Innovative and Sustainable Groundwater Management in the Mediterranean

D4.4 Report on Simulation-Based Scenario Analyses and Policy Design

VERSION 1.0

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Executive Summary

The overall objective of the InTheMED project is to implement innovative and sustainable management tools and remediation strategies for MED aquifers (inland and coastal) in order to mitigate anthropogenic and climate-change threats by creating new long-lasting spaces of social learning among different interdependent stakeholders, NGOs, and scientific researchers in five field case studies, located at the two shores of the MED basin, namely in Spain, Greece, Portugal, Tunisia, and Turkey.

InTheMED will develop an inclusive process that will establish an ensemble of innovative assessment and management tools and methodologies including a high-resolution monitoring approach, smart modelling, a socio-economic assessment, web-based decision support systems (DSS) and new configurations for governance to establish efficient and sustainable integrated groundwater management in the MED considering both the quantitative and qualitative aspects.

The objective of Deliverable 4.4 is to document the findings of the simulation-based scenario analyses and share the lessons learnt from different sets of policies designed based on multiple perspectives. To fulfil this objective, this document first summarizes the structure of the dynamic simulation model, and then presents the behaviour of key system variables under different policy options, as they were put forth in the living labs. Lastly, the policies are integrated into various policy sets and their relative performance are discussed based on environmental and economic indicators.

1. Introduction

This is the documentation of D4.4 of the "Innovative and Sustainable Groundwater Management in the Mediterranean" Grant Agreement Number 1923 project. In this deliverable we report the outputs of the simulation-based scenario analyses and policy design.

1.1. Research Purpose and Design

Konya Closed Basin is a semi-arid watershed located in Central Anatolia, Turkey. It is well known for its agricultural production potential; however, the lack of sufficient surface water supply render groundwater a vital element for the continuation of irrigated agriculture. The unsustainable use of groundwater in the basin resulted in a steeply declining groundwater level over the last 50 years. The drivers of unsustainable groundwater consumption in the basin and a social-economic system characterization of Konya Closed Basin are reported by Saysel et al. (2021).

A dynamic simulation model was built to explore the drivers of unsustainable groundwater use and to build a shared understanding of sustainable pathways for the future in the Çumra district of Konya Closed Basin. To that end, a participatory system dynamics methodology was adopted (Saysel et al., 2022a); the research team organized two field trips to get to know and to initiate a conversation with the relevant stakeholders in the field, and then organized three participatory model building workshops, i.e., living labs. Throughout the living labs, first a conceptual model was developed which was converted into a seed model (Saysel et al., 2022b; Saysel et al., 2022a). Then, the researchers continued to further develop the model and translate the conceptual model into a numerical model (Saysel et al., 2022c). In the last living lab, the final version of the numerical model was shared with the participants through a user-friendly interface designed to communicate the model findings with the public in a simple, easy-to-understand manner (Saysel et al., 2023).

1.2. Dynamic Simulation Model

The dynamic simulation model was built on Stella Architect; the model operates on a yearly basis (i.e. the model time unit is a year), and simulates the period 2004-2044. The numeric simulation of the model is in continuous time (i.e. computational interval less than or equal to 2^{-1}) with Euler's method.

Figure 1 shows the main feedback overview of the model. How much to irrigate each crop is one of the most prominent decisions in the model. Irrigating a crop more results in higher yields, which boosts the income and profit of farmers. But when they draw more groundwater from the aquifer, the groundwater level drops, pumping costs rise, and correspondingly, the profit shrinks. The second important decision in the model is land allocation. Farmers choose how much land to spare for each crop-land use option in the model, based on the relative attractiveness of crops, given that the total amount of land available for agriculture is assumed to remain constant during the simulation period. The profitability of each crop variety is a key factor in determining its attractiveness, because farmers' main objective is to maximize their profits. In the end, how much a farmer decides to irrigate each crop and how much area is allotted to it will determine the desired groundwater extraction. These connections are seen in Figure 1's R1 and B1 loops. While the former encourages extraction, the latter limits it due to financial viability. On the other hand, there are additional factors that can prevent extraction from going up indefinitely. First, there is a physical limit; if the aquifer's water supply is depleted, further extraction is not feasible, as seen in the B2 loop. Additionally, the capacity of the available pumping infrastructure, such as the groundwater wells and the pump power, places a limit on the volume of extraction. The annual extraction capacity is defined by the number of active wells and the average well yield because one cannot extract an infinite amount of water from a well over a certain period of time. Under equal conditions, the average well yield drops as groundwater head declines owing to extraction, as shown in the B3 loop. Therefore, more wells are constructed, and pump power is raised to meet demand, anytime the current infrastructure is unable to do so (R2 and R3 loops).

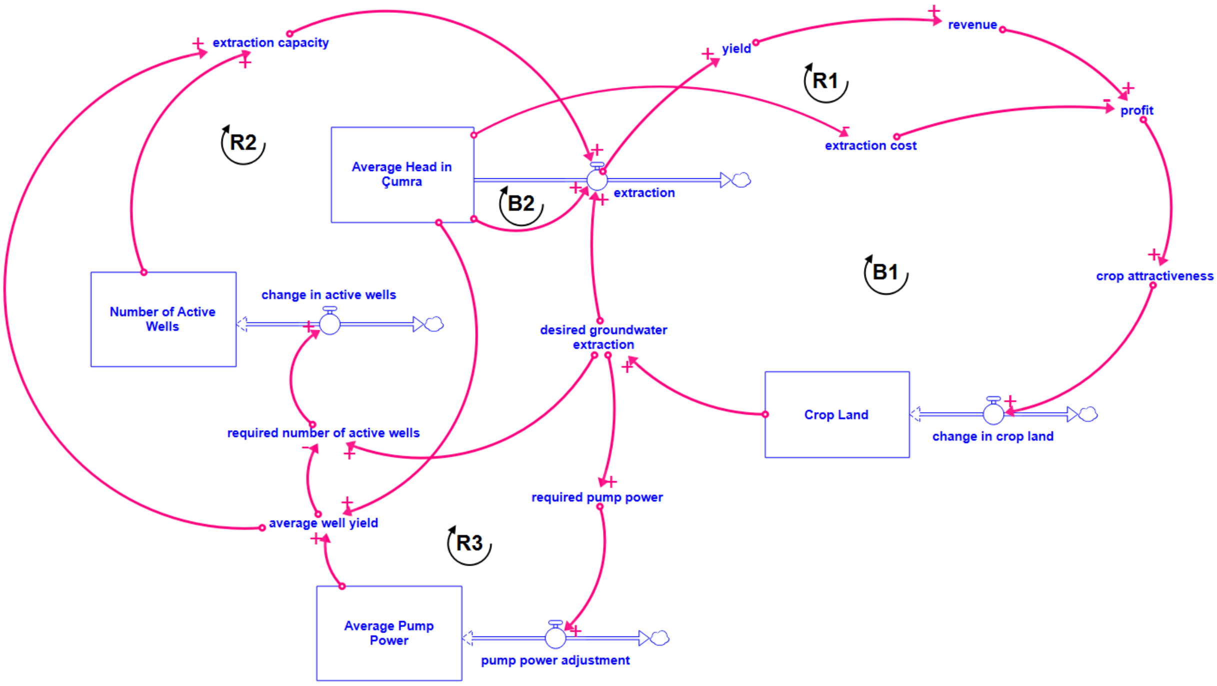

Figure 1. The main feedback overview of the model

The model consists of four sectors: namely, water and groundwater infrastructure, crop land use, production factor adjustment and yield goal setting, and irrigation technology. Figures 2-5 show the simplified stock-flow structures of each model sector.

The water and groundwater infrastructure sector includes the groundwater stock, the surface water availability, and the groundwater pumping infrastructure, i.e., number of active pumping wells and the average pump power (Figure 2). The infrastructure is adjusted according to the groundwater demand, and the change groundwater level is driven by the rates of extraction, recharge, and lateral velocity.

The crop land use involves the 5 different crop-land stocks: namely, land for green plants, land for sugar beet, land for irrigated cereal, land for rainfed cereal, and fallow land (Figure 3). Table 1 shows the reference water requirements of the crops included in the model, to provide insight regarding the relative water-intensity of different crops. It should be noted here that the fallow land is treated as bare land in the model, implying that it has a potential evaporation value, which is not explicitly incorporated in the model. Additionally, the crop revenues, production costs, and profits are calculated in this sector. Then, based on their relative attractiveness, the share of each crop within the total agricultural land are adjusted.

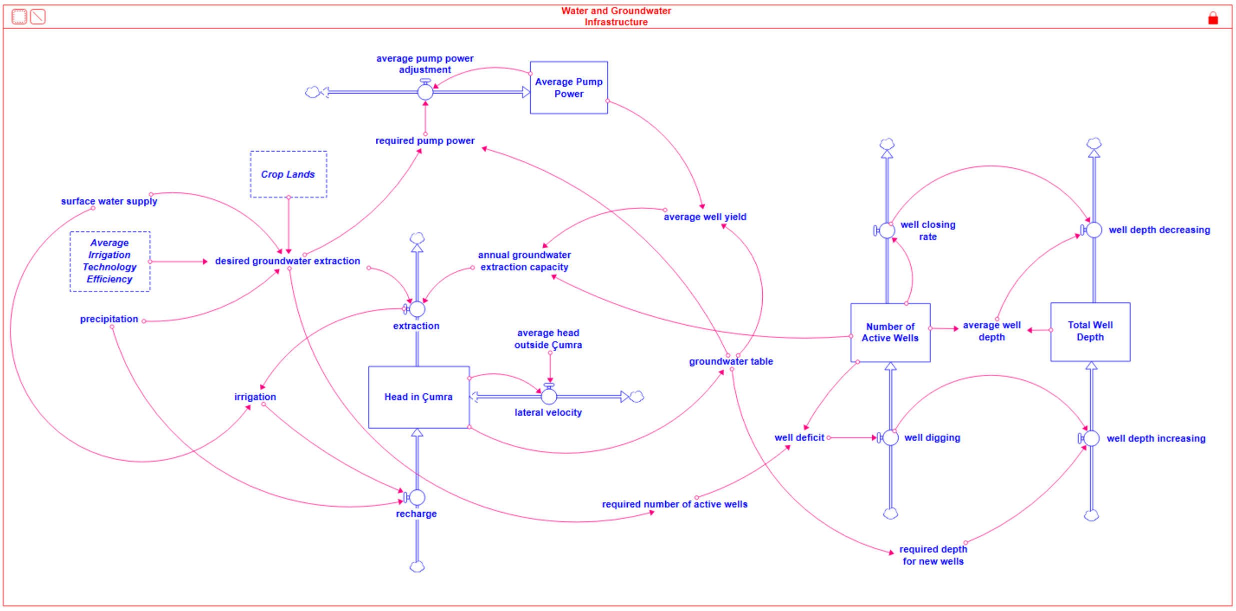

Figure 2. Simplified stock-flow structure of water and groundwater infrastructure sector

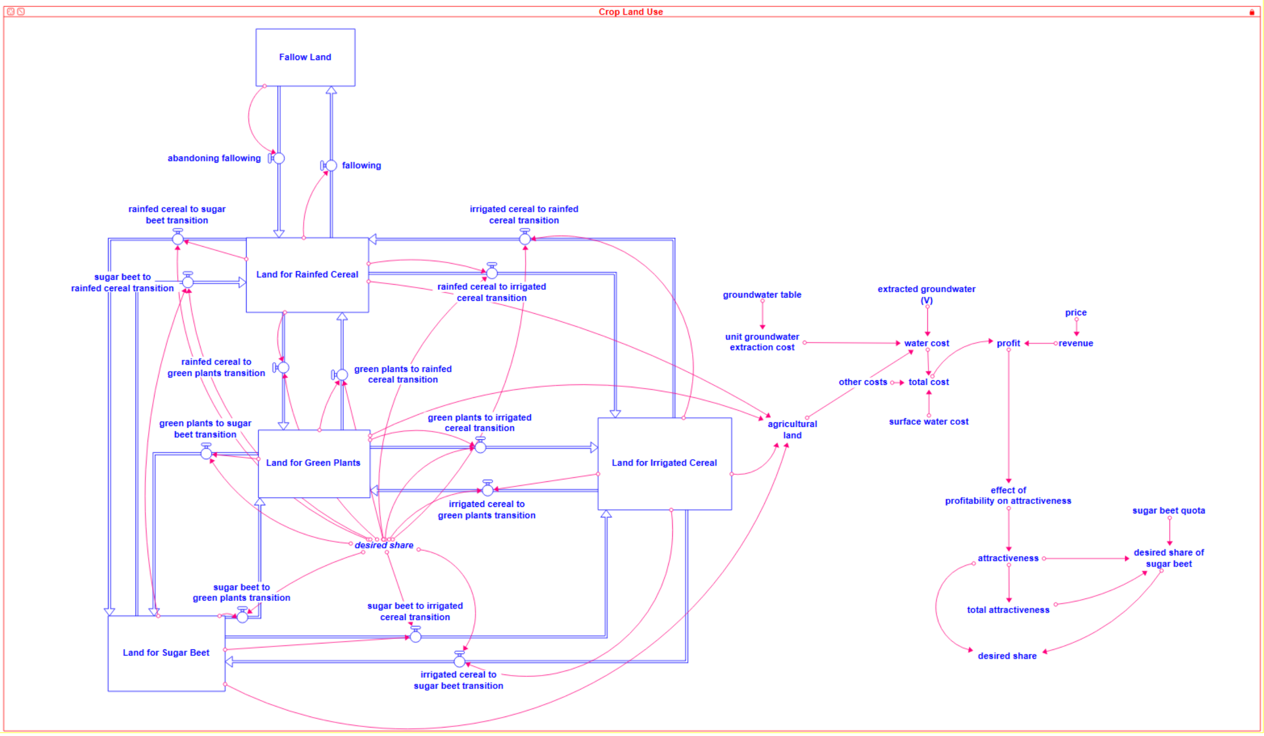

Figure 3. Simplified stock-flow structure of crop land use sector

Table 1. Reference water requirement of crops

Crop	Reference Water Requirement (mm)
Cereal	521
Green Plants	604
Sugar Beet	732

The production factor adjustment and yield goal setting sector are comprised of two main dynamics, both adjusting the level of irrigation (Figure 4). The first one is the difference between the yield goal set for each crop and the obtained yield; when the gap between the goal and the crop yield is high, farmers tend to irrigate more to achieve their goals. Second, the level of irrigation is adjusted by the economic feasibility of extraction. As long as the cost of extraction is lower than the income generated by additional irrigation (increase in the yield), increasing the level of irrigation is reasonable. However, when the increase in the revenue does not compensate for the cost of additional irrigation, farmers may stop increasing the level of irrigation to achieve a higher profit level even if they compromise the crop yield.

The irrigation technology sector is the smallest in the model; it has only one stock (Figure 5). The average irrigation technology efficiency is increased by new investments and decreased by equipment depreciation. The rate of investment increases when there is water stress.

