HYPOWAVE

Concept for sustainable wastewater treatment and water reuse in the Alentejo, Portugal

A HypoWave Case Study

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1. New pathways towards water reuse in agriculture

Limited water resources and increasing demand for domestic, industrial, agricultural and other uses poses a serious challenge to regional, national and international politics. Climate change, urbanisation and pollution of water resources aggravate the situation and bear the potential of conflicts in decades to come. New concepts and methods for water reuse might alleviate the local lack of water and improve the quality of surface and groundwater resources.

In the research project "HypoWave – Use of hydroponic systems for resource efficient water reuse in agriculture", a concept was developed and tested that couples domestic wastewater treatment with hydroponic plant production. The wastewater treatment in this concept is composed of a modular system that combines biological treatment, filtration and disinfection. The optimal combination depends on influent quality, pretreatment and effluent quality demand. Once treated, the water is used in a hydroponic plant growth system that does not contain soil. Compared to conventional crop production, the hydroponic system reduces water and nutrient losses to an absolute minimum. The plants growing in the hydroponic system under addition of small amounts of micronutrients remove efficiently residual nutrients from the treated wastewater and capture metals in their dense root mat. Thus, the nutrient load is reduced to a level that allows direct discharge into water bodies. Additional disinfection and removal of micropollutants from the wastewater can be achieved by activated carbon filtration, ozonation and UV radiation depending on the local requirements.

The concept has been thoroughly tested in a pilot installation at the Hattorf wastewater treatment plant near Wolfsburg in Germany between 2017 and 2019. Results show that lettuce, the plant used for system validation, grows vigorously even at the low inherent nutrient concentrations of the treated domestic wastewater. Hence, enough water, nitrogen, phosphorus and most other nutrients are provided while the concentrations of micropollutants and pathogens are minimised (cf. Bliedung et al. 2019).

Case studies were conducted at four different sites in Germany, Belgium and Portugal to estimate the potential of the concept in contrasting environmental and social settings. These case studies were developed by interdisciplinary teams. The disciplines represented were urban water management, crop production, social sciences and landscape design. Together with the local actors, beneficial and inhibiting factors for the use of the specifically treated wastewater in hydroponic systems have been discussed in order to elaborate appropriate regional applications of the concept. Case study reports integrate and summarize the intermediary results, thus providing a basis for informed decision making.

This case study focuses on the application of the HypoWave concept in the village of Albernoa, southwest of the City of Beja. The aim is to demonstrate an alternative pathway tailored to the actual local conditions for domestic wastewater treatment and water reuse. Beyond technical considerations, the necessary interaction of key actors involved at local, regional and national level and their responsibilities are discussed.

2. Potentials for the Alentejo region

The Portuguese region Alentejo stretches from the Atlantic coast south of Lisbon to the Portuguese-Spanish border above the Algarve. The population structure in the region is heterogeneous and the levels of implemented wastewater infrastructure varies vastly. The Alentejo is a semi-arid region with annual precipitation usually below 600 mm. While the amount of average annual precipitation is comparable to Central Europe it occurs concentrated from October to March and does not exceed the annual evapotranspiration. Spring precipitation is becoming more erratic and decreases in comparison with the long-term average. Beyond the negative water balance, the erratic occurrences of precipitation events within and between the years challenges rain-fed agriculture. At least once in every decade severe droughts caused crop losses as a review of precipitation and yield data from the past 70 years reveals (Vizinho et al. 2015). Furthermore, with increasing distance from the coastline, low temperatures limit plant production in winter (cf. Lorleberg 1994: 62/63).

The national climate adaptation strategy comprises three pathways to which the HypoWave approach can contribute: a) more efficient water use in irrigated agriculture, b) strengthening the role of agriculture in protecting soil and water, and c) increasing capacity by storing water (cf. MAMAOT 2013). In recent years, the water management focus in the Alentejo has been set on establishing new irrigation infrastructure and construction of reservoirs. The Alqueva Dam created the largest artificial lake in Western Europe (cf. Estrela 2009; Vizinho et al. 2015: 21). Since flooding the area, the microclimate in the region has changed and the air humidity increased, making fog a common weather feature. The irrigation infrastructure for agriculture and the Santa Clara dam in south-west Alentejo date back to state investments in the 1960's. Recently, the water demand of the growing number of producers could not always be satisfied.

