 mill tones is due to *scope 3* emissions from intermediate input use in the rural economy. As for the demand-induced emissions, agricultural sectors generate a total of 26.9 mill tons of CO2 emitted in response to the aggregate demand it faces.

3.2 Policy scenarios towards a green agriculture

As an indispensable step towards attaining a *sustainable and climate friendly agriculture*, we first study the policy of reduction of chemicals (fertilizers, in particular) and fossil fuels (coal, gas, oil and petroleum products) usage in the sector. We simulate the scenario under two alternative rates of ambition, by 30% and 50%, respectively. This quantitative distinction is aimed at investigating the sensitivity of the policy results to the differential impact of the given policy intervention. In Scenario 2, we extend this base scenario by first introducing a taxation instrument to effectively price the carbon emitted to further reduce gaseous emissions; and then secondly, to study the returns from strategically earmarking the proceeds to enhance productivity of the agricultural sector and fund transitions to sustainable practices.

Mitigation measures towards reducing chemicals and fossil fuel usage in the rural economy is among the most strategic components of the most recent *Long-Term Climate Strategy* (UNFCC 2024) document which was developed under the coordination of the *Ministry of Environment, Urbanization, and Climate Change*. The *Climate Strategy* document explicitly calls for reducing methane emissions from livestock; ensuring efficiency in the use of chemical fertilizers; and minimizing the use of pesticides and antimicrobials. (UNFCC 2024, 16).

At a more general level, reduction of chemicals used in agriculture is also a well-discussed and articulated item within the *European Green Deal*. The two pillars of the EU's *Farm-to-Fork* and the *Biodiversity Strategy* for 2030 envision major adaptations along the whole food chain, from farming and processing to transportation and retail sectors. Specifically, they aim to achieve by

2030 a reduction of the sales of antimicrobials for farmed animals and chemical pesticides, nutrient losses in the environment by 50%, an increase of the agricultural land under organic farming by at least 25%, and a reduction of the use of chemical fertilizers by at least 20 percent. In view of the higher inefficiency, waste and large-scale use, we consider a 30% reduction in the use of fertilizers and chemicals in our medium-term scenario.

In their applied general equilibrium modeling analysis of the impact of climate change on the Turkish agricultural economy, Dudu and Çakmak (2013, 2018) report that the economic effects of climate change will not have serious economic effects over the short run, yet the negative effects dominate the economy over the post-2050s. Utilizing an integrated framework that combines an economy-wide CGE model with a crop water requirement model, Dudu and Çakmak found that the impact of climate change will likely be non-even across regions, and yet agriculture and food production will be adversely affected. Main drivers of the loss in GDP are found to be due to the significant decline in private consumption and up to two percent increase in imports. A trade liberalization scenario where tariffs on imports from the EU are eliminated unilaterally by Türkiye is also simulated to investigate the interaction between climate change and trade liberalization. The authors argue that these may provide Türkiye an excellent opportunity to increase resilience and to implement appropriate adaptation policies in the rural economy.

Thus, in line with the targets of *Farm-to-Fork* discussed above, our scenario presents an extension of this policy agenda to Turkish agriculture, and envisages two distinct rates of policy intervention, a moderate 30% *versus* a more ambitious 50% reduction rate. These targets should be considered as medium to long-run objectives in the context of Turkish agriculture. To implement the policy, we use the shadow price of the input usage constraint in the agricultural sector, and rely on the laboratory characteristics of our model to reimburse the shadow tax monies back to private households in a lump sum manner (so as not to generate neutral fiscal effects on aggregate GDP). The institutional design of this policy move is beyond the confines of this study. However, we would like to note that our upper target of 50 percent reduction in the use of chemical fertilizers alone would mean going back to the level of 1990 for Türkiye in fertilizers per unit of cropped area (see Figure 2 above). Such a comprehensive reversion will, no doubt, necessitate substantial increases in the efficiency in fertilizer and fertilizers use, and the introduction of renewable energy sources in agriculture.