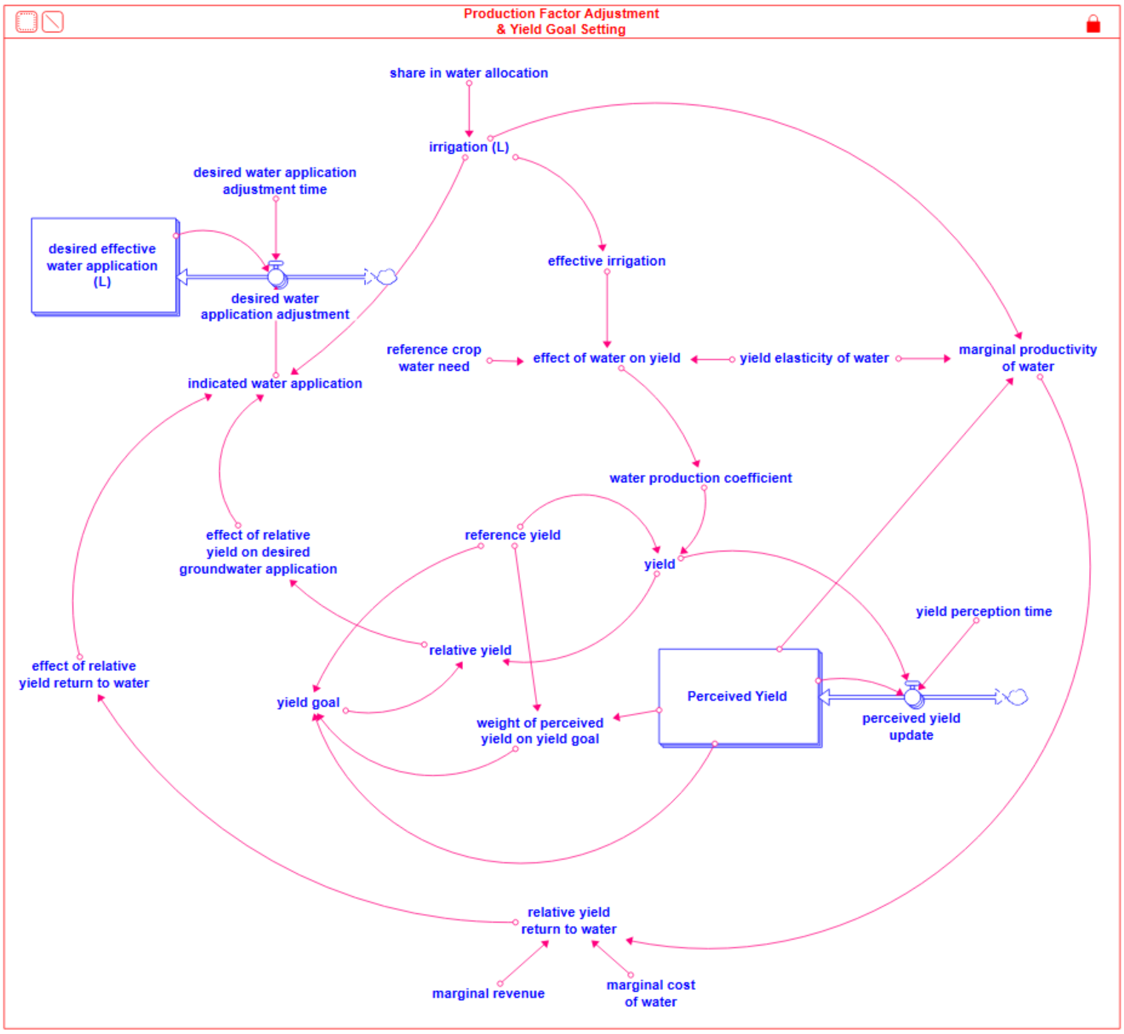

Figure 4. Simplified stock-flow structure of production factor adjustment and yield goal setting sector

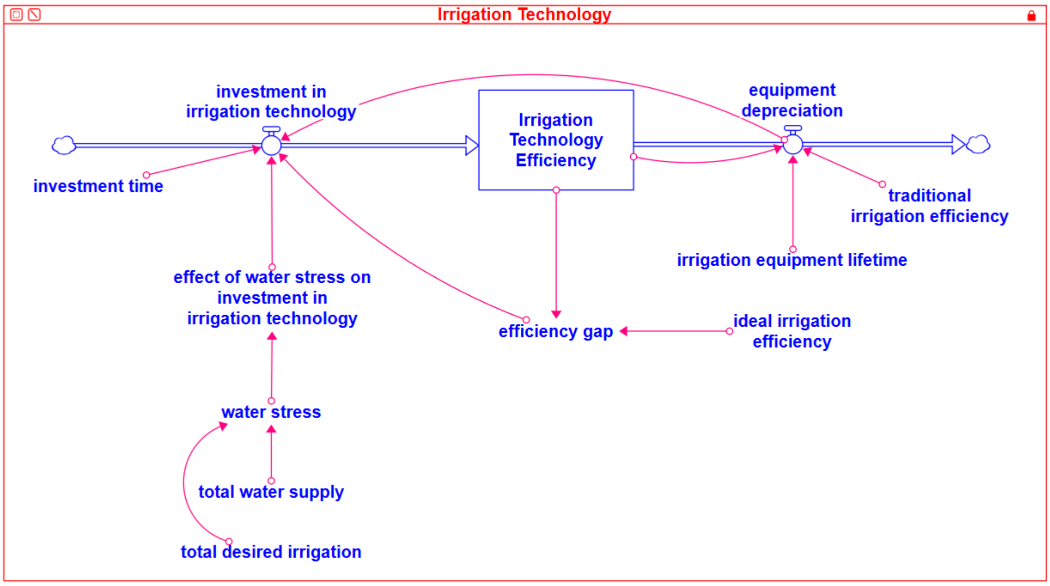

Figure 5. Stock-flow structure of irrigation technology sector

1.3. Model Interface

Figure 6 presents the model interface that is designed to allow non-expert users to easily operate the model. On the left-hand side is the cockpit, which users can alter to simulate various policies under different scenarios.

First, users can update the crop prices or the unit electricity price. The new prices will be effective starting in year 2025. Below the price setting section, there is a crop rotation section. Here, the user may alter the current convention of crop rotation. For example, enforcing a crop rotation for green plants (every 2-4 years) is a popular option among the stakeholders in Çumra. Then, there is the surface water supply. The switch allows users to choose whether they wish to implement an additional surface water supply in the model. If so, the user also should set a surface water supply goal, which will realize starting from 2025 and reach the goal in 2030, within a five-year period. Additionally, the user can select a well regulation policy; the default regime in the district is open access, which implies that whenever an extra groundwater well is needed, it can be opened. The well amnesty policy implies that the current number of wells might be protected i.e., a new well can only be opened when an existing well is closed. Under the prohibition of new wells regulation, no new wells can be opened whatsoever. The user also sets a policy start year and duration, and the new well regulation will become valid in the start year, and the model will return to the open access regime when the well policy duration is over. Later, the user can select which irrigation methods they would like to implement, and the model will adjust the average irrigation technology efficiency, accordingly, starting from 2025. Lastly, users can select whether they prefer to implement limits on the pump power or pumping, and if so, set the upper limits.

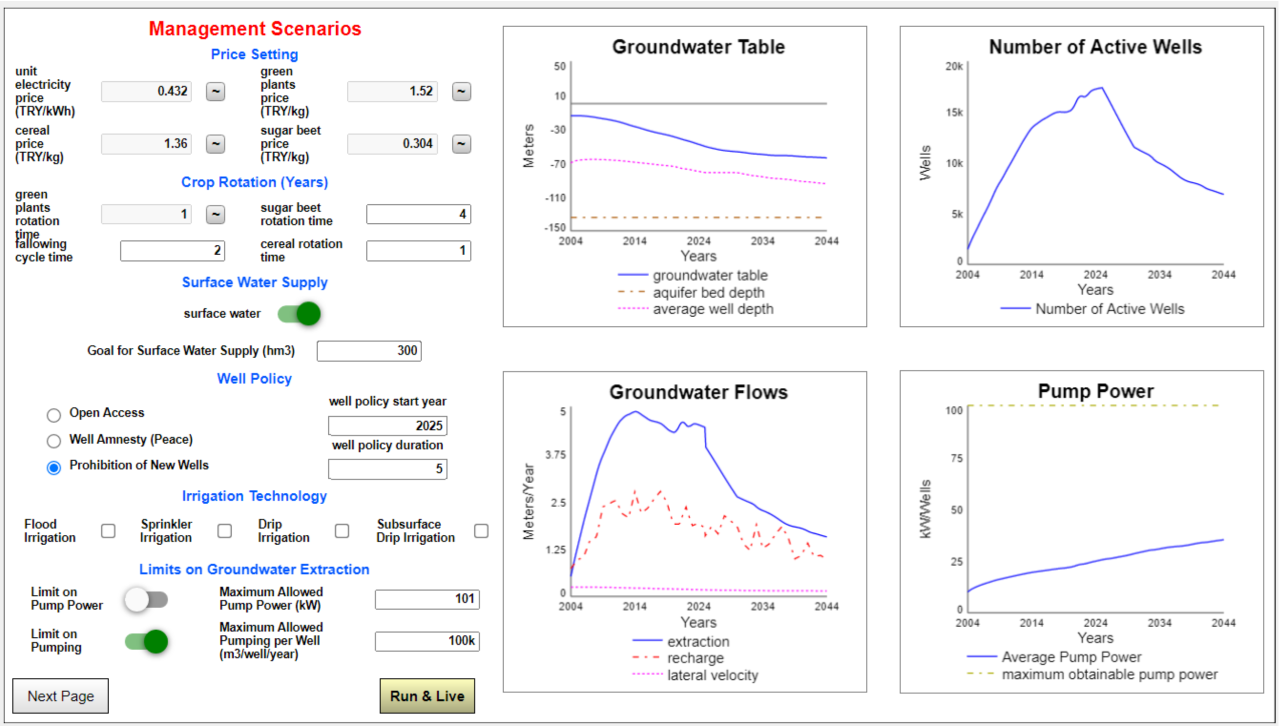

Figure 6. Model interface

2. Scenario Analysis

2.1. Surface Water Supply

We run three simulations with three different surface water transfer values to examine the impact of surface water on the system. First, we set an annual surface water supply goal of 300 hm^3, which provides a sense of the Blue Tunnel project's impact. The Blue Tunnel project is an inter-basin water transfer project with annual capacity of 400 hm^3 expected to be completed in the mid-2020s. Then we set quite ambitious surface water transfer goals of 700 and 1500 hm^3/year. The objective of these scenarios is to determine whether the inter-basin water transfer will have the anticipated impact, as certain groups of stakeholders (some farmers and irrigation cooperatives) are eagerly waiting for the transfer because they believe it will put an end to the water scarcity issue, and their hopes for the future rely on it.

The groundwater level for the base run and the three surface water transfer scenarios are depicted in Figure 7. According to the graph, the 300 hm^3 of water that will be carried through the Blue Tunnel will have a small influence on groundwater conservation. The final depth of the groundwater level in this scenario is -84.3 m, indicating a 2.3-meter increase compared to the base run. As we increase the volume of surface water transfer, the groundwater level lowers less. However, given the financial and environmental costs of inter-basin water transfers, which are not considered in the model, the pros and cons of such projects should be thoroughly evaluated.

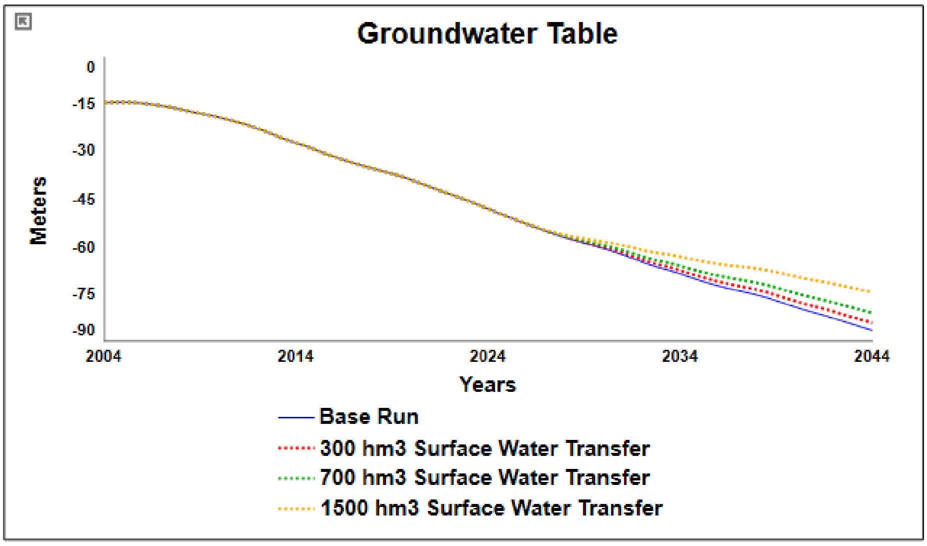

Figure 7. Scenario 1: Groundwater level

Figure 8 displays the number of active wells and average pump power under the surface water transfer scenarios and in the base run. Since the transferred surface water supplies a portion of groundwater demand, the need for groundwater pumping infrastructure diminishes. Therefore, there are fewer wells and the pump power is reduced as yearly surface water transfer rises.

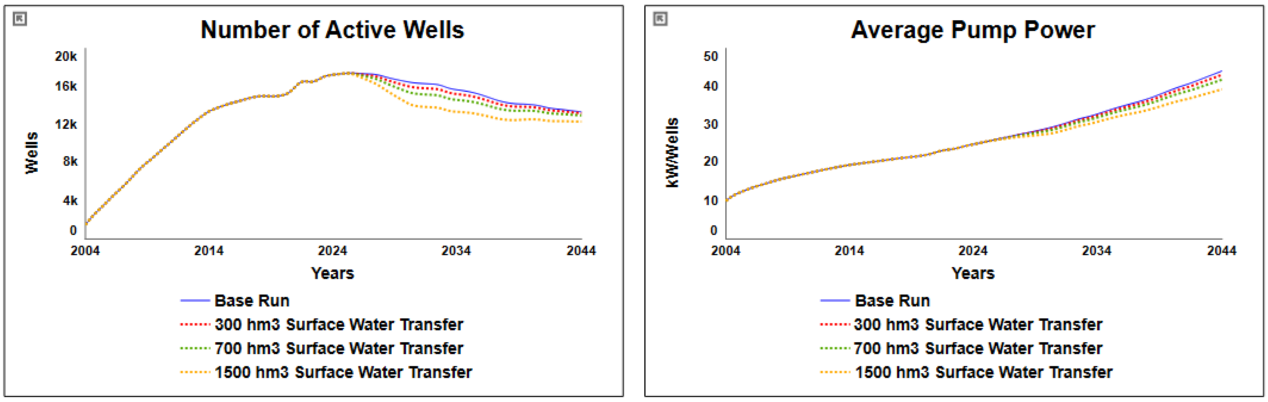

Figure 8. Scenario 1: Number of active wells and average pump power

Figure 9 illustrates a comparison of total profit in the Çumra district under various surface water transfer scenarios. The revenue does not differ much because land use and crop yields do not change substantially in between different runs. Nevertheless, since surface water is relatively cheaper than groundwater, overall irrigation expenditure drops as the supply of surface water increases and the total profit is increased.

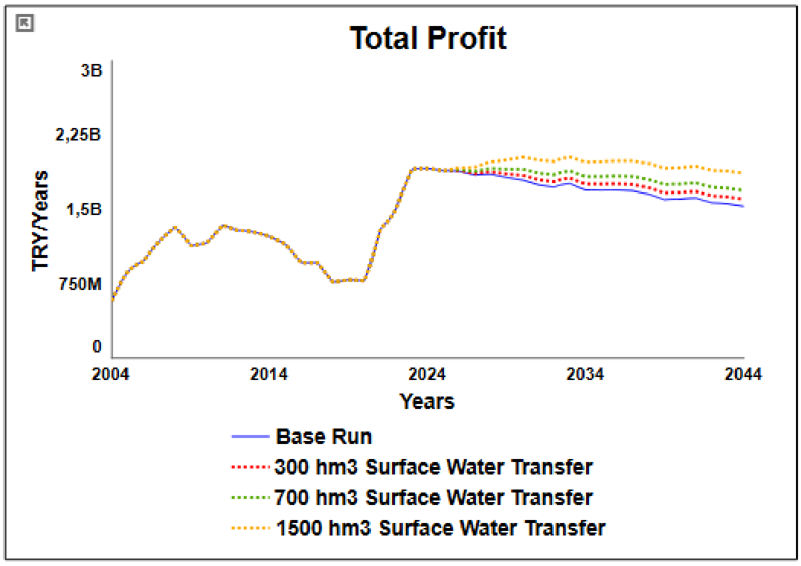

Figure 9. Scenario 1: Total profit

2.2. Well Regulation

We run three simulations in this scenario analysis. The first is the base run, in which the open access regime governs until the simulation time ends. In the other two simulations, we start well amnesty (i.e., new wells are not allowed but existing wells are legalized) and the prohibition of new wells (i.e., new wells are not dug even to replace drying wells) in 2025 and continue to enforce the regulations until 2044.