As of 2011, only one percent of the treated wastewater (6.1 million m^3/a) is reused. The potential for water reuse in contrast is estimated at 67 million m^3/a in 2025 (Gancheva et al. 2018). To realise this potential, a massive investment in the wastewater infrastructure would be required, as the Water Framework Directive (2000/60/EC) demands high ecological and chemical standards for surface waters. Águas Públicas do Alentejo (AdgA) is a joint organisation, integrating Águas de Portugal and municipalities, responsible for fresh water supply and sanitation in 21 municipalities (cf. AdP 2017: 88). Smaller wastewater treatment plants are operated autonomously by the municipalities. Larger plants are under the directive of AdgA. During the past ten years, AdgA invested over 70 million euros in infrastructure of which 28.5 million euros were dedicated to the wastewater infrastructure. The latter investments were aimed to upgrade wastewater treatment plants that were subject of infringement proceedings initiated by the EU Commission due to non-compliance with the Municipal Wastewater Directive. AdgA's investment plans for the period 2016 – 2020 provide a total of 108 million euros, including 34.8 million euros for wastewater infrastructure (AgdA 2016). Linking these public investments with alternative treatment and water reuse solutions would contribute to ecological sustainability and support the AgdA's objective to promote regional economic development (cf. AgdA 2016). New perspectives due to the availability of new water resources for irrigation in agriculture could minimise the tendency of rural citizens moving to the urban centres (cf. Gonçalves 2016: 25; Vizinho et al. 2015: 8). A newly designed production system could also be more adapted to the needs of rural workers. For example, a year round production mode could be more attractive than the currently offered seasonal

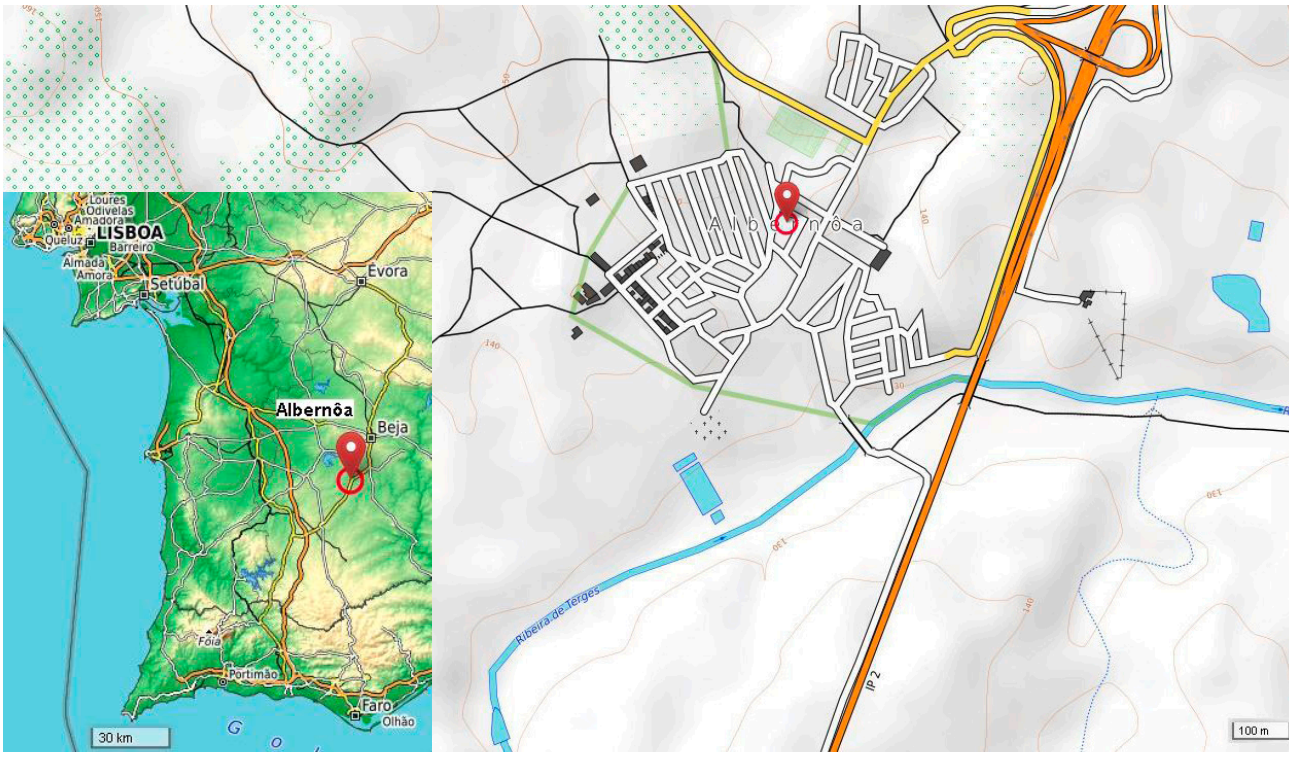

Fig. 1: Location of the Case Study – Albernoa (Alentejo, Portugal, openstreetmap.org).