Table 1 presents the main macroeconomic results of the model simulations under the scenarios in two reduction rates displayed under two separate columns. Assuming that the policy is implemented in full, the model solutions suggest a fall of 1.6% (under 30% reduction) versus 4.5% (under 50% reduction) in real agricultural output, relative to the base equilibrium. That corresponds to a decrease from 55,241 million US$ to 54,370 million US$ with the 30% reduction in contrast to 52,737 million US$ with the 50% reduction -all in 2014 fixed prices. On the other hand, the scenario does not predict any significant impact on the industrial sector. One major reason is that Türkiye, being a significant importer of fertilizers and energy, the domestic industrial activity is minimally affected by the direct decline of intermediate input demand from the agricultural sector. The effects on sectoral employment are broadly in line with the simulated changes in real output, yet their magnitudes are smaller.

Table 1 Macroeconomic Aggregates (Millions US$) under Alternative Policy Scenarios

		Ratios to Base Equilibrium		
		Scenario 1: Reduce Chemical & Fossil Fuel Inputs		Scenario 2: Scenario 1 + productivity enhancing investments in Agriculture financed by a carbon tax
	Base Equilibrium	Reduction by %30	Reduction by %50	Reduction by %50
Real Output (Millions US$)				
Agriculture	55,241.0	0.984	0.955	1.131
Industry	538,025.7	0.995	0.992	0.956
Services	898,400.7	0.999	0.998	0.993
Index Total Employment (Thousand persons)				
Agriculture	100.00	99.18	97.57	106.35
Industry	100.00	99.88	99.96	97.50
Services	100.00	100.11	100.24	100.06
Aggregate Rural Real Factor Income (Millions US$)	31,657.8	1.033	1.042	1.128
Real Wage Rate Index	100.00	99.83	99.62	99.95
Real Profit Rate Index	100.00	100.16	100.19	100.11
Real GDP (Millions US$)	798,536.3	0.999	0.997	1.000
Aggregate Social Welfare	127,318.6	0.999	0.997	1.001
Real Pivate Disposable Income	672,666.4	0.999	0.997	1.000
Aggregate Real Investment	165,487.5	0.999	0.999	1.027
Aggregate real Private Consumption	566,472.8	0.999	0.997	0.993
Aggregate Real Government Consumption	125,869.9	0.999	0.999	0.999
Real Public Sector Revenues	280,476.9	0.998	0.995	1.009
Exports	155,812.7	0.993	0.987	0.956
Imports	245,119.5	0.995	0.992	0.968

While the agricultural output is estimated to decline, we find the aggregate rural incomes to increase. This is mainly the result of improved rural terms of trade in response to reductions in agricultural output. In other words, higher farm prices because of contracting agricultural supply leads to higher incomes, given rising farm prices. Nevertheless, those who gain are mainly the land and capital owners due a rise in the rate of profit, therefore effectively the bulk of the small and medium family farm business that own land. Overall, the remaining macro aggregates do not experience much significant change.

As a result of reduced fertilizer and fossil fuel use, agriculture succeeds in reducing its overall carbon emissions per dollar value added. From an initial base value of 179.9 kg/$, CO2 emission intensity falls to 128.3 kg/$ and to 94 kg/$ under the 30% versus 50% reductions, respectively. However, the total impact of this sectoral gain is rather mediocre, as aggregate CO2 emissions from energy deployment in the domestic economy is reduced only by 1.5% (256 million tons) versus 2% (254 million tons) under the 30% versus 50% reductions. (See Table 3 below).

Against all this, across the sub-sectors in agriculture, we observe substantial variations in output responses (Table 2). The implemented scenario results in output fall of *crops* (4.8% versus 12.7%), *wool* (6.5% versus 16.2%), *plant-based fibers* (6.8% versus 17.2%) and *vegetables* (2.8% versus 8.1%). Output declines in the remaining agricultural goods range around 1.5-2%. Similar adjustments in employment accompany the downward adjustments of sectoral output, yet to conserve space we only note in passing that the most significant employment loss is observed in *crops* (4.3% versus 11.4%), *wool* (5.5% versus 13.2%), and *plant-based fibers* (3.1% versus 7.9%). The range of predicted employment responses is comparable to those for the output responses.