Figure 10 compares groundwater level outputs from the three simulations. While open access and well amnesty regulations generate similar groundwater level behaviour, the groundwater level stabilizes at -67 meters if all new wells are restricted.

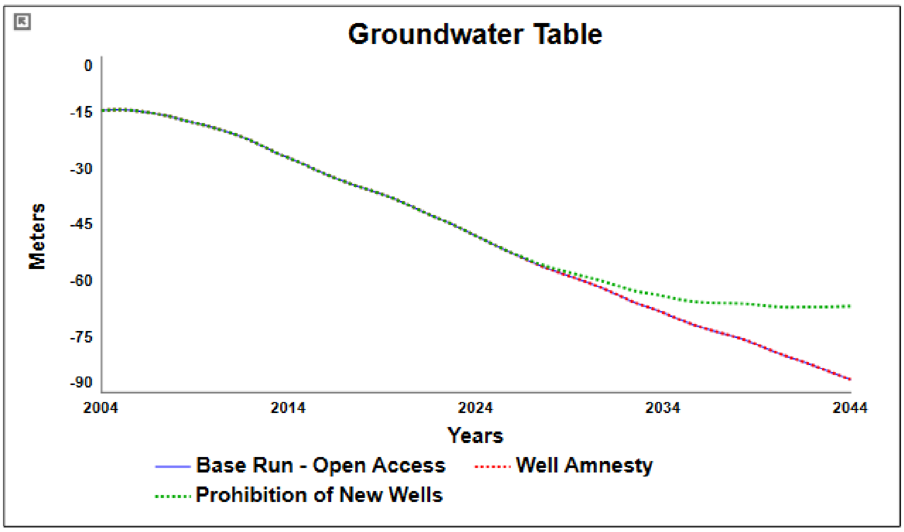

Figure 10. Scenario 2: Groundwater level

Figure 11 demonstrates why the groundwater level in open access and well amnesty runs is the same. After 2025, the number of active wells begins to decline in the base run. In that case, the well amnesty regulation mimics the open access case, because the well amnesty regulation provides protection to existing wells. However, if there is not a demand to increase or maintain the existing wells, the regulation does not force farmers to open more wells in the place of the ones that are closed. When new wells are outlawed, the number of wells falls drastically. To compensate for the loss of pumping wells, average pump power is quickly raised after 2025.

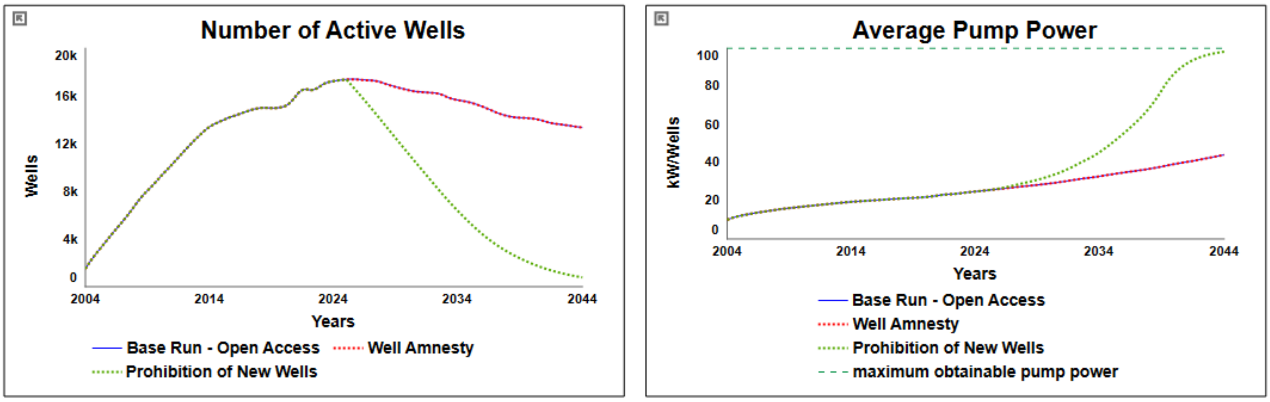

Figure 11. Scenario 2: Number of active wells and average pump power

A significant decline in yield with is seen each irrigated crop after 2025 if well opening is completely hindered (Figure 12). It should be underlined, however, that prohibiting new wells for 19 years (2025-2044) is an unreasonable and unrealistic approach, as groundwater conservation is not the sole objective for all actors in the system. For example, the primary goal for farmers is to make a living for themselves and their families. Çumra is a major crop production centre in Turkey. So, another target is to keep each crop production at an adequate level. However, crop production decreases dramatically as new wells are prohibited (Figure 13), in line with the yield loss. As a result, hindering well opening completely is not a viable option for groundwater conservation.

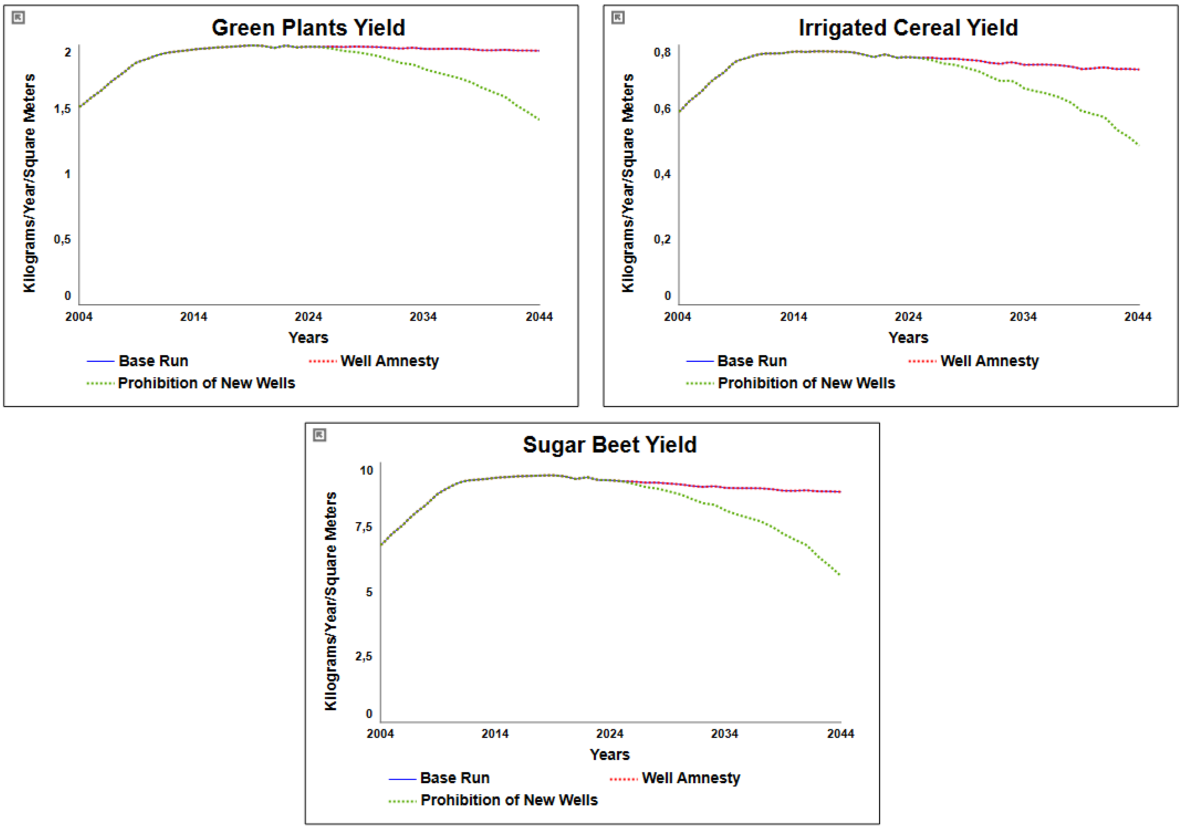

Figure 12. Scenario 2: Irrigated crop yields

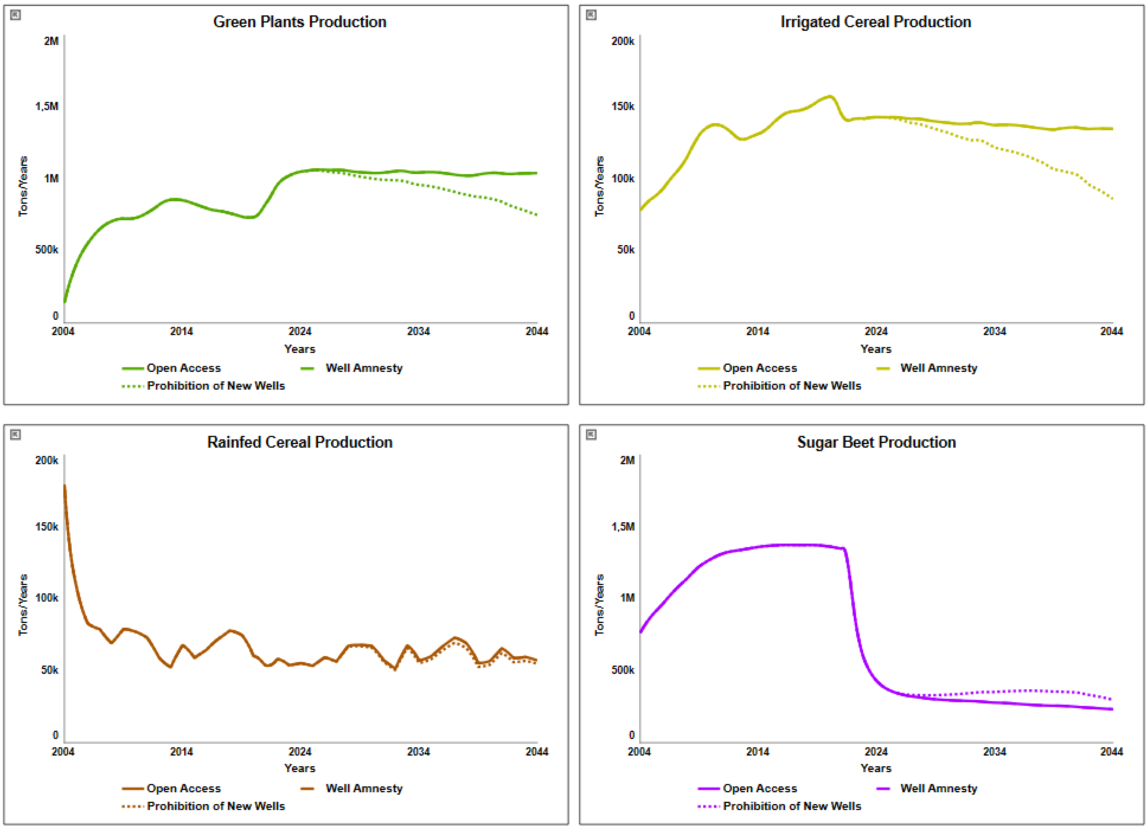

Figure 13. Scenario 2: Crop production

2.3.Crop Rotation

Crop rotation is described as the growing of different crops in succession on the same block of land with the purpose of avoiding soil exhaustion and preventing weeds, diseases, and pests. Crop rotation is currently established in Çumra for sugar beet, since cultivating sugar beet successively depletes the soil of nutrients. Many stakeholders recommended during the group model-building workshops that a similar crop rotation approach could be implemented for green plants, because they are water-consuming plants. They suggested that rotation could decrease overall groundwater demand. In this section, we run the model with a four-year green plant rotation time, which means that the green crops are cultivated on the same parcel of land once every four years, beginning in 2025 and continuing until the end of the simulation, and compare the behaviour of the important system variables to the base run.

Figure 14 depicts the groundwater level in the base and policy runs. We observe that the green plant rotation improves the groundwater level significantly, as anticipated by the stakeholders.

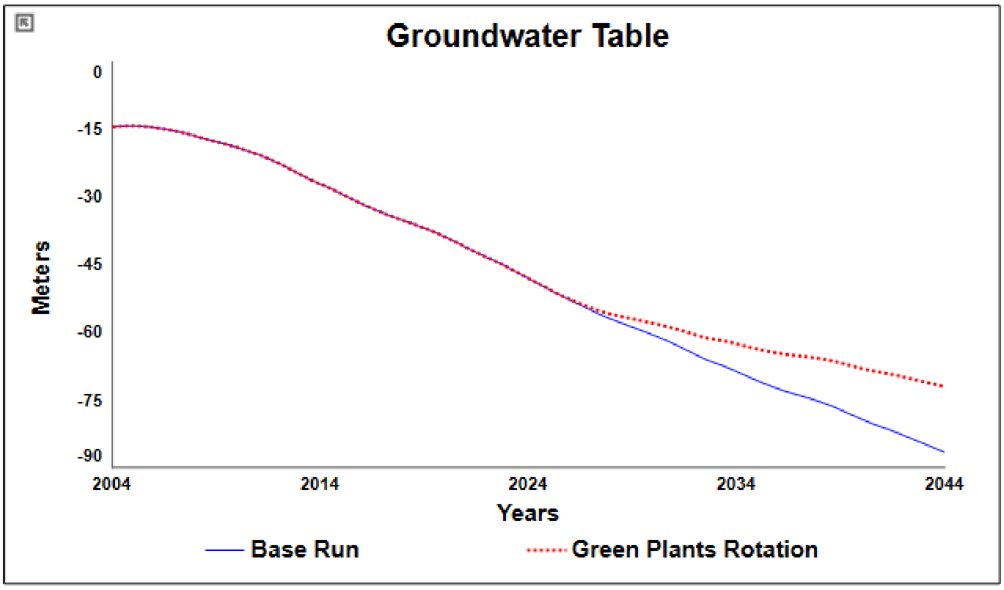

Figure 14. Scenario 3: Groundwater level

The rotation system significantly alters the land cover; after the rotation is in effect, the land for green plants declines sharply, while all other crop lands expand, but total agricultural land remains constant throughout the simulation (Figure 15).

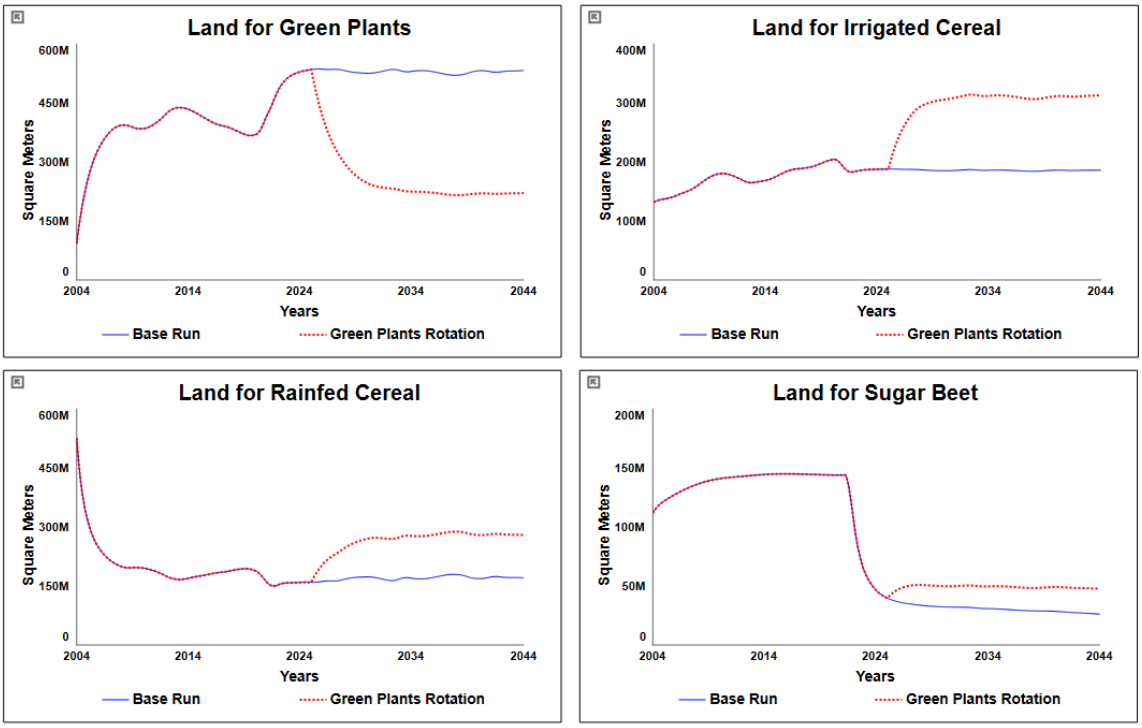

Figure 15. Scenario 3: Crop land cover

The changes in land cover have a substantial impact on crop production and total profit. Crop yields are not considerably impacted by the rotation plan, therefore the change in crop production mostly driven by the changes in land cover. Figure 16 depicts crop production in both the base run and the green plants rotation run.

