COST-BENEFIT-ANALYSIS

Infrastructure improvements for irrigated agriculture in the Guadalquivir Basin, Tarija

The San Jacinto dam was built south of the city of Tarija in 1984 in order to provide water for electricity generation and irrigation, as well as to promote tourism in the area. Located in a basin that contributes approx. 240 hm³/year, the dam has a total capacity of 50 hm³, of which approx. 90% are destined to electricity generation and 10% are destined to irrigation (Castillo, G., 2019). This situation is changing due to the expansion of agriculture in the basin, greater demands for irrigation, lower demand of water for electricity generation and climate change.

In the framework of the Territorial Plan for Integrated Development of the department of Tarija (GADT 2021), the Management Plan of the Guadalquivir basin and the goals of the national Plan for Economic and Social Development (MPD 2021) and Nationally Determined Contributions (MMAYA and APMT 2021) related to increased water storage capacity and expansion of cropland, among others, the optimization of the so-called “San Jacinto-CENAVIT-Calamuchita Irrigation System” has been prioritized. This system transports water from the San Jacinto dam to the grape-cultivated area of the Central Valley of Tarija and up to the Calamuchita region (southeast) where mostly maize and vegetables are cultivated (Figure 1).

1 The energy demand may be covered to a greater extent by the National Interconnected System in the following years
What can be expected in the future?

Agricultural development in the basin is expected to change in the coming years, focusing especially on the introduction of high-value crops like strawberries. This places two requirements: 1) intensification of agricultural practices and 2) water in sufficient quantity.

Intensification aims to generate optimal production (both in quantity and value) on a limited area of land. This can be achieved through strict control and treatment of the crop and the agro-inputs used, as well as through the adoption of technology for efficient irrigation and harvesting, among others. Given the interest of farmers, in recent years they have improved their capacities regarding access to information on new inputs in the market and incentives for the cultivation of new products.

Water management for crops requires strict and measurable control, especially in Tarija, since it is a region vulnerable to extreme weather events. As shown in the main report, the frequency of extreme droughts could increase in the future and the projected flow changes for the San Jacinto dam are negative in the medium term. Although Tarija is the department with the largest quantity and density of water reservoirs in the country, the distribution and use of water for agriculture are very inefficient. Up to 50% of the water allocated for irrigation is wasted due to pipe leaks, evaporation, and infiltration in irrigation canals (El País, 2021). This situation is unsustainable considering that high-value crops have high water requirements. For example, using drip irrigation systems, strawberry requires approx. 45,000 litres of water per Ha each month.

In this context, it’s necessary to analyse investment alternatives that are robust, that is,
investments that cover both the need for intensification and the demand for water for irrigation in future climatic conditions, different from the current ones.

**Justification**

In the Guadalquivir River basin and in the San Jacinto Irrigation System in particular, (Figure 1) several options have been considered, including changes in the management of the dam, construction of new reservoirs, rehabilitation/change of existing infrastructure and more efficient irrigation systems. The costs of these alternatives vary, and are high in proportion to the available public and/or private financing capacity.

The current management of the dam requires that the reservoir be kept as full as possible during and after the rainy season, in order to dispatch as much water as possible during the dry season. For power generation, water delivery during the dry season can be constant, since there are usually no significant seasonal differences in power demand. However, the provision of water for irrigation requires finding a balance between adequate reservoir levels and the required water supply according to the vegetative cycle of crops and drought conditions. Figure 2 shows this difference, projected into the future and considering global warming conditions SSP1-2.6 and SSP5-8.5. No significant differences are perceived between the two climatic conditions (because there are no major changes in water flow to the dam due to climate change). This means that the management of water levels in the dam is the only factor that would influence water supply in the San Jacinto Irrigation System in the future.