Fig. 2: Agricultural landscapes of the Alentejo.

jobs. Farmers offering better employment conditions might be less dependent on a migrant workforce (see Morén-Alegret et al. 2018).

A diversification of Alentejo's agriculture, currently specialised on cork, olive, wine and almond production, could contribute to a regional supply of food and hence reduce the export and import dependency. A demand for local products becomes apparent in various integrative and solidarity-based projects (e.g. Gonçalves 2016). These projects take up ideas of the socialist rural movement that roots back to the revolution of 25th April 1974, but nowadays manage to integrate the polarised perspectives of landowners and farm workers (cf. Lousda and Lavrador 2008). With the land reform of 1974, deforestation and the wheat campaign under the "Estado Novo" deteriorated the quality of soils. The market liberalization and the rising competition in the 1980's aggravated land pressure, decreasing soil fertility further and enhanced soils and water pollution (cf. Leão 1997: 127, Fernandes 2006, Lousda and Lavrador 2008, Vizinho et al. 2015: 7, Guimarães et al. 2018: 424).

Hydroponic plant production, independent of fertile soil, appears to be a promising alternative for the region. In order to achieve the highest possible water use efficiency, the effluent of the hydroponic system could be further used to irrigate perennial cultures such as cork oaks (UNESCO World Natural Heritage), persimmon, almond, olive trees or wine yards. In the area of olive production, intensification strategies can be identified (cf. Roxo; Ventura 2012: 13/14). A climate-related decline in cork production of up to 40% could be compensated by irrigation and thus sustain supply chains in the traditional cork-processing industry (cf. Vizinho et al. 2015: 9; Guimarães et al. 2018: 423).

3. Implementation scenario for Albernoa

Albernoa is a typical settlement of the Alentejo hinterlands, about 20 km south-west of Beja. Since the 1940's, the village has undergone a rapid population decline from 3,500 to currently 800 inhabitants. The water availability for agriculture in and around the village improved with the completion of the Alqueva dam. The municipality's wastewater is collected and treated in a system of stabilization ponds prior to discharge into a small stream, the Ribeira de Tegres. In the parish of Albernoa e Trindade the stream falls dry in summer and is exclusively fed from the pond effluent. The wastewater collection and treatment infrastructure is operated by EMAS (Empresa Municipal de Água e Sanemento) of Beja. In general, stabilization ponds are not able to eliminate nutrients efficiently from wastewater. Therefore, especially in the dry season, when the treated wastewater is not diluted, considerable N and P concentrations can be expected in the Ribeira de Tegres stream.

Instead of disposing partially treated wastewater into the environment, its reuse should be considered. HypoWave offers an approach to employ nutrient rich, pretreated wastewater in hydroponic systems for the production of vegetables, fruits and flowers. Depending on demand, distribution infrastructure and existing local knowledge, hydroponic cultivation of the following crops appears to have potential for Albernoa: lettuce, coriander and other leafy vegetables and herbs, strawberries, raspberries and flowers such as roses. Subsequent to the hydroponic system, the effluent could be fed into the existing irrigation systems for perennial crops or discharged into the stream.

Fig. 3: Waste stabilization ponds in Albernoa.

Water reuse example: Hydroponic strawberry production

For the theoretical impact assessment in the following, the hydroponic cultivation of strawberries using the effluent of the existing waste stabilization ponds in Albernoa is assumed. Wastewater volumes and nutrient concentrations are estimated based on our experience with similar systems (Tab. 1) as no data of the existing ponds in Albernoa was available for the case study.

Since hardly any nitrification takes place in non-aerated ponds, the predominant nitrogen form is ammonium. Strawberries thrive best at a nitrate to ammonium ratio of 6:1; therefore, nitrification is essential. Further necessary treatment steps include barriers against pathogens and micropollutants (e.g. drug residues). In the HypoWave pilot project, an activated carbon biofilter proved suitable for both nitrification as well as the removal of micropollutants and a significant part of pathogens. To increase hygienic safety further, a UV system is suggested for disinfection following the activated carbon biofilter.