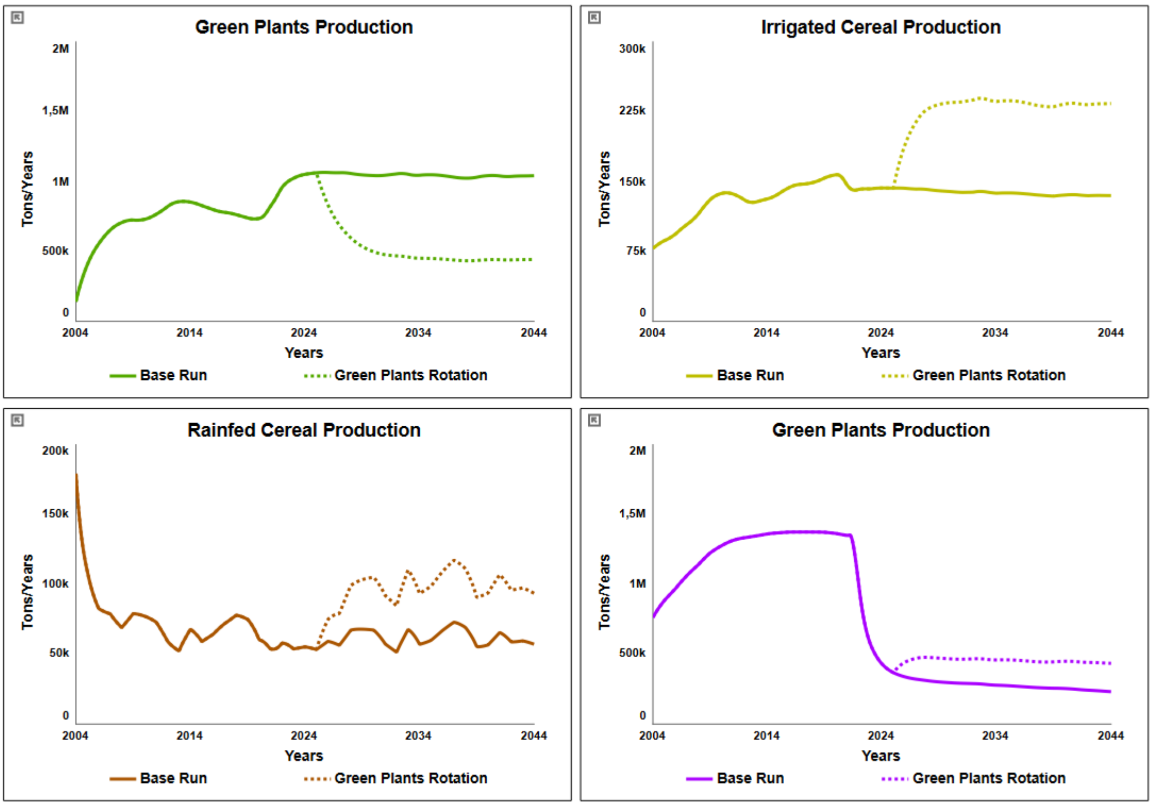

Figure 16. Scenario 3: Crop production

Green plants are the most profitable crops in terms of profit per unit area under the current cost and pricing arrangement. Therefore, when the production of green plants shrinks and is substituted with other, less profitable crops, total profit declines significantly, as can be seen in Figure 17.

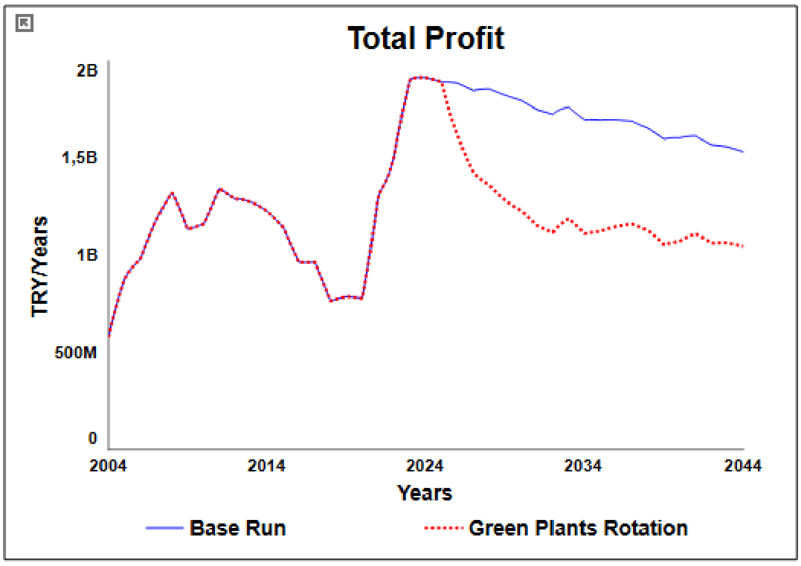

Figure 17. Scenario 3: Total profit

2.4. Extraction Cap

To evaluate the impact of extraction caps on the system, we take three simulation runs with varying extraction cap values, as presented in Table 2.

Table 2. Extraction cap runs

Runs	Extraction Cap (m^3/well/year)
Extraction Cap I	100.000
Extraction Cap II	80.000
Extraction Cap III	60.000

Figure 18 shows the groundwater level behaviour in the base run and three different extraction cap policies. As expected, the lower the extraction cap, the higher the groundwater level. We observe a stabilization of the groundwater level and even a modest improvement after 2035 in the Extraction Cap III run.

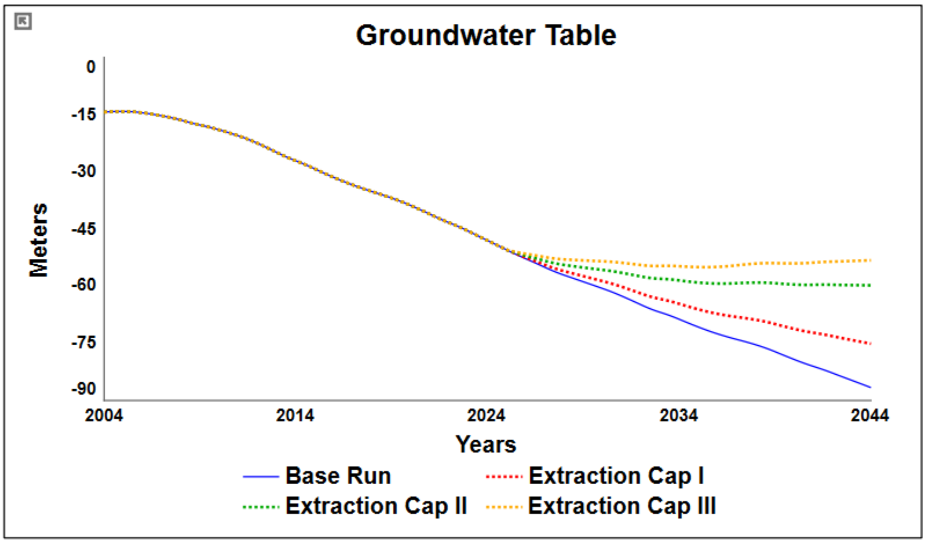

Figure 18. Scenario 4: Groundwater level

The extraction cap scheme has little effect on crop land cover. However, it has a significant impact on irrigation rates, and consequently crop yields and production. As can be seen in Figure 19, irrigation for each crop has been cut by more than half. Sugar beet irrigation reduced the most of the three irrigated crop types.

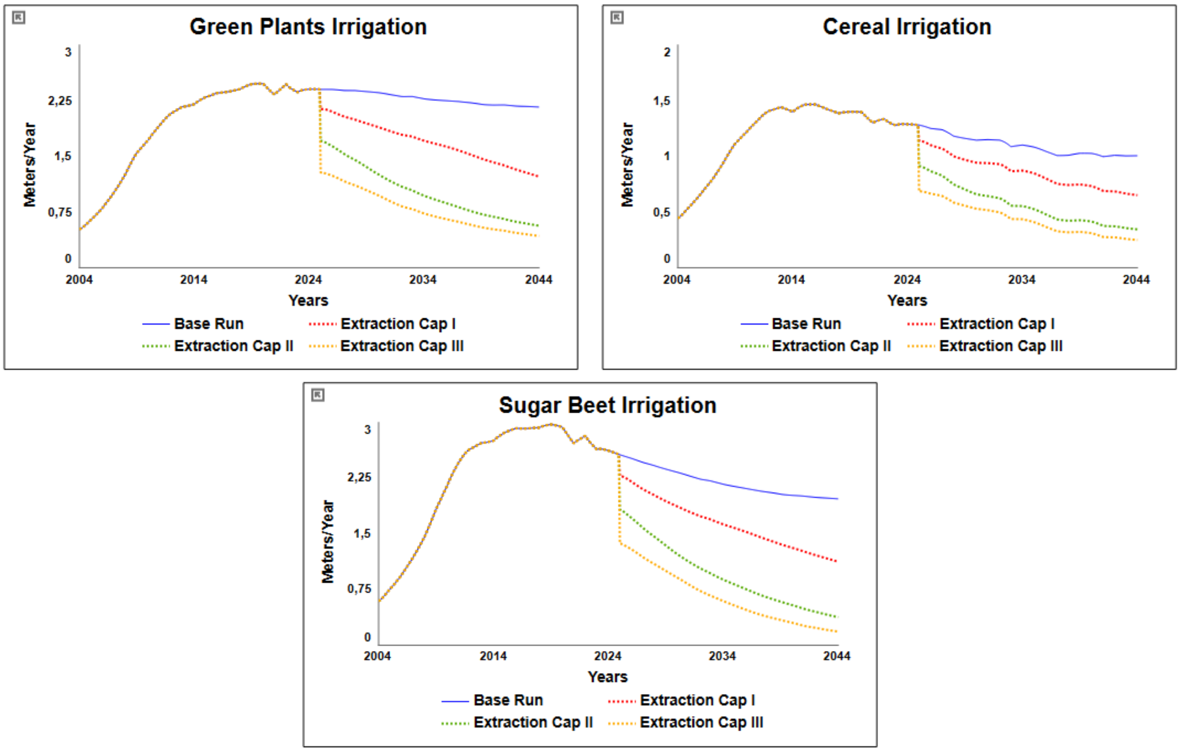

Figure 19. Scenario 4: Crop irrigation

The yield loss is severe as a consequence of the reduced irrigation (Figure 20). It is evident in crop production as well; under the most stringent extraction quota, crop production is reduced by nearly 30% for green plants and irrigated cereal, but sugar beet production marginally increases due to a slight rise in sugar beet area.

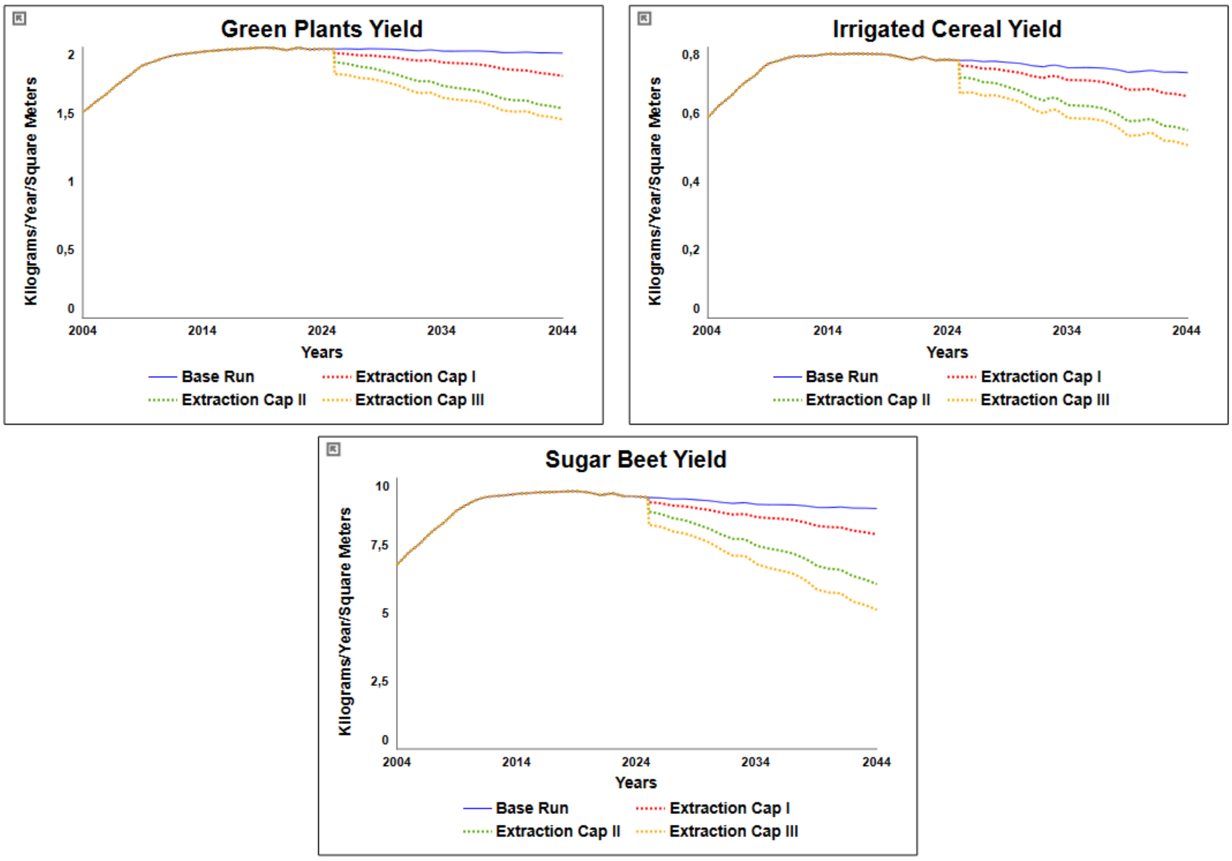

Figure 20. Scenario 4: Crop yield

One of the most intriguing findings in the present scenario is that, despite the extraction cap, total profit improves in comparison to the base run (Figure 21). Farmers fear that when there is a restriction on pumping, their crops will not receive sufficient water and they will have to forfeit profit. However, the outcome of the quotas may be influenced by the quota itself. The field observations revealed that there is an over-irrigation pattern on average. A reasonable quota can help farmers reduce irrigation expenses while sustaining comparable yields and production levels, boosting the overall profit.