Table 2 Sectoral Output Responses under Alternative Policy Scenarios

		Scenario 1: Reduce Chemical & Fossil Fuel Inputs		Scenario 2: Scenario 1 + productivity enhancing investments in Agriculture financed by a carbon tax
	Base Equilibrium	Reduction by %30	Reduction by %50	Reduction by %50
Paddy rice	100.00	98.60	95.80	113.85
Wheat	100.00	99.00	96.90	111.62
Cereal grains nec	100.00	98.52	95.48	107.81
Vegetables, fruit, nuts	100.00	97.21	91.97	112.00
Oil seeds	100.00	98.22	94.69	116.48
Sugar cane, sugar beet	100.00	98.68	95.89	105.00
Plant-based fibers	100.00	93.22	82.85	92.10
Crops nec	100.00	95.20	87.29	179.50
Bovine cattle, sheep and goats	100.00	99.44	98.27	117.99
Animal products nec	100.00	99.42	98.26	115.31
Raw milk	100.00	99.51	98.44	108.48
Wool, silk-worm cocoons	100.00	93.58	83.79	142.79
Forestry	100.00	99.53	98.94	107.55
Fishing	100.00	98.70	96.15	108.00

The impact of Scenario 1 on aggregate CO2 emissions appears trifling. Table 3 below reveals that the aggregate emissions in energy combustion are reduced at a minimal rate by only 4 to 6 million tons, from 260 to 256 versus 254 million tons. To put it into context, these gains came at the expense of a fall in agricultural output on the order of 1.6 to 4.5%.

In Scenario 2, on top of the input reduction in agriculture in the first scenario, we further introduce a *hybrid strategy* of environmental abatement *cum* an agricultural investment programme to enhance rural productivity. In formal terms, we first introduce an explicit carbon tax on CO2 polluters to combat gaseous emissions at the nation-wide level. The tax monies are earmarked towards an agricultural investment fund to increase agricultural technical efficiency. We implement this by an exogenous 1% increase of the agricultural output productivity, which, we argue, is to be achieved by a combination of land and labor-saving technical change such as precision agriculture, sustainable agriculture, and re-organization of the farming economy. The importance of attaining productivity gains in the rural economy is strongly argued also in Beckman et al. (2022) who note that, if successful productivity enhancing mechanisms can be enacted under the EU's *farm to fork strategy*, adverse market effects could be lessened; and yet, these will necessarily call for increased investments.

Table 3 Environmental Indicators under Alternative Policy Scenarios

		Scenario 1: Reduce Chemical & Fossil Fuel Inputs		Scenario 2: Scenario 1 + productivity enhancing investments in Agriculture financed by a carbon tax
	Base Equilibrium	Reduction by %30	Reduction by %50	Reduction by %50
Index of Chemicals & Fossil Energy Use In Ag-Sectors	100.00	70.00	50.00	50.00
Total CO2 Energy Related (Mill Tons)	260.183	256.561	254.169	224.136
Total CO2/GDP (kg/$GDP)	325.8	321.3	318.5	279.0
CO2 Emissions in Agriculture (Mill tons)	9.937	6.978	5.005	5.000
CO2 Emissions in Industry&Services (Mill tons)	250.246	249.583	249.164	219.137
CO2 Emissions Intensity in Agriculture (kg/$)	179.9	128.3	94.9	80.0
CO2 Emissions Intensity in Industry&Services (kg/$)	174.2	174.2	174.2	155.8
Total CO2 Taxes (Millions US$)				6092.030
Total CO2 Taxes to GDP (%)				0.76
Marginal Abatement Cost of CO2 taxes in US$ per ton				0.17

Under the current scenario we advocate the use of carbon tax monies to provide funds towards such investments and avoid adding extra burden on the fiscal balances. The carbon tax is imposed on an *ad valorem* basis as a ratio of the demand for fossil fuels (coal, oil, petroleum, gas, and gas manufacturing) as differentiated by the energy users. We utilize the more ambitious case of 50% chemicals and fossil fuel input reduction to complement the tax policy. We administer the tax rate as 10% of the value of (fossil fuel-based) energy input demanded. The scenario results are displayed under the "Scenario 2" identifier in Tables 1-3.