Inhabitants	800
Specific wastewater quantity	100 l/PE/d
Volume of wastewater	80 m^3/d
Specific nitrogen load	10 g/PE/d
Specific phosphorus load	1.6 g/PE/d
Nitrogen elimination in the pond treatment plant	50%
Nitrogen load	4 kg/d
Phosphorus load	1.3 kg/d
Nitrogen concentration in the effluent	50 mg/l
Phosphorus concentration in the effluent	16 mg/l

Tab. 1: Assumed key-parameters of the wastewater stabilization ponds in Albernoa (PE: Population Equivalent).

The hydroponic system should be operated in a feed and deplete mode. In the beginning, the containers for the nutrient solution are filled with pre-treated water and nutrients. As soon as it comes to deficiencies in plant nutrition during the system's operation, nutrients are added proportional to the plants' demand. As soon as the nutrient concentration reaches a defined threshold, the system is drained and refilled. The area required for the greenhouse hosting the hydroponic system, calculated on the assumed nutrient load (Tab. 1), is in the order of one hectare. The facilities for treating the effluent from the ponds for the hydroponic system have a small area requirement of only 20 – 50 m². In result, the combined wastewater treatment and hydroponic plant production system would use water and contained nutrients highly efficiently, unburdening the environment and creating more qualified jobs in the Alentejo.

4. Necessary alliances for water reuse: An approach for cooperation in Albernoa

The operation of the wastewater pre-treatment and hydroponic systems require stakeholder alliances across several societal levels. Water reuse in Portugal is, as in many other European countries, not an essential task of established water suppliers and wastewater disposal companies. Wastewater treatment responsibilities in Portugal are divided into thirteen regional units. Águas de Portugal (AdP) pools expertise in research and in optimising planning of wastewater infrastructure at the national level. However, decision making on details in planning, construction and operation of wastewater treatment plants takes place at the regional level. Cooperation with private companies requires a permission by the national inspection body (Entidade Reguladora dos Serviços de Águas e Resíduos (ERSAR)), whether in the field of delegated maintenance and services at wastewater treatment plants or in the field of cross-sector cooperation, e.g. together with agricultural players. Such cooperation with private companies has to minimise operational risks for public entities arising from these alliances (cf. Marques 2008: 217).

Collective action through integration of service providers for water management

The approach presented takes into account the principle of operational risk minimisation in two ways: First, it is proposed to entrust a service provider for water (reuse) management. The monitoring of wastewater treatment plants in general and for the further treatment of irrigation water in particular gets assigned to this actor. Secondly, the invitation to tender service providers for water management and reuse shall be conceptualised by the municipal wastewater disposal company EMAS de Beja in cooperation with an agricultural cooperative. Service providers for water management are well established in the Alentejo. In the planned cooperation model, they can contribute to the successful operation of wastewater treatment and respond to the needs of farmers and retailers with respect to quality standards of the irrigation water (see Fig. 4).

The relationship between the service providers for water management and the cooperative should be based on communication on equal terms. Ideally, the cooperative represents a collective purchaser of irrigation water within the cooperation model. In negotiations with actors in the wastewater treatment sector, government bodies and the retail sector, the cooperative ensures the representation of the farmers' interests. Furthermore, the cooperative contributes with its knowledge and laboratory facilities for quality assurance and takes responsibility in the fair distribution of water. In the event of economic failure of individual farmers, the cooperative searches among its members for new operators. This way of organising the cooperation ensures a long-term perspective for water reuse relevant to the negotiations with ERSAR.