![Figure 2. Monthly average flow of the San Jacinto dam, simulated by SWIM using 10 CMIP6 models. A constant power generation of 1.3 MW/day and water requirement for strawberry cultivation are considered.](image)

2 Shared Socioeconomic Pathways (SSP) are the future global warming scenarios established by the Intergovernmental Panel on Climate Change. These describe different possible climatic conditions influenced by socioeconomic development and their corresponding greenhouse gas emissions. The values 2.6 and 8.5 are radiative forcing values that result in global warming between 1.9 and 5°C in 2100.
Although changing the water allocation regime of the San Jacinto dam is a flexible and economic option, in which it is possible to make changes in water dispatch both in the short and long term, this option only partially solves the water requirement. Given that currently a large amount of sediment has accumulated in the dam and the main irrigation pipe shows considerable wear (producing leaks and less flow for irrigation), this measure does not meet the needs of agricultural intensification either.

For this reason, this Cost-Benefit-Analysis investigates whether the investment into improved irrigation infrastructure and the pipe remodelling make sense from an economic point of view, given the expansion of cultivated land planned for the next decades.

**Metodología**

A Cost-Benefit Analysis (CBA) is a comparison of costs and benefits. Hence, model output parameters reflect this comparison:

1. **The net present value (NPV):** this indicator represents the benefits minus costs calculated at their present value, i.e. using a discount rate for future benefits and costs. If the calculation leads to a positive NPV, then an adaptation measure makes sense from an economic point of view.

2. **The Benefit-Cost-Ratio (BCR):** simply is the ratio of benefits to costs. Any BCR above 1 makes sense from an economic point of view since in such a case the benefits are higher than the costs. The larger the BCR becomes, the better the adaptation option shall be judged.

3. **Internal rate of return (IRR):** it can basically be considered the interest rate an adaptation option would generate for the society. Technically speaking, the IRR is the discount rate at which the NPV becomes zero. Hence, a resulting IRR higher than the discount rate to be chosen is a good sign. However, no distinct value can be provided at which an IRR should be considered as economically reasonable.

4. **Net cash flow:** Net cash flow is the difference between the cash inflows and outflows within a given time period.

The methods factsheet attached to the Climate Risk Report includes more details on the rationale of CBA.
Baseline and Scenarios

Baseline

The San Jacinto dam is slowly becoming an obsolete infrastructure. Due to illegal settlements around the catchment area, more and more sediments are accumulating in the reservoir and irrigation pipes are corroding. According to SIHITA (2023) and GADT (2019), the San Jacinto irrigation system covers 2,975 ha of agricultural land (Figure 3), with parcels of different sizes and crops (Table 1). Generally, only a small part of the parcels (3.16 %) is cultivated with strawberries (GAD Tarija, 2019). For this analysis, parcels in the size range of 2-10 Ha and 10-60 Ha have been considered, since parcels whose size is less than 1 Ha may only have 1 type of crop (corn, grapes or other) and parcels that have a size greater than 60 Ha may already have an irrigation system installed.

![Figure 3. Productive plots in the San Jacinto Irrigation System](image)

Table 1. Characteristics of the San Jacinto irrigation system

<table>
<thead>
<tr>
<th>Size of parcels (Ha)</th>
<th>Number of parcels</th>
<th>Total area of parcels (Ha)</th>
<th>Estimated area of parcels with strawberry crops (Ha)</th>
<th>Drip irrigation</th>
<th>Included in the CBA</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 Ha</td>
<td>152</td>
<td>111,78</td>
<td>0</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>2 – 10 Ha</td>
<td>104</td>
<td>476,84</td>
<td>15,1</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>10 – 60 Ha</td>
<td>66</td>
<td>1693,00</td>
<td>53,5</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>&gt;60 Ha</td>
<td>4</td>
<td>693,00</td>
<td>21,9</td>
<td>yes</td>
<td>No</td>
</tr>
</tbody>
</table>

Source: Prepared by the authors based on the Tarija Water Information System (SIHITA, 2023) and GADT (2019).
Scenario 1: Adaptation (action, climate change impacts)

In the adaptation scenario, by 2050, successive parts of the irrigation pipeline are renewed: the first 6 km by 2025, another 6 km by 2030 and another 13 km by 2050, increasing the water flow capacity from 1,000 l/s to 1,700 l/s. In parallel, small reservoirs and tanks are introduced to meet the irrigation needs of medium-sized plots that are far from the mains. Also, drip irrigation systems are installed to promote efficient water use for irrigation. The costs and benefits of this scenario are projected up to 2050 compared to the baseline.