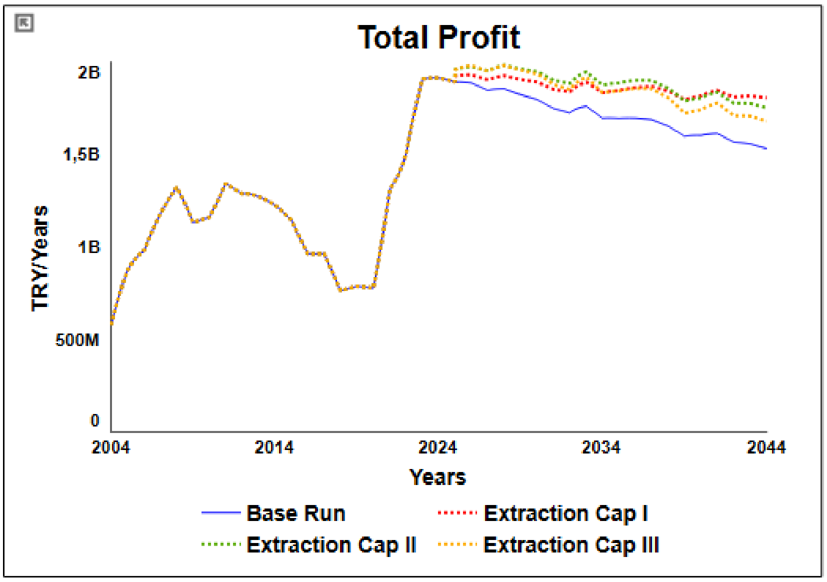

Figure 21. Scenario 4: Total profit

2.5. Crop Repricing

In this particular section, we compare the findings of three simulation runs to the base run. In the first simulation, we reduce the price of green plants by 20% beginning in 2025. In the remaining two runs, we raise cereal prices by 30% and 50%, respectively, starting in 2025.

Figure 22 exhibits the groundwater level outputs. While all three policies lead to a decrease in the water table drop by around 4-5 meters over the base run, it may be suggested that the various adjustments do not generate significantly different groundwater level outcomes.

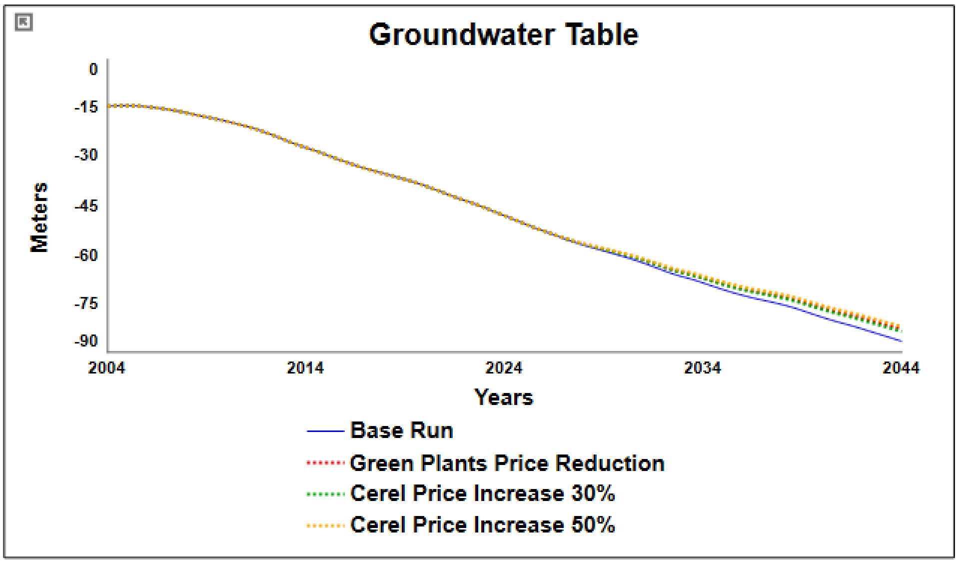

Figure 22. Scenario 5: Groundwater level

In all three repricing policy scenarios, green plant land decreases while irrigated and rainfed cereal land grows. Sugar beet land is shrinking slightly, but it is not affected as much as the other crops. The attractiveness of crops alters in response to price changes. As a result, as the price of a single crop rises, it becomes more appealing, and its land share in total agricultural land rises, and vice versa. Crop yields are unaffected by changes in agricultural prices. Thus, crop production is mostly impacted by land cover change, and its behaviour correlates with that of the land cover.

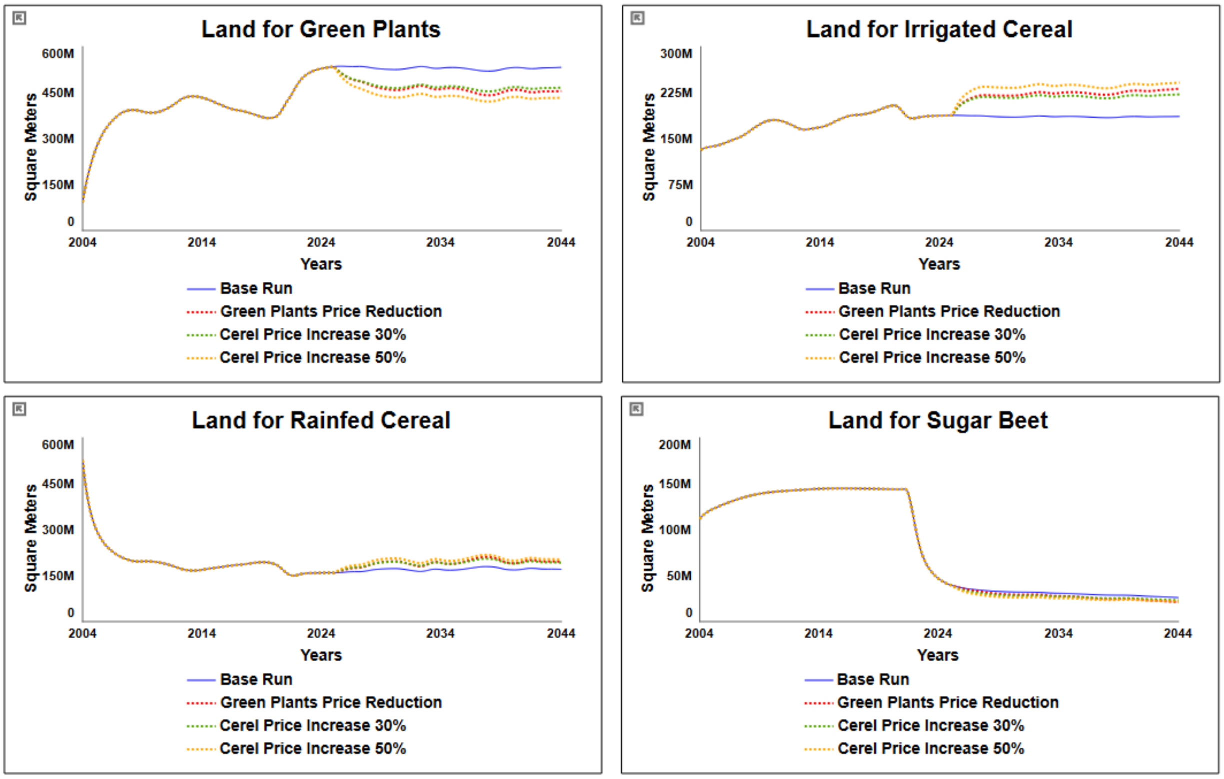

Figure 23. Scenario 5: Crop land cover

Figure 24 depicts the total profit. As predicted, raising the cereal prices boosts total profit in simulations, whereas reducing the green plant price lowers total profit.

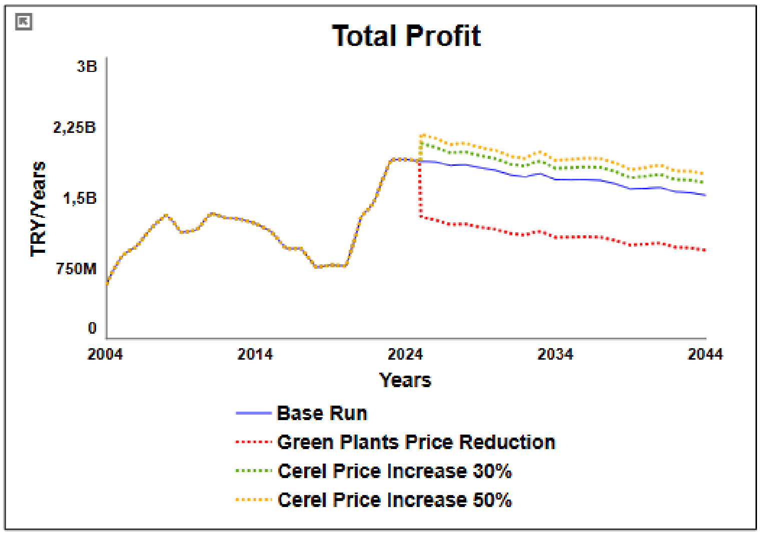

Figure 24. Scenario 5: Total profit

2.6. Electricity Repricing

In this scenario, we double the unit price of electricity beginning in 2025 and compare the results to the base run.

The simulated groundwater level is presented in Figure 25. We see that raising the unit electricity price helps conserve groundwater; the policy simulation leads to 6.4 meters higher water table than the baseline run.

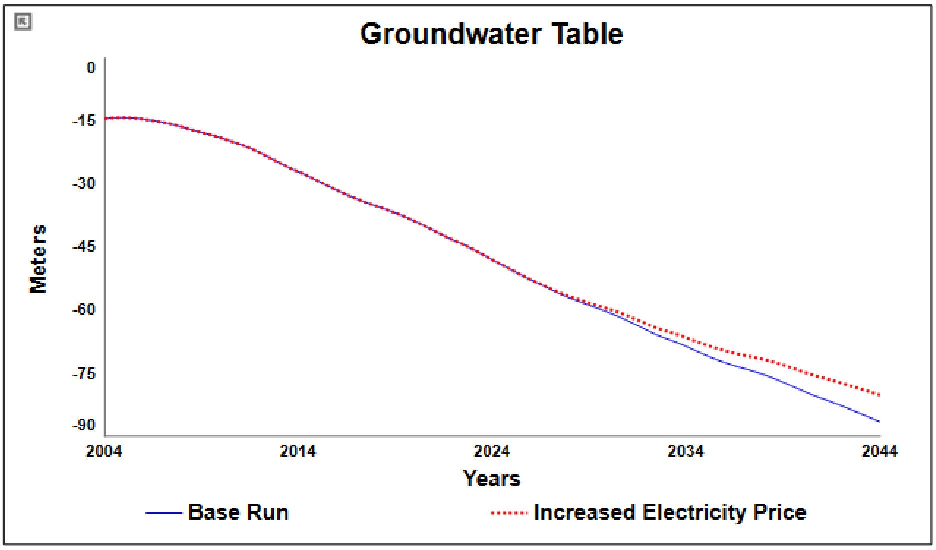

Figure 25. Scenario 6: Groundwater level

The increase in the unit power price has a significant impact on the land cover, as seen in Figure 26. Because irrigation costs have been increased, the profitability of irrigated agriculture has decreased considerably. As a result, farmers begin to prefer rainfed agriculture over irrigated, and we see an expansion in rainfed cereal land while all irrigated crop lands shrink. The most notable impact is that sugar beet is nearly abandoned because sugar beet production induces a monetary loss with the current price setting in the model.

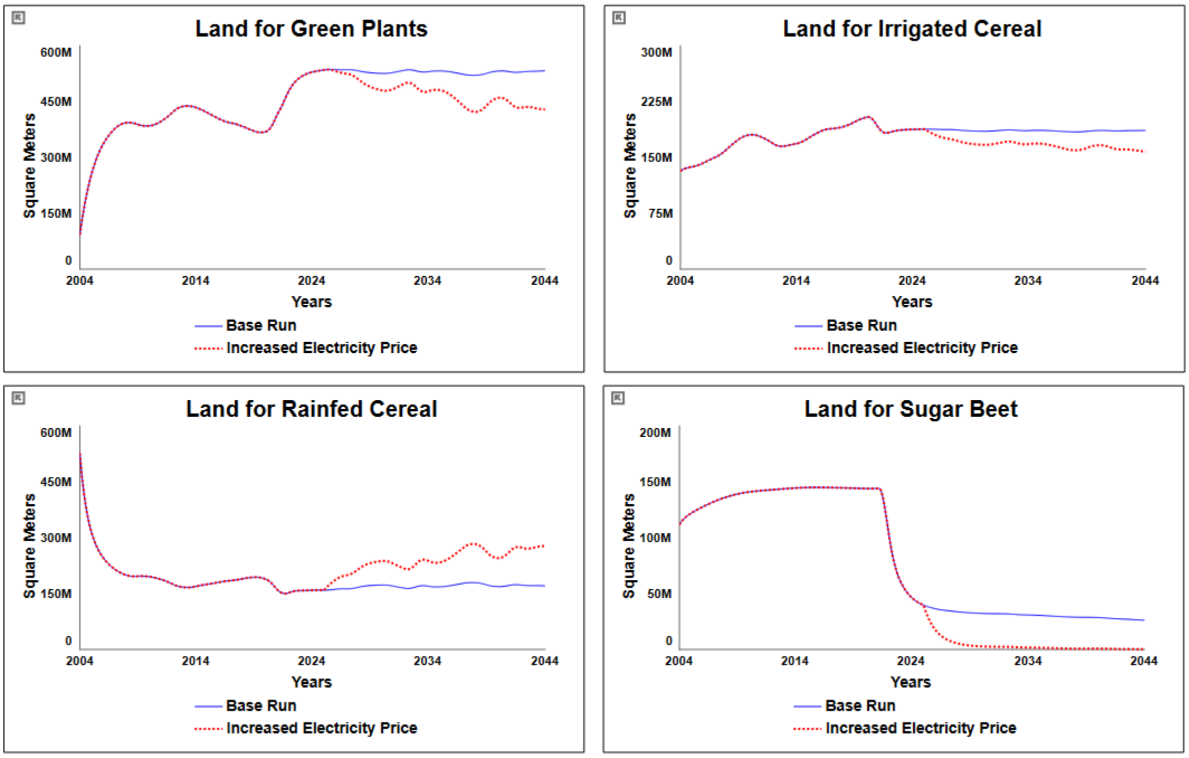

Figure 26. Scenario 6: Crop land cover

The rise in electricity price has no major impact on irrigation levels or crop yield. However, as shown in Figure 27, the district's total profit reduces significantly; even though crop yields remain stable, the decrease in irrigated agricultural land results in decreased production levels, because yields are always higher when practicing irrigated agriculture. Additionally, the price of electricity directly drives up costs. Due to reduced income and increased costs, the overall profit is lower than it is in the base run.

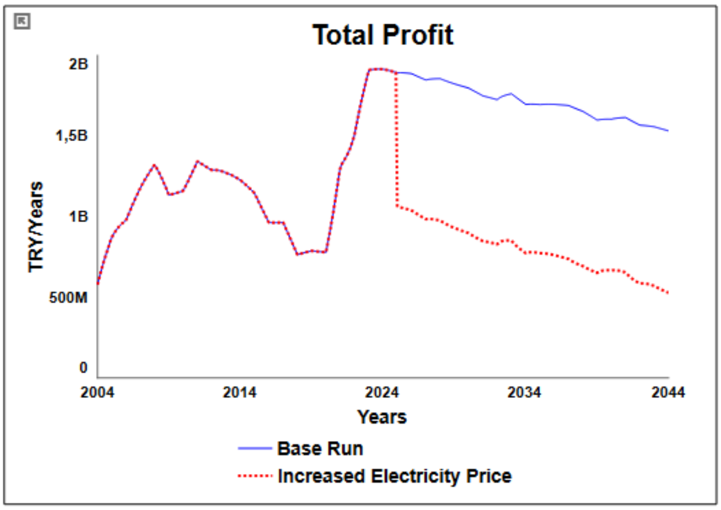

Figure 27. Scenario 6: Total profit

3. Integrated Policy Analyses

In the previous section, the outcomes of the proposed policies are evaluated one by one. Some policy alternatives have advantages in terms of groundwater conservation; nevertheless, only a more extreme extraction cap appears to be capable of stopping the declining trend on its own, while others slow but do not stop the decrease in groundwater level. Furthermore, while the strict extraction cap may restore the groundwater level to an equilibrium it results in a significant loss in crop yield, which is an adverse consequence. Therefore, in this section, we look for a set of policies that when integrated, can both help preserve groundwater and maintain the crop yield, production, and profits.