In this combined scenario, the aggregate energy-related emissions decline by 13.8% from 260 to 224 million tons. The significant bulk of this reduction originates from the non-agricultural sectors (by 12.4%). CO2 emissions intensity is reduced from 179.9 kg/$ to 80.0 kg/$ in agriculture, and from 174 kg/$ to 155.8 kg/$ in industry and services sectors (Table 3). The model also predicts that the carbon tax remunerations will amount to, on average, 0.76% of the GDP. The *marginal abatement cost* (MAC)[4] is calculated at 17 cents per ton of CO2 reduced due to the carbon tax. Our detailed sectoral results (that we do not report in further detail due to space limits) show that coal and gas combustion emissions are reduced roughly by 12% each, from 107 to 94 million tons in coal, and from 68 to 60 million tons in gas.

[4] MAC calculates the cost to the domestic economy (as a result of imposition of the carbon tax in US$) due to 1 ton of reduction achieved in aggregate emissions.

The effects on agricultural output are positive. The sectors that gain the most are *crops* (79.5%) and *wool* (42.8%). Overall, the agricultural economy expands by 13.1%, pulling in an extra employment gain of 6.3%. The expansion of the agricultural sector pulls resources out of the urban economy, thereby reducing opportunities in industry in the short run (upon impact).

Furthermore, with increased efficiency gains, agriculture recovers the potential decline of the GDP, and of social welfare (measured as unit equivalent variation of the households' aggregate utility). The implementation of the carbon tax (that asymmetrically affects industry) and diversion of domestic resources into the rural economy leads to a decline in industrial output around 4.4%. This suggests that a *new targeted industrial strategy* should be on the policy agenda in the medium to long run to complement the gains in the agricultural economy. Finally, the wage and profit rates are minimally affected (even though wage labor becomes worse off slightly), and the foreign economy shrinks, as exports fall by 4.4% and imports by 3.2%. This is primarily due to the decline in industrial activity given its relative openness.

4. Discussion

All in all, we find that significant gains in GhG emissions in Türkiye's agriculture can be achieved through the reduction of chemicals, fertilizers and oil use, albeit at the expense of a decline in agricultural output on the range of 1.6 - 4.5 percent, and in GDP on the range of 0.1 - 0.3 percent (Table 1). In contrast, farm incomes are estimated to increase by 3.3 - 4.2 percent due to the rise in food prices enabling more favorable terms of trade for agriculture. In what follows, our simulations show that the negative effects on agricultural output can be reversed by a targeted rural investment programme that could facilitate technological change along with a one-time permanent 1 percent TFP growth in agriculture. In order to neutralize the potential pressures of the given rural investment programme on fiscal balances we envisage a nation-wide carbon tax to be implemented at 10%. We find that such a productivity boost could not only expand agricultural output and employment, but it could also mitigate the negative effect on GDP and social welfare. However, the combined effect of these interventions on industrial output remains negative, as this policy mix implies a net shift of resources away from industry towards agriculture in the absence of productivity changes in the urban economy.

Under the auspices of her *Long-Term Climate Strategy* document (UNFCC 2024) Türkiye plans to invest approximately $59 billion in renewable energy, $2.5 billion in energy storage, $4.1 billion in demand-side participation by 2035, and $20.2 billion in energy efficiency by 2030. Within this framework, it is anticipated that additional investments needed in sectors such as energy, buildings, services, industry, transportation, agriculture, and forestry should reach an annual average of at least 1.7% of national income compared to the current scenario where pre-Plan trends continue (UNFCC 2024, 46-48). Accordingly, "The use of pesticides and antimicrobials will be reduced, and the use of alternative products will be promoted. Biological and biotechnical control methods will be supported and promoted. The use of organic (such as farmyard manure, compost) and organo-mineral fertilizers will be increased through subsidies, and the solid-liquid fermented products from biogas plants, as well as all kinds of organic waste, will be utilized in the production of green fertilizers and compost. Infrastructure investments will be supported to promote the use of agricultural and other organic wastes in the form of compost fertilizer. By 2053, at least 10% of cultivated agricultural land will be used for organic farming". (UNFCC 2024, 44)