Scenario 2: No adaptation (no action, climate change impacts)

In the non-adaptation scenario, as mentioned above, the San Jacinto-CENAVIT-Calamuchita Irrigation System slowly becomes an obsolete infrastructure. Enough resources for public investment are not available, so the pipeline is not renewed, and small reservoirs are not built. In consequence, agricultural land cannot be expanded and the irrigation demand of over 1,100 farmer families is not covered.

The changed climate conditions affect the overall availability of water in the reservoir. The costs and benefits of this scenario are projected to 2050, assuming climate change impacts in scenarios with global warming of SSP1-2.6 and SSP5-8.5 with reference to the baseline.

Input data

Yield simulations under climate change

The hydrological modelling shows a tendency to increased water availability in the Guadalquivir basin up to more than 20 percent, especially during the rainy season and under high global warming (SSP5-8.5). The overall increases in precipitation and temperature are favorable and strawberry yields profit from the warming and that slight increase (20%) in precipitation. As enough water is available in the rainy season, irrigation happens only in the dry period. Two harvests are considered in the wet season and an additional one with irrigation in the dry season. The increasing temperatures lead to more water demand and transpiration by the plants, but are compensated by the increase in precipitation, and the increase in actual transpiration is accompanied by increases in biomass and finally yields.

To include the climate change effects on yield
Development until 2050, crop yields for strawberries were simulated using the Soil and Water Integrated Model (SWIM), which translates the simulated climate conditions into hydrological processes, water resources and finally into changes in yield. The model includes the effects of drip irrigation in the adaptation scenario versus the effects of flood irrigation in the non-adaptation scenario.

**Figure 4.** Change in strawberry crop yield under future climate change scenarios and irrigation conditions. No adaptation = flood irrigation; adaptation = drip irrigation. Future climate projections are shown for the near future (FC; 2015-2045), middle future (FM; 2035-2065), and far future (FF; 2065-2095). Baseline period 1985-2015.

**Costs**

Costs have been calculated taking into account the following:

**Table 2. Investments in irrigation**

<table>
<thead>
<tr>
<th>Size of parcels (Ha)</th>
<th>Area with strawberry crops (Ha)</th>
<th>Characteristics</th>
<th>Investments</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1</td>
<td>0</td>
<td>Parcels dedicated to staple crops or subsistence farming. No strawberry crops are planned for this producer segment</td>
<td>No investments are allocated for this group</td>
</tr>
<tr>
<td>Size of parcels (Ha)</td>
<td>Area with strawberry crops (Ha)</td>
<td>Characteristics</td>
<td>Investments</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------------------</td>
<td>-----------------</td>
<td>-------------</td>
</tr>
<tr>
<td>2 – 10</td>
<td>15.1</td>
<td>Parcels with diversified production, mostly staple crops and vegetables. Farmers have started to plant strawberries, but water supply and investment constraints are often a barrier for improvements.</td>
<td>Small water reservoirs with approx. 5,200 liters capacity each are constructed to supply water to clusters of 10 parcels. Water from these reservoirs is distributed through canals to the respective parcels. Additionally, there is an initial investment of 27,000 Bs per hectare for the installation of the drip irrigation system, which needs renewal every 5 years. Annual maintenance and operation cost for the drip irrigation system is 5,860 Bs per hectare.</td>
</tr>
<tr>
<td>10 – 60</td>
<td>53.5</td>
<td>Parcels already have technified irrigation systems in place</td>
<td>No additional investments are required for this producer segment</td>
</tr>
<tr>
<td>&gt;60</td>
<td>21.9</td>
<td>Parcels already have technified irrigation systems in place</td>
<td>No additional investments are required for this producer segment</td>
</tr>
</tbody>
</table>