3.1. Policy Integration Based on Farmers' Perspectives

First, the proposed policy alternatives are segregated into two groups based on whether or not they are supported by farmers, and then the findings of both sets are compared with each other and with the base run. Table 3 shows the policy sets. Policy Set 1 includes policy alternatives that are favoured by farmers, while Policy Set 2 includes policies that are not favoured by farmers.

Table 3. Integrated policy sets based on farmers' points of view

Policy Options	Policy Set 1	Policy Set 2
Surface Water Transfer	600 hm^3/year	300 hm^3/year
Well Regulation	-	Prohibition of New Wells (2025 – 2030)
Crop Rotation	Green Plants, once every 2 years	-
Extraction Cap	-	100.000 hm^3/well/year
Crop Repricing	Cereal Price: 50% increase Sugar Beet Price: 100% increase	Green Plants Price: 20% reduction
Electricity Repricing	0,5 TRY/kWh (33% reduced)	1,0 TRY/kWh (33% increased)

Both policy sets include surface water transfer because it is a popular scenario among farmers. It is included it in the second policy set as well, given that the building of the Blue Tunnel project is already underway and will be completed in the mid-2020s. On the other hand, the first policy set entails a greater volume of water transfer, indicating the possibility of an additional water transfer project comparable to the Blue Tunnel.

Aside from surface water transfer, the first policy set contains a crop rotation scheme for green plants, in which green plants are to be planted on the same patch of land once every two years. Cereal prices are being raised by 50%, and sugar beet prices are doubled because sugar beet is a highly important crop for the area; it has spawned an entire food sector in the Konya region. As a result, it is an essential crop for the region's economy. However, sugar beet prices have been low in recent years when compared to other crops, and farmers have expressed dissatisfaction about sugar beet prices. Furthermore, in the first policy set, the electric energy price is cut by 33% because farmers argue that current electricity prices have a significant impact on their profitability.

In the second policy package, a five-year ban on new wells is imposed, from 2025 to 2030. There is also a restriction on extraction at 100.000 m^3/well/year. The price of green plants is cut by 20% and the unit electricity price is raised by 33% to disincentivize the cultivation of water-consuming crops.

Figure 28 depicts the outputs of the groundwater level from the base run and the two policy sets. In regard to groundwater conservation, both policies outperform the base run; however, while the first policy set maintains the continuously declining pattern, the second substantially slows the drop and seems to result in a steady state in a future beyond the model time horizon.

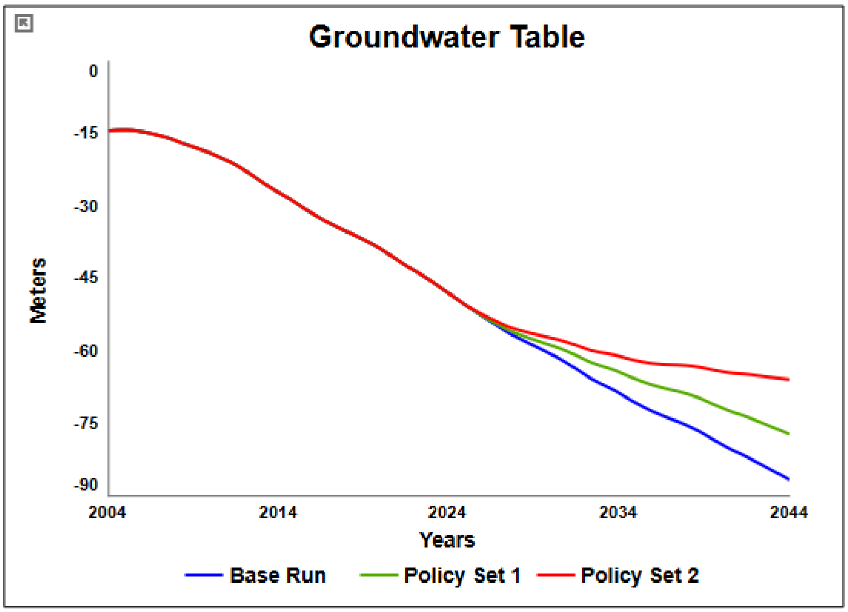

Figure 28. Integrated policy analysis 1: Groundwater level

The number of wells in the two policy set runs differs significantly, because of the restriction of new wells regulation in the second policy set, as well as the different groundwater demands in the two simulations (Figure 29). Since the groundwater demand is lower in the second policy set, the growth in average pump power is also slower.

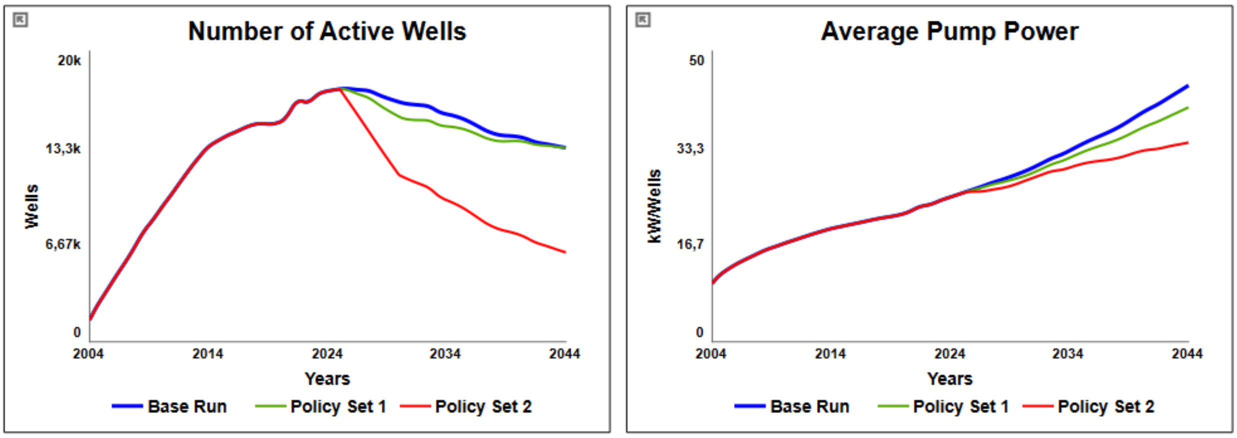

Figure 29. Integrated policy analysis 1: Number of active wells and average pump power

Figure 30 depicts how the land cover varies under both policy options compared to the base run. Despite the fact that the price of green plants remains unchanged, the price increases in cereals and sugar beet decrease the relative profitability of, and hence the attraction to, green plants in the first policy set. The change in land cover follows the same pattern as the first policy set, but it is smaller.

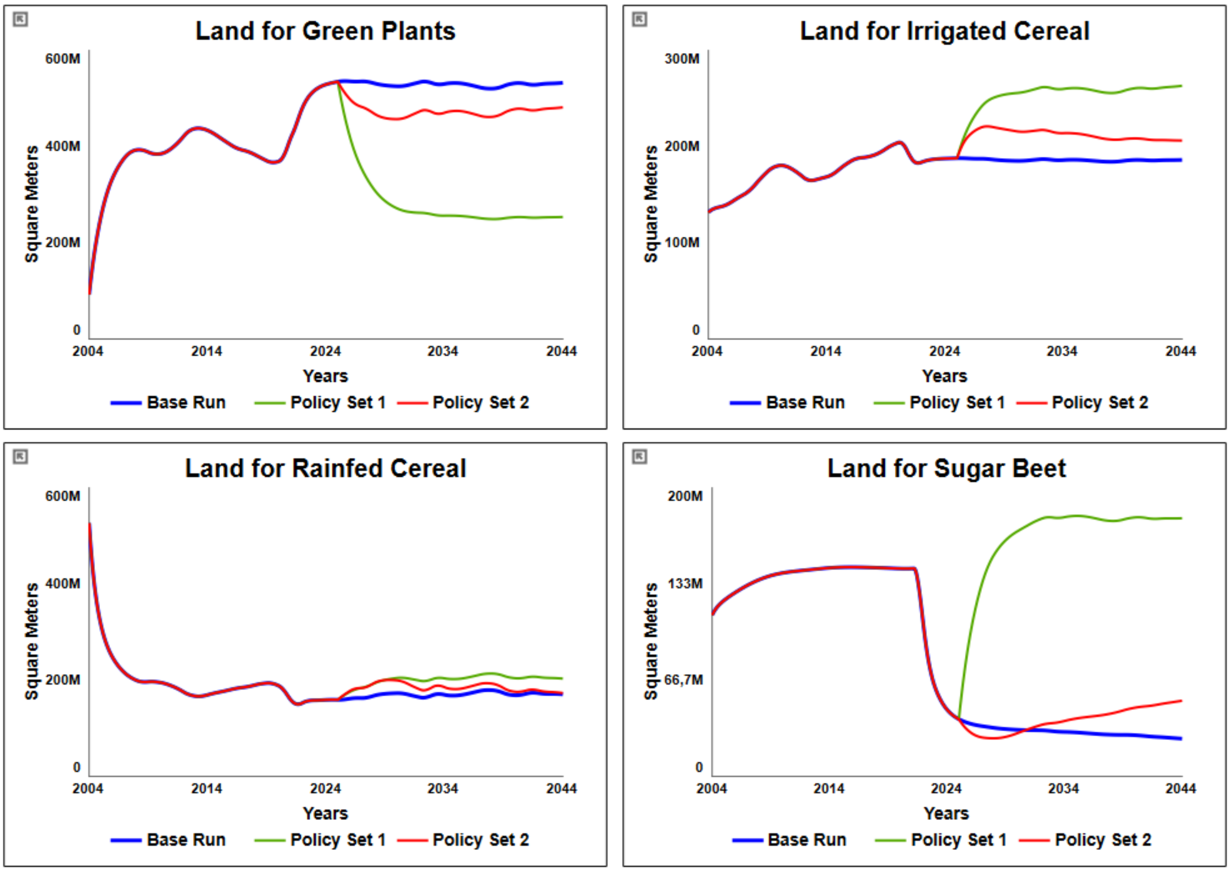

Figure 30. Integrated policy analysis 1: Crop land cover

As can be seen in Figure 31, policy set 1 has the highest irrigation levels and policy set 2 has the lowest. In policy set 1, irrigation is promoted indirectly by a lower unit electricity price than in the base run. The second policy set, on the other hand, includes both direct intervention on extraction through the extraction cap and well regulation, as well as indirect intervention through the increase in the unit electricity price. As a result, irrigation levels are lowest in the second policy set.

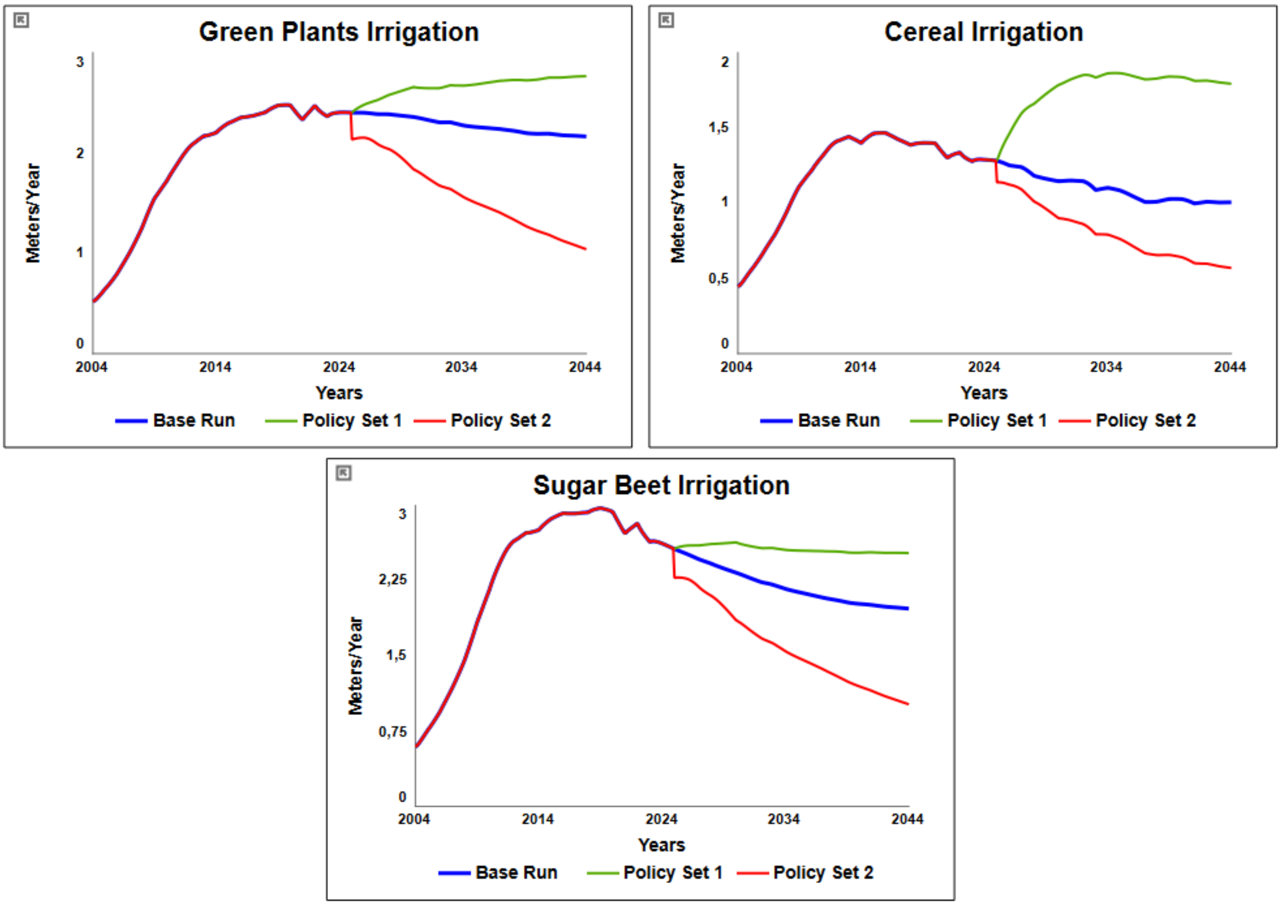

Figure 31. Integrated policy analysis 1: Crop irrigation

The crop yield outputs of the two policy sets, in addition to the base run, are displayed in Figure 32. Policy set 1 produces higher yields for irrigated crops than both the base run and policy set 2, which is expected given that irrigation levels are highest in the first of the policy sets. Policy set 2, on the other hand, generates lower yields.