The aforementioned target of 1.7% increase in the investment / GDP ratio can be contrasted with our productivity enhancing investment fund reported by the model simulations found at 0.75% (see Table 3 above). A further contrast can also be made against the World Bank's *Türkiye Country Climate Development Report* (WordBank 2022) which had set the annual necessary green investments to the order of US$11- 12 billions, approximately 0.9% to the current GDP.

Our findings are mostly in line with the other available studies of comparable supply-side interventions towards sustainable agriculture. Using a CGE model, Beckman et al. (2020) run a range of medium-long run simulations of the EU's Strategies (substantial reduction in pesticides, antimicrobials, fertilizers and the expansion of the organic and biodiversity areas), and report that (i) the aggregate agricultural output loss would be within the range of 7-12 percent; (i) agricultural prices would increase, (iii) the EU's competitiveness would decline for most products, and (iv) EU's GDP would decline by 0.3 percent. Our findings for the magnitude of the decline in agricultural output and GDP are comparatively more reserved than the estimates of Beckman et al. (2020), the reason being mostly be due to the fact that the simulated intervention in the present study is limited to the use of chemicals and oil, while Beckman et al. (2020) further consider the expansion of organic and biodiversity areas, as well. In particular, the lower yields in the organic production could contribute to the higher decline in the crop output.

Barerio-Hulle et al. (2021) investigate the market and environmental effects of *the Strategie*s combined with several scenarios regarding the reforms in Common Agricultural Policy (CAP), using the CAPRI model (a global partial equilibrium model designed to study the effects of CAP). They find that, without ambitious CAP reforms, the decline in agricultural output and GHG emissions would be substantial. Crucially, they underline that the carbon leakage to the rest of the world would be significant, undermining the rationale of *the Strategies* for lowering the total carbon emissions. In a similar vein, Bremmer et al. (2021) and Henning and Witzke (2021) also reach similar conclusions regarding output and prices via variants of partial equilibrium models combining farm-level expert views and global trade.

Notably, latter studies, utilizing methods of partial equilibrium modeling, do not report on the net effect on the resulting farm incomes, yet, they predict a negative effect, which appears in conflict with the results of the CGE modelling as in Beckman et al. (2020) and in the present work. Henning and Witzke (2021) argues, however, given sufficiently inelastic EU demand, the disproportionate price effects could increase the farm value added (particularly for animal rather than crop products), emphasizing the so-called *reverse treadmill effect*.

On the other hand, the ways the developing economies could experience the input reductions in agriculture are yet to be explored. Beckman et al. (2021) investigates the effects of the *Strategies* on several low-medium income countries under alternative scenarios. The comprehensive simulations provide a sense of how the effects depend on whether the scope of the adoption of Strategies. If the adoption is limited to the EU, they may gain from higher international food prices, and decline in the competitiveness of the EU, however, once they also need to adopt the input reductions, voluntarily or because of the trade restrictions of the EU, they are also expected to experience similar effects. Baguedano et al. (2023) reinforces these findings emphasizing that the global adoption of the Strategies would lead to increase in food security in developing economies, if the input reductions are not accompanied by mitigation mechanisms.

In an effort to counteract the estimated unfavorable effects of *the Strategies* on prices, output, and possible food security, the existing studies commonly emphasize the role of technical change and productivity. Henning and Witzke (2021), deeming the objectives of *the Strategies* as “inconsistent” with the underlining the current consumption and agricultural production patterns in the EU, argues that the prevention of carbon leakage depends on agricultural adaptation by means of technical change, as well as the reduction in food waste, and trade policy interventions to prevent the production shifts to the rest of the world. Wesseler (2022) points out that a necessary way to mitigate the negative effects of *the Strategies* is provision of technical change and increased productivity in farming. Noleppa (2021) underlines the potential effects of the plant breeding on food security.