Source: Prepared by the authors

### Investment and production costs

<table>
<thead>
<tr>
<th>Cost item</th>
<th>Unit cost (Bs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small reservoirs (renewal after 20 years)</td>
<td>56,000/piece</td>
</tr>
<tr>
<td>Tank 5,000 litres (renewal after 20 years)</td>
<td>5,000/piece</td>
</tr>
<tr>
<td>Pipe change</td>
<td>21.7 Mio/km</td>
</tr>
<tr>
<td>Installation of drip irrigation system (renewal every 5 years)</td>
<td>27,000 Bs/ha</td>
</tr>
<tr>
<td>Maintenance and operation of drip irrigation system</td>
<td>5,860 Bs/ha/ year</td>
</tr>
<tr>
<td>Strawberry production cost</td>
<td>55,000 Bs/ha/ year</td>
</tr>
</tbody>
</table>

Cost estimations based on various public sources

The cost per hectare and unit is applied to the land expansion of 1,964 ha under SSP1- 2.6 and 2,023 ha under SSP5- 8.5 by 2050 as described in the adaptation scenario.

### Benefits

In addition to the benefit of cropland expansion for high-value crops, the investments in the San Jacinto Irrigation System can also have other benefits, as described below. Nevertheless, not all benefits have been included in this analysis as some cannot be expressed in monetary terms or are out of the scope of a CBA.
Table 3. Potential benefits

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Explanation</th>
<th>Monetized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water use efficiency</td>
<td>The use of tanks and reservoirs allows the farmers to control closely their water consumption and fosters rational use. The introduction of strawberries and similar crops that require efficient irrigation methods (like drip systems) also promote a rational use of water resources in the agricultural sector.</td>
<td>No</td>
</tr>
<tr>
<td>Loss reduction and equitable distribution</td>
<td>The expansion of the San Jacinto Irrigation System can facilitate an equitable distribution of water resources among farmers.</td>
<td>No</td>
</tr>
<tr>
<td>Increased resilience to climate change</td>
<td>The construction of reservoirs and/or tanks do not only serve as a complement to the main infrastructure – they can also serve as rainwater harvesting devices and provide water for subsistence in case of heavy drought periods.</td>
<td>No</td>
</tr>
<tr>
<td>Economic reactivation</td>
<td>High-value crops like strawberries increase farmers' revenues.</td>
<td>Producer price (10 Bs/kg)</td>
</tr>
</tbody>
</table>

Assumptions

To conduct the CBA, the previous data had to be complemented with the following assumptions:

- By increasing the water flow capacity of the pipelines and optimising the irrigation system it is assumed that additional areas can be planted with strawberries. As the pipe renovation moves on and farmers start to adequate their parcels, the irrigated area is projected to increase gradually, assuming by 1,964 ha under SSP1-2.6 and by 2,023 ha under SSP5-8.5 until 2050.

- The average water use decreases by 66 percent when switching from flood to drip irrigation under the SSP1-2.6 emission scenario. Under the pessimistic emission scenario SSP5-8.5, an average decrease in water demand of 68 percent is assumed.

- It is assumed that the productivity of the farmers’ area increases due to autonomous technological change by 1.89 percent per year. This is an extrapolation of previous strawberry yield increases over the last 45 years in Bolivia (FAOSTAT, 2022).

- To depict the inflation rate, we calculated the exponential growth rate of the Gross Domestic Product per capita of Bolivia from the last 50 years, its value is 3.68 % (FAOSTAT, 2022).

- It is assumed that the area to be cultivated with strawberries has been fallow. This means that no opportunity costs are applied.
Results

The results of the CBA clearly demonstrate the economic viability of investing in dam infrastructure improvements, introducing small reservoirs and tanks to meet the irrigation needs of medium-sized plots, and optimizing irrigation system in the long term. Under both low and high emission scenarios, the benefits significantly outweigh the costs, with positive Net Present Values and favorable Benefit-Cost Ratios.