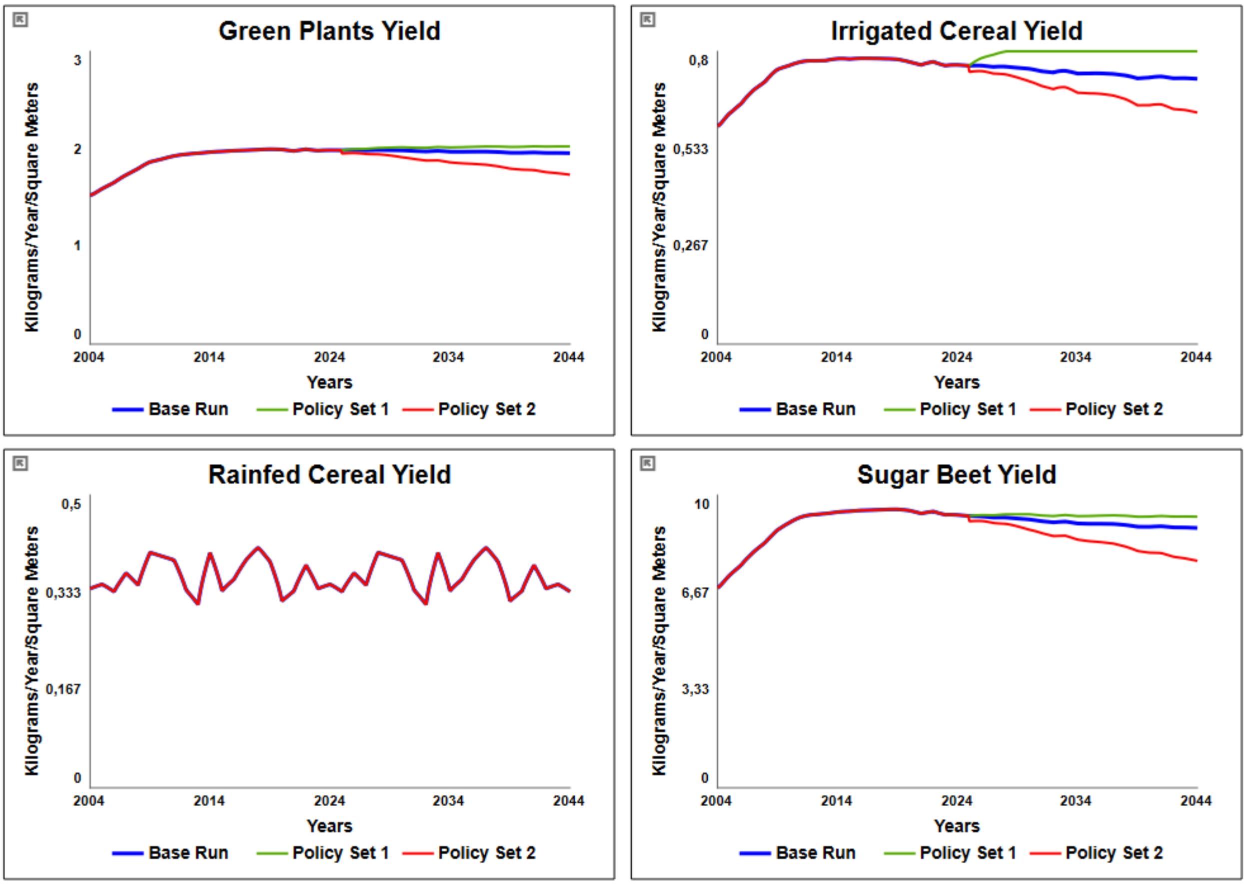

Figure 32. Integrated policy analysis 1: Crop yield

Figure 33 shows a comparison of agricultural production outputs in the three simulation runs. The second policy set creates a production pattern that is similar to the base run. Crop production discrepancies between the base run and the second policy set are due to price changes and interventions on annual extraction capacity. The first policy set, on the contrary hand, results in a severely different production pattern; green plant production is halved, instead sugar beet production is five times more than in the base run.

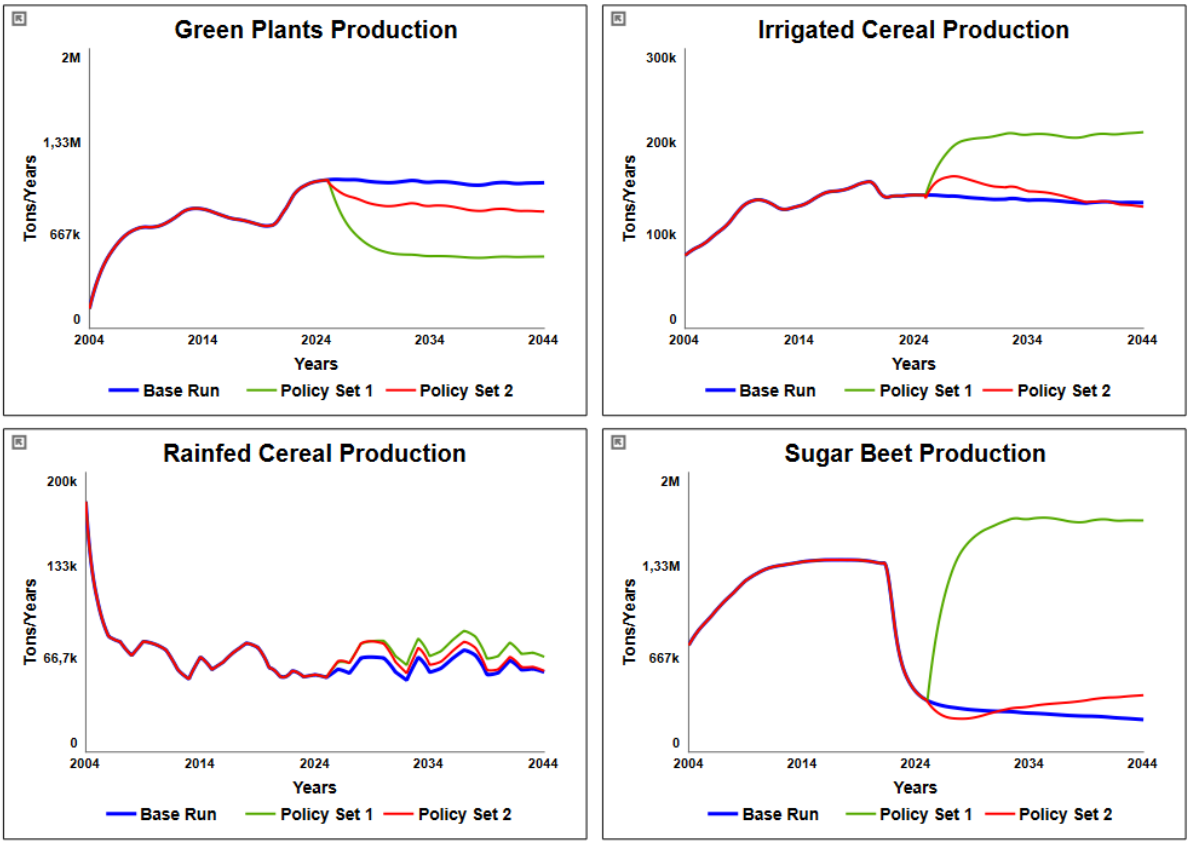

Figure 33. Integrated policy analysis 1: Crop production

Finally, in Figure 34, we compare the efficacy of the two policy settings in terms of overall profit. The first policy set outperforms the second from 2025 to the end of the simulated period. However, they differ in terms of behavioural characteristics; while the first policy set initially boosts profit but later declines, the second policy set initially reduces total profit but then follows an increasing trend.

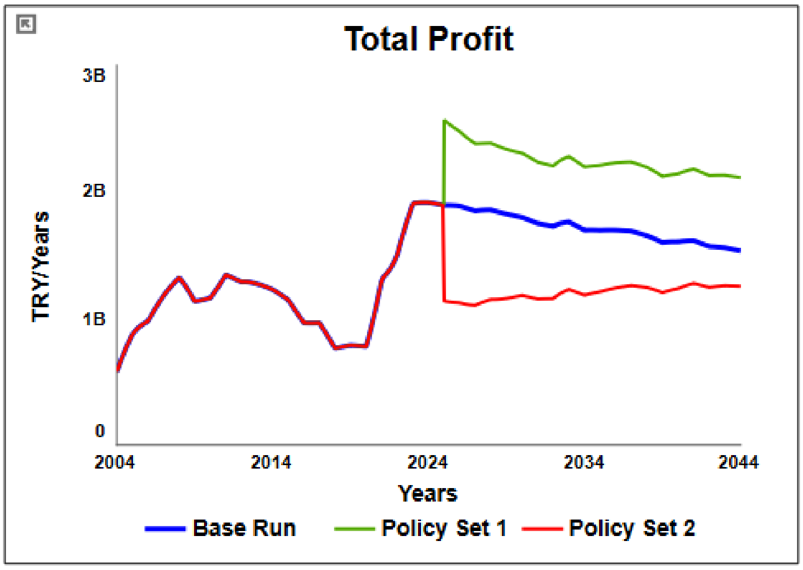

Figure 34. Integrated policy analysis 1: Total profit

3.2. Mixed Policy Set

Table 4 presents the Policy Set 3. It is a hybrid of the first two policy sets. The transfer of surface water from the Blue Tunnel is involved in this policy set. New wells are entirely prohibited from 2025 to 2030. For the green plants, a 2-year crop rotation set up is in place, as well as an annual extraction cap of 100.000 hm^3/well. Cereal prices have been pushed up by 50%, and sugar beet prices have been doubled. Lastly, the unit price of electricity is decreased by 33%.

Table 4. Policy set 3

Policy Options	Policy Set 3
Surface Water Transfer	300 hm^3/year
Well Regulation	Prohibition of New Wells (2025 – 2030)
Crop Rotation	Green Plants, 2 years
Extraction Cap	100.000 hm^3/well/year
Crop Repricing	Cereal Price: 50% increase Sugar Beet Price: 100% increase
Electricity Repricing	0,5 TRY/kWh (33% reduced)

Figure 35 compares the third policy set's simulated groundwater level, to the prior policy settings and the base run. The graph shows that policy set 3 outperforms the prior two policy sets in terms of groundwater conservation.

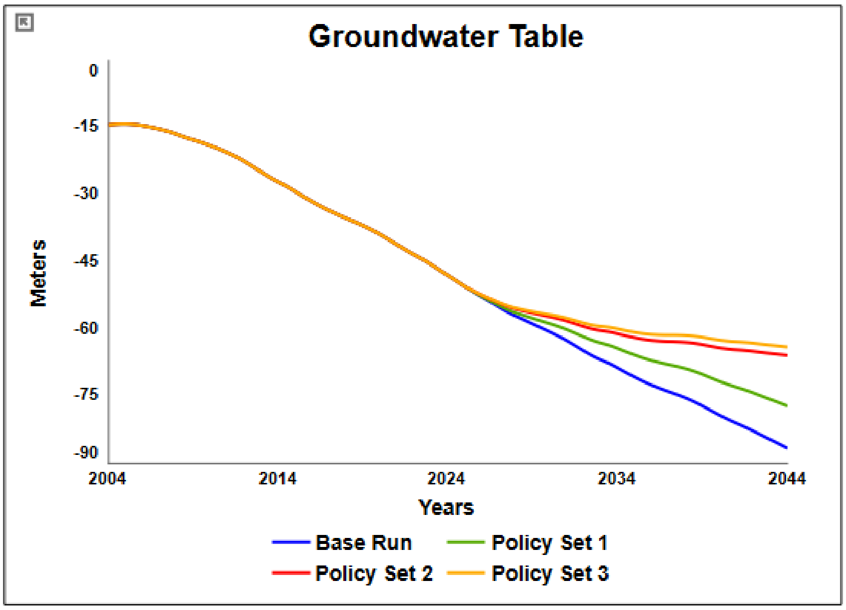

Figure 35. Integrated policy analysis 2: Groundwater level

The third policy set produces similar behaviour patterns in the number of active wells and average power, with those of the second policy sets (Figure 36). When compared to the base run and the first policy set, the prohibition on new wells and the extraction cap minimizes the necessity to increase the existing number of wells and improve the average pump power.

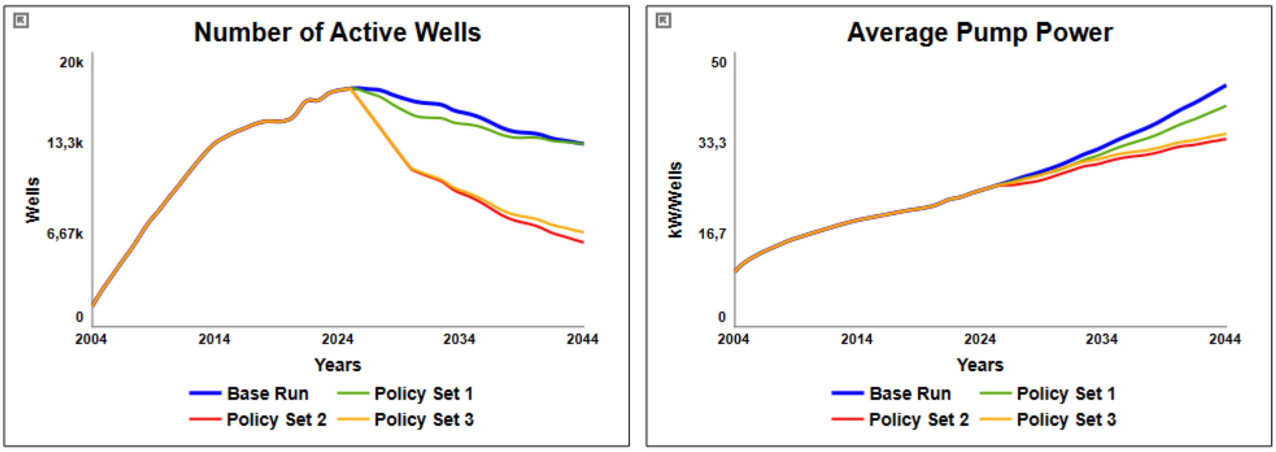

Figure 36. Integrated policy analysis 2: Number of active wells and average pump power

The crop land cover in the three policy sets and the base run are depicted in Figure 37. Land cover in policy sets 1 and 3 are nearly identical because crop and power price changes are equal in these two policy sets.

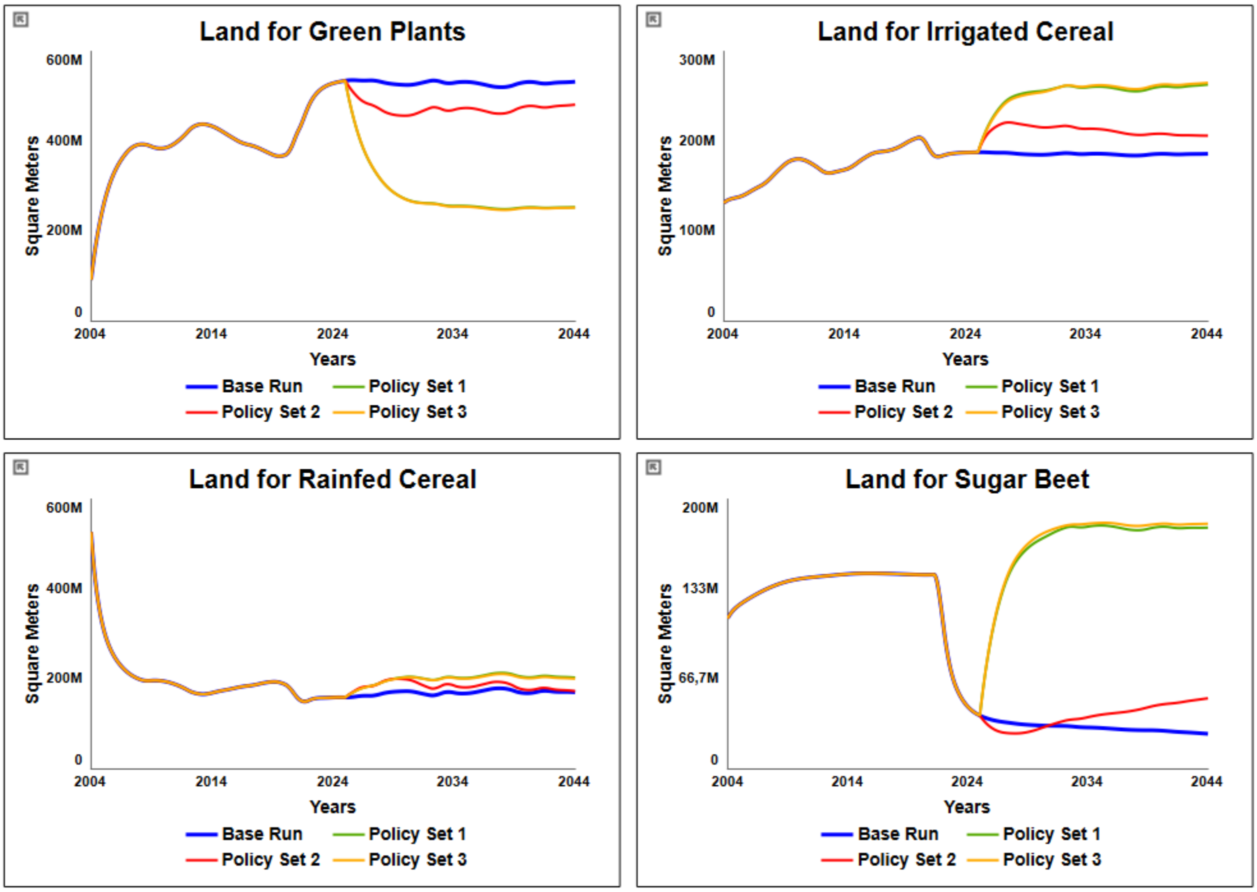

Figure 37. Integrated policy analysis 2: Crop land cover

Figure 38 depicts crop irrigation levels. The outcomes of green plants and sugar beet irrigation in policy set 3 are notably similar to those of policy set 2. Policy set 3's cereal irrigation level, on the other hand, is greater than policy set 2 and the base run, but lower than policy set 1.