More specifically, Beckman et al. (2022) suggest simulation results on the productivity growth needed to counteract the output losses. Their model simulations show that social welfare loss is significantly mitigated by the total TFP growth on the order of 9 - 48 percent, varying for different crops, and it would take 9 to 27 years to achieve the desired levels of productivity, if the historical trends are taken as a benchmark. Our results of Scenario 2 in the present work is also an attempt to quantify the potential effect of a reasonable permanent TFP growth in agriculture. We show that one-time, across-the-board and permanent 1 percent growth in productivity would suffice to reverse the fall in aggregate social welfare and GDP.

The ways in which such productivity growth could be achieved is beyond the scope of this study. Nevertheless, Turkish agriculture is notoriously a sector burdened by inefficiencies due to the market failures in product and credit markets, inadequate access to information and technology, land fragmentation and the lack of organizational and institutional structures warranted to provide a coherent environment for innovation. In a long-term study of the TFP growth in Türkiye, Altuğ et al. (2008) report that the average TFP growth in agriculture between 1980-2005 had been 0.82 percent, whereas it was 1.03 % for the non-agricultural sectors, close to the average of the 1950-2005 period. In a more detailed study, Atiyas and Bakış (2014) documents increasing average TFP growth from the 1990s (0.76%) to the 2000s (2.49%). This is in line with the pattern of the change of average land and labor productivity in the last three decades (Figure 1). It seems that the upward trend in all productivity measures peaked in the 2000s. Therefore, further increases in productivity growth, as envisaged in Scenario 2, would require major reduction of inefficiencies and an investment spurt towards a technical change using less-inputs and more technology to keep in line with sustainable agriculture.

5. Conclusion

The structural challenges outlined in this study can be generalized to many developing economies which have undergone substantial structural change and rural-urban migration in the second half of the twentieth century. The rise in land productivity, thanks to better seeds, irrigation, mechanization and fertilizers, enabled them to keep food prices low and supported industrialization. On the other hand, agricultural intensification led to adverse environmental effects, such as land degradation, nutrient loss, water and soil contamination, and contributed to global carbon emissions. Although the challenges in the way of sustainable transformation of agriculture are complex and unprecedented, we argue that there exist viable policy frameworks that can be combined in a way to stabilize the food supply, decarbonize the food production, and even increase the farm incomes. A significant reduction in chemicals, fertilizers and oil use would have non-negligible adverse macro effects, yet such effects can be reversed by increasing the efficiency of agriculture with the implementation of a well-financed, rural investment programme.

It ought to be clear that the magnitude of the existing challenges necessitates a significant overhaul of agricultural and agro-industrial policies. Crucially, the policy framework should prioritize bolstering the resilience and adaptability of small and medium-scale family farms. This necessitates an approach encompassing technological and financial innovations, coupled with the creation of novel organizational and institutional structures in rural areas.

In our analysis we only focused on gaseous pollution and considered only a limited range of tools to mitigate the negative effects of the supply-side restrictions of the use of chemicals, mineral fertilizers, and oil. A more direct policy should accompany organic, conservationist or regenerative practices to reinforce both the reduction of GHG emissions and counteract potential yield losses.

Not least, we do not consider the role of consumption patterns that could potentially provide a powerful mitigation method. Guagamard (2023), Schiavo et al. (2023) and Boix-Fayos et al. (2023) rightfully point out that it is hard to prevent the adverse effects of *the Strategies* or any other supply-side agri-environmental policy on the food security without major changes in the food regime, perhaps more notably, in the consumption preferences skewed towards processed food industries under the prevailing subsidy and incentive systems that otherwise encourage these preferences.

A final caveat to share with respect to our modelling efforts on climate change is that we do not report on the c*ounterfactual*, that is, what would have happened with unabated climate change? Yet, it has been underlined in many instances that without concerted action to address climate change, agricultural output would be even lower, food prices even higher, and food security even worse. According to a study by SwissRe, for example "*the world stands to lose close to 10% of total economic value by mid-century if climate change stays on the currently-anticipated trajectory, and the Paris Agreement and 2050 net-zero emissions targets are not met*" (SwissRe 2021). The ultimate remaning question, thus, is not whether or not we ought to take action; but rather, how and when?