Under the low emission scenario, the investment pays off from 2029 onwards, while under the high emission scenario the breakeven point is marked in 2030. These are the years when the cashflow becomes positive for the first time. In 2050, and under SSP-2.6 the net cash flow reaches 187,551,885 Bs for the entire area under consideration of 3,602.2 ha. This means a cash flow per ha of 52,066 Bs. Under the pessimistic scenario SSP-8.5, the net cash flow for the entire area under irrigation of 3,646.6 ha in 2050 is 209,685,748 Bs. This results in a net cash flow per year and ha of 57,502 Bs.

The Internal Rate of Return (IRR) is very positive and yields 16.98 percent for the SSP1-2.6 scenario and 15.34 percent for the SSP5-8.5. In total, for both scenarios, the benefits outweigh the costs being 1.42 times as high under the SSP1-2.6 scenario and 1.41 as high under the SSP5-8.5 scenario.

The Net Present Value (NPV) is calculated for a gradually increasing area as described above. In 2050 and under a low emission scenario, the NPV yields more than 784 million Bs for an area of 1432.2 ha and more than 770 million Bs for an area of 1475.4 ha under the high-emission scenario.

**Table 4. Key economic indicators**

<table>
<thead>
<tr>
<th></th>
<th>Adaptation under SSP1-2.6</th>
<th>Adaptation under SSP5-8.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRR</td>
<td>16.98 %</td>
<td>15.34 %</td>
</tr>
<tr>
<td>NPV</td>
<td>784,078,527 Bs</td>
<td>770,097,918 Bs</td>
</tr>
<tr>
<td>BCR</td>
<td>1.42</td>
<td>1.41</td>
</tr>
</tbody>
</table>
Discussion

While a CBA is a valuable tool for evaluating the economic feasibility of a project, there are several limitations and challenges that may arise. While this analysis focuses on monetary costs and benefits, important social and environmental considerations such as the impact on local communities, biodiversity, and ecosystem functions are not captured. To overcome these limitations of underestimating certain aspects, it can be valuable to complement the CBA with other assessment tools, such as environmental impact assessments, social impact assessments, and stakeholder consultations, to provide a more comprehensive understanding of the implications of adaptation measures (e.g., infrastructure improvement).

For long-term projects like the dam infrastructure development, accurately predicting costs and benefits over an extended period is challenging since changes in economic conditions, technology, and environmental factors are uncertain and may not be fully accounted for which introduces uncertainty into the analysis. This is related to the fact that CBAs rely on various assumptions, and the results can be sensitive to changes in these assumptions. Small variations in parameters, such as discount rates or market prices, can significantly affect the outcome of the analysis. For example, if the market price of strawberries increased by 20 percent, the IRR would change from 16.98 to 26.61 percent under SSP1-2.6 and from 15.34 to 23.54 percent under SSP5-8.5. The BCR would change from 1.42 to 1.70 percent under SSP1-2.6 and from 1.41 to 1.69 under the pessimistic scenario SSP5-8.5. Another variable that has a big influence on whether the project is economically valuable is the cost for pipe renovation and the cost for strawberry
production itself. At 55,000 Bs per hectare per year these are high and if they were to fall, it would immediately have a significant impact on the results. Furthermore, it’s essential to note that this analysis focuses solely on the cultivation of strawberries. The more plausible situation involves a diverse range of crops being cultivated, each with distinct water demands.

**Conclusion**

In conclusion, the investments proposed in the San Jacinto dam basin hold great promise for the region’s economic prosperity, agricultural sustainability, and climate resilience. They represent a proactive response to the challenges posed by climate change and evolving agricultural demands. They not only offer economic returns but also pave the way for sustainable agricultural development. By enabling the cultivation of high-value crops, such as strawberries, and promoting efficient water use through drip irrigation, they align with the goals of enhancing agricultural productivity while conserving resources. However, careful and responsible implementation, coupled with adaptive planning, is crucial to realizing these benefits while safeguarding the environment and ensuring the equitable distribution of gains.
References


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