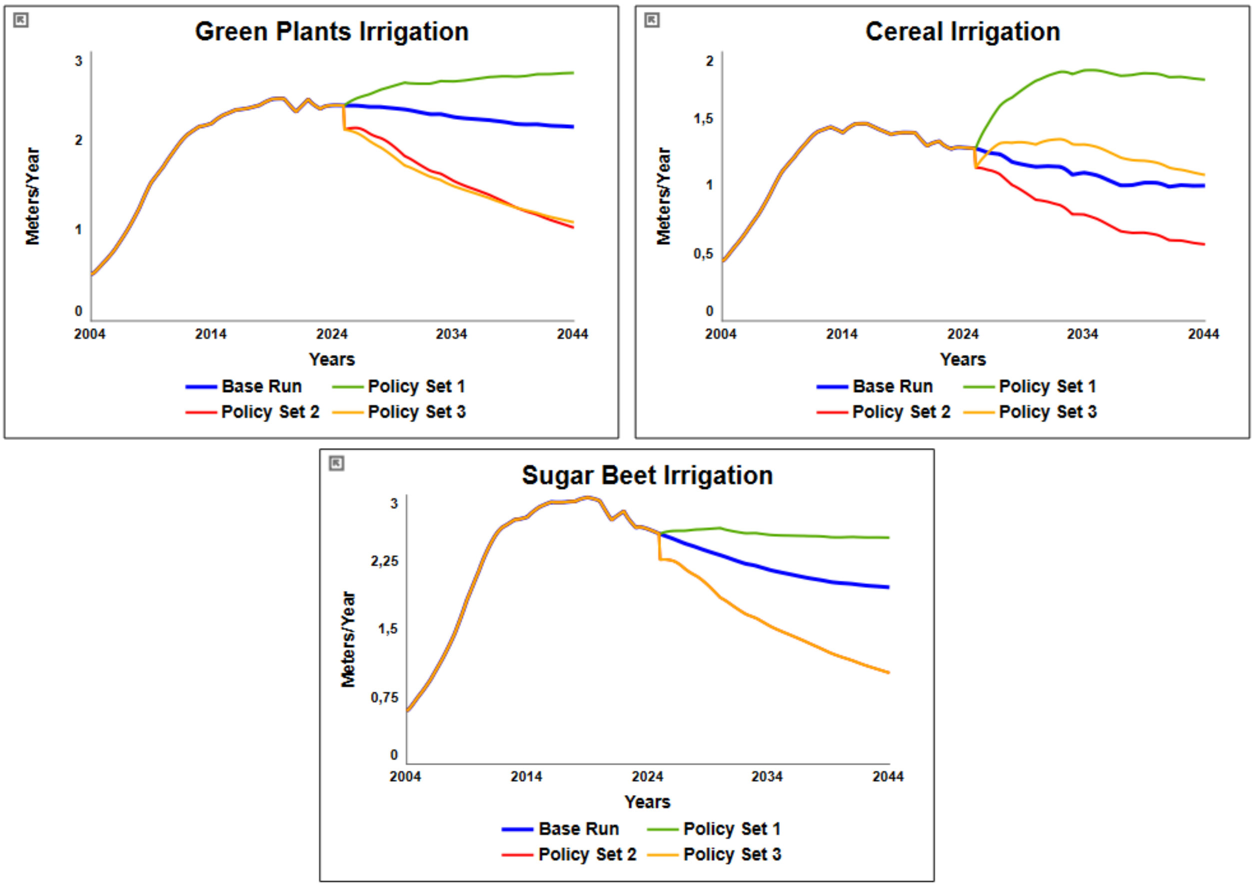

Figure 38. Integrated policy analysis 2: Crop irrigation

As we observe in Figure 39, the behaviour trends in crop irrigation are reflected in crop yields. As a result, under the third set of policies, green plant and sugar beet yields decline to policy set 2 levels, and irrigated cereal yield increases modestly relative to the base run.

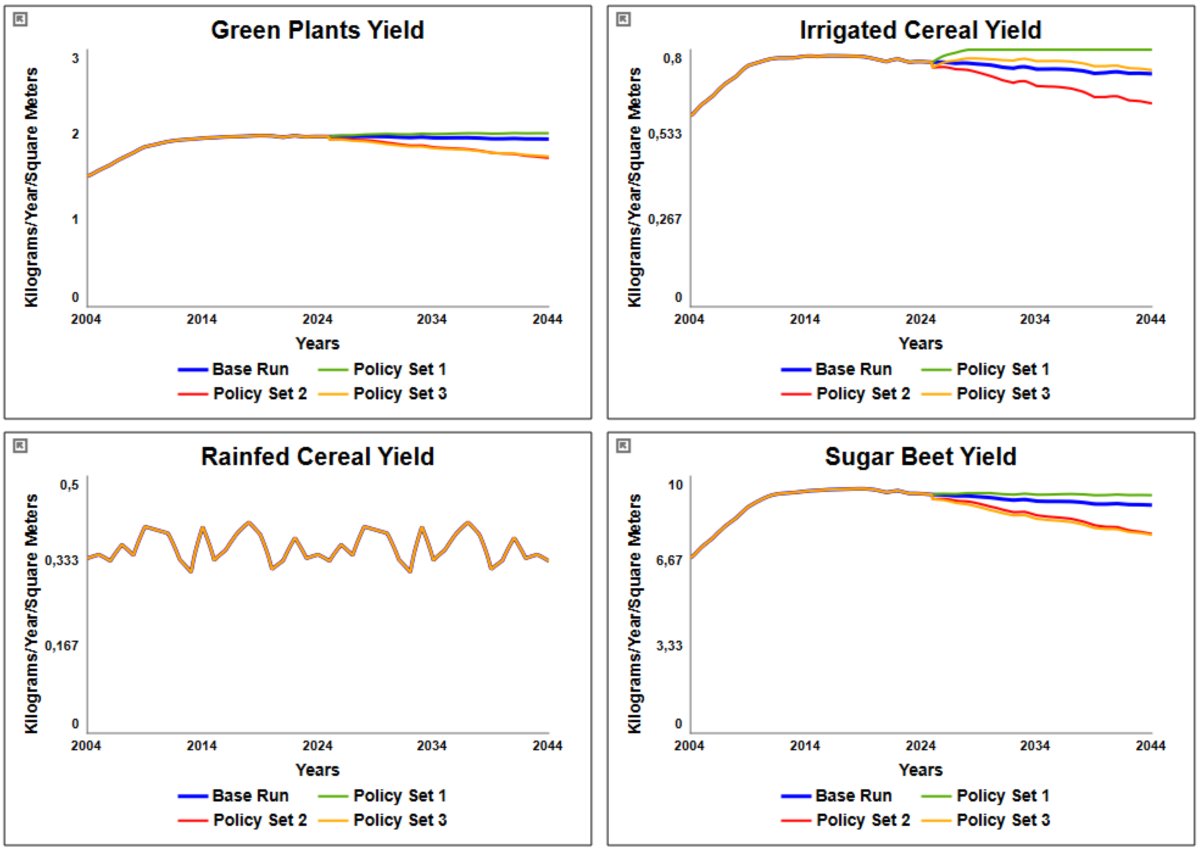

Figure 39. Integrated policy analysis 2: Crop yield

The agricultural production outputs are displayed in Figure 40. Among the three policy sets, green plants production is lowest in the third one, but it is close to that of the first policy set. Similarly, the irrigated cereal and sugar beet production are much higher than in the base run and the second policy set, but lower when compared to the first policy set.

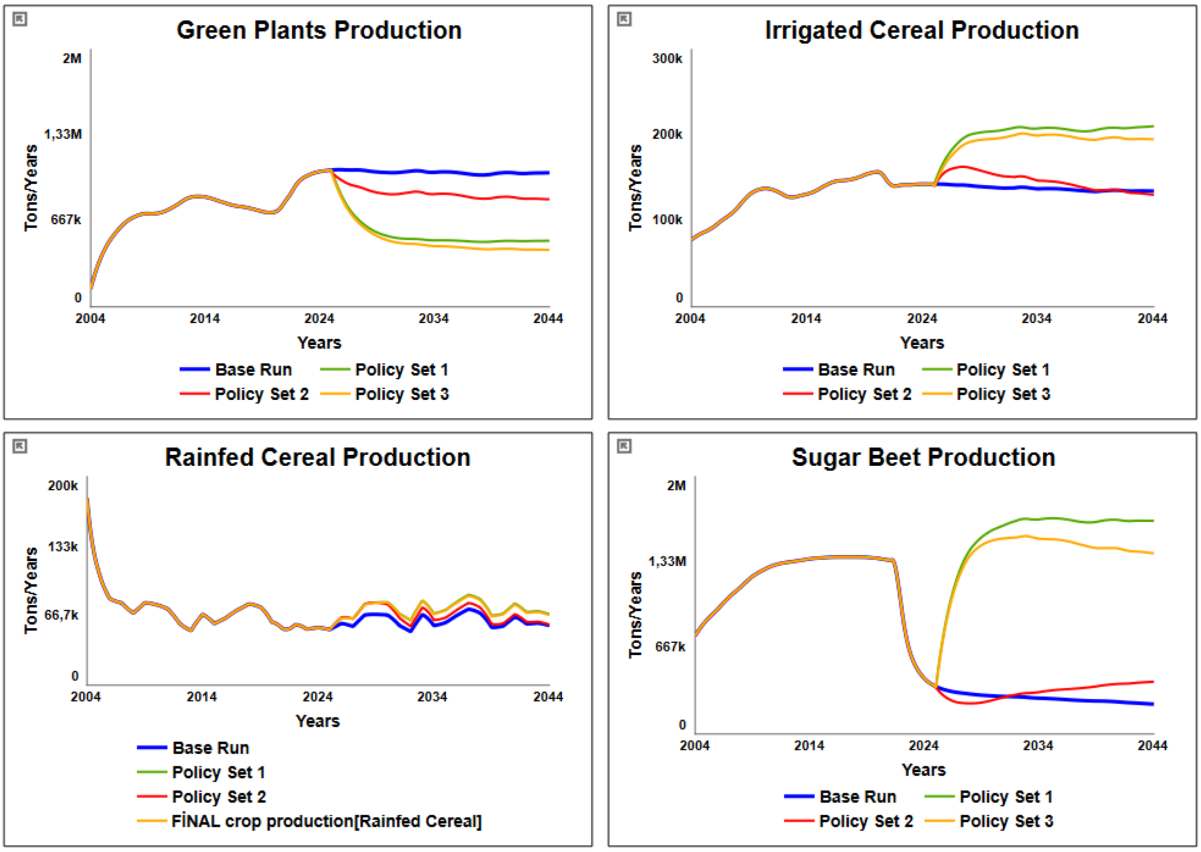

Figure 40. Integrated policy analysis 2: Crop production

Finally, in Figure 41, we compare the overall district profit in the third policy configuration to the prior two. In terms of profit, the third policy set appears to outperform the others.

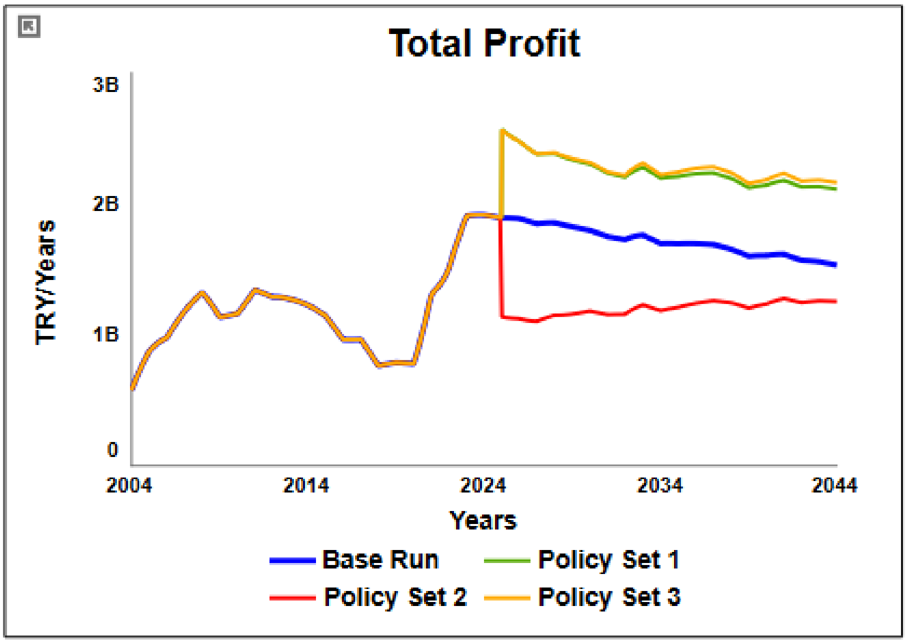

Figure 41. Integrated policy analysis 2: Total profit

4. Discussion and Conclusion

In this document, six policy scenarios are tested and analysed on the dynamic simulation model built as part of the WP4. All of the policy scenarios are based on discussions with stakeholders in semi-structured interviews as well as conversations from the living labs. The policy analyses are thoroughly explained in Section 2. Following that, an integrated policy analysis is carried out. First, the policies are classified into two groups based on whether or not they are favourably welcomed by agricultural communities. The objective of such a grouping is to investigate the system behaviour under various policy settings and assess if the policies commonly preferred by farmers would be effective in achieving their goals, or whether the policies they wish to avert would result in an economic downfall for them, as they anticipate.

Policies favoured by farmers include crop rotation, higher amounts of surface water transfer, rises in cereal and sugar beet prices, and reduced electricity price. This policy set can help increase total production and profit. It also delays the dip in the groundwater level, implying that it is more water-conserving than the base run. However, it does not reverse or halt the drop in groundwater level; rather, it appears that these regulations just postpone groundwater depletion.

Farmers use their lobbying power to prevent the enforcement of measures in the second policy set, which includes prohibition of new wells, groundwater extraction cap, price reduction for green plants, and price rise in unit electricity. With this strategy in place, the downward trend in the groundwater level is significantly halted and may achieve equilibrium in the far future beyond the model time horizon. However, the profit generated by this set of policies is lower than the business-as-usual scenario. As a result, it is possible to argue that farmers have a valid reason to oppose these measures.

Nonetheless, after analysing the strengths and limitations of each policy set, we seek for a third set of policies, a mix of the first two sets, to determine whether a different configuration of policies can exceed both of the previous policy sets in terms of environmental and economic indicators. We employ the following policies in the third set: surface water transfer from the Blue Tunnel project, prohibition of new wells from 2025 to 2030, a 2-year crop rotation scheme for green plants, an extraction cap of 100 hm^3/well annually, a 50% rise in cereal and 100% rise in sugar beet prices, and 33% reduction in electricity prices. We find that the third policy set outperforms the others because it conserves groundwater more while improving total agricultural production and overall district profit. Therefore, the key is to come up with a set of policies that work well as they interact within the system, and a well-designed set of policies can sustain the groundwater resources without having to compromise production or profitability.

5. References

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