References

Acar, Sevil, Ebru Voyvoda, and Erinç Yeldan. 2018. *Macroeconomics of Climate Change in a Dualistic Economy: A Regional Computable General Equilibrium Analysis*. Amsterdam: Elsevier.

Acar, Sevil, and Erinç Yeldan. 2016. "Environmental Impacts of Coal Subsidies in Türkiye: A General Equilibrium Analysis." *Energy Policy* 90: 1-15.

Ağır, Seven, Ulaş Karakoç, and Aylin Topal. 2023. *Yeşil Dönüşüm ve Türkiye'de Gıda ve Tarım Sektörü*. Istanbul: Maliye Hesap Uzmanları Vakfı Yayınları.

Altuğ, Sumru, Alpay Filiztekin, and Şevket Pamuk. 2008. "Sources of Long-Term Economic Growth for Turkey, 1880-2005." *European Review of Economic History* 12 (3): 393-430.

Atiyas, İzak, and Ozan Bakış. 2014. "Aggregate and Sectoral TFP Growth in Turkey: A Growth Accounting Exercise." *İktisat İşletme ve Finans* 29 (341): 9-36.

Baquedano, Felix, Jeremy Jelliffe, Jayson Beckman, Maros Ivanic, Yacob Zereyesus, and Michael Johnson. 2022. "Food Security Implications for Low- and Middle-income Countries under Agricultural Input Reduction: The Case of the European Union's Farm to Fork and Biodiversity Strategies." *Applied Economic Perspectives and Policy* 44 (4): 1942-54.

Barreiro-Hurle, Jesus, Mariia Bogonos, Mihaly Himics, Jordan Hristov, Ignacio Perez Dominguez, Amarendra Sahoo, Guna Salputra, Franz Weiss, Edoardo Baldoni, and Christian Elleby. 2021. "Modelling Environmental and Climate Ambition in the Agricultural Sector with the CAPRI Model." JRC121368. Joint Research Centre (Seville site).

Beckman, Jayson. 2020. *Economic and Food Security Impacts of Agricultural Input Reduction Under the European Union Green Deal's Farm to Fork and Biodiversity Strategies*, EB-30. Washington, DC: U.S. Department of Agriculture, Economic Research Service.

Beckman, Jayson, Maros Ivanic, and Jeremy Jelliffe. 2022. "Market Impacts of Farm to Fork: Reducing Agricultural Input Usage." *Applied Economic Perspectives and Policy* 44 (4): 1995-2013.

Boix-Fayos, Carolina, and Joris De Vente. 2023. "Challenges and Potential Pathways towards Sustainable Agriculture within the European Green Deal." *Agricultural Systems* 207 (April): 103634. https://doi.org/10.1016/j.agsy.2023.103634.

Bouzaher, Alex, Şebnem Şahin, and Erinç Yeldan. 2015. "How to Go Green? A General Equilibrium Investigation of Environmental Policies for Sustained Growth with an Application to Türkiye." *Letters in Spatial and Resource Sciences* 8 (1): 49-76.

Bremmer, Johann, Ana Gonzalez-Martinez, Roel Jongeneel, Hilfred Huiting, Rob Stokkers, and Marc Ruijs. 2021. "Impact Assessment of EC 2030 Green Deal Targets for Sustainable Crop Production." Wageningen Economic Research Report no. 150, December.

Çevre ve Şehircilik ve İklim Değişikliği Bakanlığı (ÇŞB). 2024. *İklim Değişikliği Azaltım Stratejisi ve Eylem Planı 2024-2030*. Ankara: T.C. Çevre ve Şehircilik ve İklim Değişikliği Bakanlığı.

Dudu, Hasan, and Erol Çakmak. 2018. "Climate Change and Agriculture: An Integrated Approach to Evaluate Economy-wide Effects for Türkiye." *Climate and Development* 10 (3): 275-288.

Dudu, Hasan, and Erol H. Cakmak. 2013. "Climate Change, Agriculture and Trade Liberalization: A Dynamic CGE Analysis for Türkiye." EconAnadolu 2013: Anadolu International Conference in Economics III. http://dx.doi.org/10.2139/ssrn.2384476.

European Commission (EC). 2020a. "A Farm to Fork Strategy for a Fair, Healthy and Environmentally-Friendly Food System." COM(2020)381. Brussels: EC.

European Commission (EC). 2020b. "EU Biodiversity Strategy for 2030. Bringing Nature Back into Our Lives." COM(2020)380. Brussels: EC.

Guyomard, Hervé, Louis-Georges Soler, Cécile Détang-Dessendre, and Vincent Réquillart. 2023. "The European Green Deal Improves the Sustainability of Food Systems but Has Uneven Economic Impacts on Consumers and Farmers." *Communications Earth & Environment* 4 (1): 358.

Henning, Christian, and Peter Witzke. 2021. "Economic and Environmental Impacts of the Green Deal on the Agricultural Economy: A Simulation Study of the Impact of the F2F-Strategy on Production, Trade, Welfare and the Environment Based on the CAPRI-Model."

Kolsuz, Güneş, and A. Erinç Yeldan. 2017. "Macroeconomics of Greening: A General Equilibrium Investigation for Türkiye." *Renewable & Sustainable Energy Reviews* 70: 1240-1250.

Noleppa, Steffen, and Matti Cartsburg. 2021. "The Socio-Economic and Environmental Values of Plant Breeding in the EU and for Selected EU Member States. An Ex-Post Evaluation and Ex-Ante Assessment Considering the 'Farm to Fork' and 'Biodiversity' Strategies." HFFA.

Schiavo, Michele, Chantal Le Mouël, Xavier Poux, and Pierre-Marie Aubert. 2023. "The Land Use, Trade, and Global Food Security Impacts of an Agroecological Transition in the EU." *Frontiers in Sustainable Food Systems* 7: 1189952.

Sen, Burak, Sevilay Topcu, Murat Türkeş, Baha Sen, and Jeoren F. Warner. 2012. "Projecting Climate Change, Drought Conditions and Crop Productivity in Türkiye." *Climate Research* 52 (March): 175-91.

SwissRe Institute. 2021. "The Economics of Climate Change: No Action Not an Option." April. https://www.swissre.com/dam/jcr:e73ee7c3-7f83-4c17-a2b8-8ef23a8d3312/swiss-re-institute-expertise-publication-economics-of-climate-change.pdf.

Tarım ve Orman Bakanlığı Tarım Reformu Genel Müdürlüğü (TOB). 2021. *İklim Değişikliği Değerlendirme Raporu*. Ankara: TC Tarım ve Orman Bakanlığı.

UNFCC. 2024. "Türkiye 2053 Long Term Climate Strategy." https://unfccc.int/sites/default/files/resource/Turkiye_Long_Term_Climate_Strategy.pdf.

Vanlı, Ömer, Burak Berk Üstündağ, Ishfaq Ahmad, Ixchel M. Hernandez-Ochoa, and Gerrit Hoogenboom. 2019. "Using Crop Modeling to Evaluate the Impacts of Climate Change on Wheat in Southeastern Türkiye." *Environmental Science and Pollution Research* 26 (28): 29397-408.

Voyvoda, Ebru, and Erinç Yeldan. 2015. "Greening Turkish Economy: A General Equilibrium Investigation of Environmental Policies for A Low Carbon Growth Path." Report prepared for the Istanbul Policies Center and World Wild Foundation (WWF-Türkiye).

Wesseler, Justus. 2022. "The EU's Farm-to-Fork Strategy: An Assessment from the Perspective of Agricultural Economics." *Applied Economic Perspectives and Policy* 44 (4): 1826-43.

World Bank. 2022. *The Country Climate and Development Report, Türkiye*. Washington, DC: World Bank.