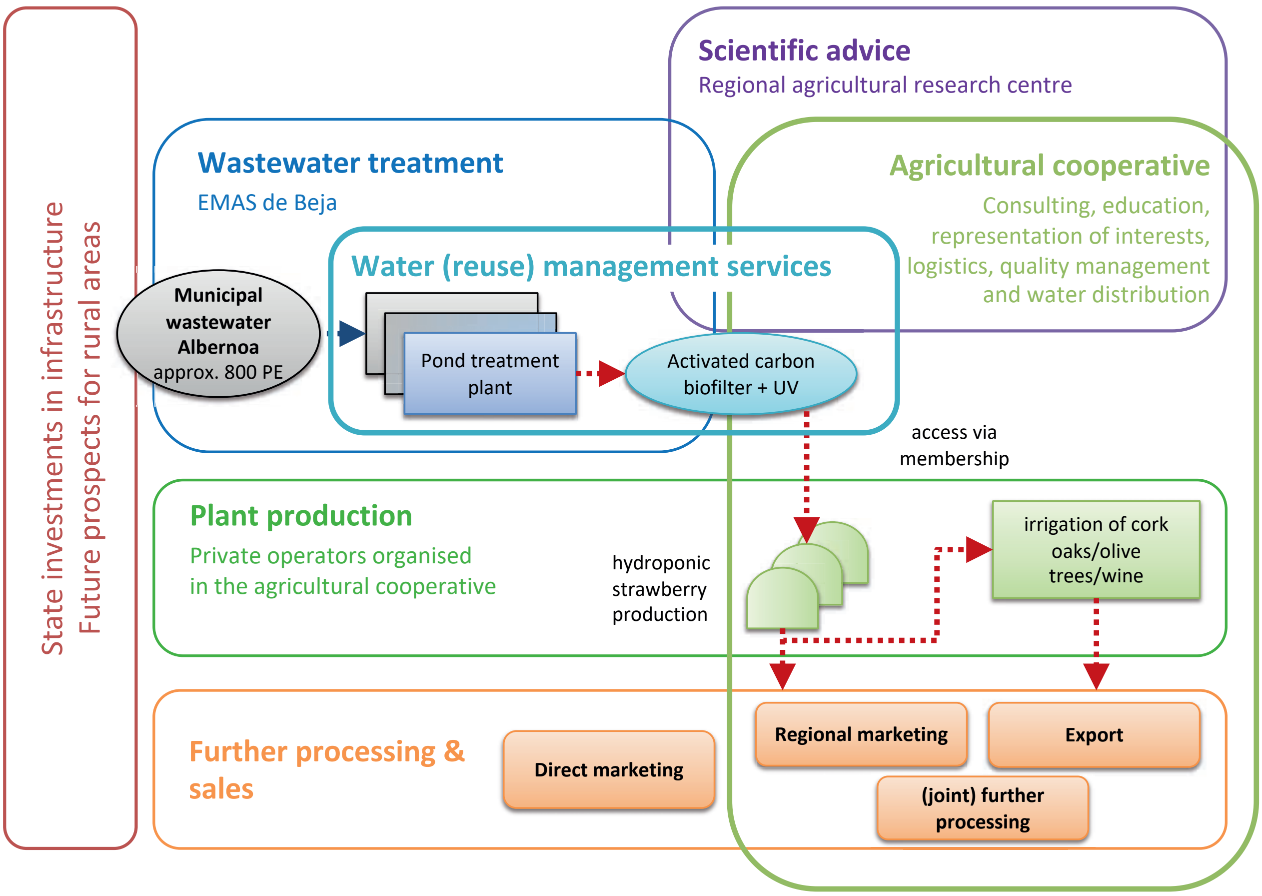

Fig. 4: Service provider for water (reuse) management and agricultural cooperative act together with a regional agricultural research centre as intermediaries between wastewater treatment services and plant production

Cooperatives as enabling entities for social and technical innovation in the agricultural sector

Agricultural cooperatives transformed their image established by the collectivisation before the carnation revolution (cf. Costa 2016: 48). Today cooperatives are oriented towards the needs of their members, putting themselves in the role of a service provider and taking an active share in the social and technical renewal of the agricultural sector. Beyond representing the interest of their members, they provide complementing educational and advisory services. Occasionally, cooperatives even fulfil public tasks such as vocational training or firefighting (cf. Fernandes 2006: 5). To keep entry barriers low, membership fees are minimal. Specific services, e.g. in the area of product quality assurance or logistics and marketing, can be provided on demand by the cooperatives. In this approach members can take own initiatives within the umbrella organisation of the cooperative. This enables choices for the individual operation of the hydroponic system such as crop selection within a coordinated and organised quality management and irrigation water distribution. Quality management is in need of an intensive alliance for everyday knowledge transfer between service providers for water management, agricultural cooperatives and their farmers (see Fig. 4).

Water reuse lowers the regional dependency on reservoir water for irrigation, which is governed by the Ministry of Agriculture. Cooperatives are already working together with regional agricultural research centres to optimise their educational and advisory activities. Thus, a 'future alliance' could make a significant contribution to knowledge transfer for a sustainable transformation of irrigation agriculture in the Alentejo.

Future alliance: Secure supply of irrigation water, knowledge transfer, new products and marketing channels

Agricultural intensification within and around the Beja district depends largely on the water supply from the Alqueva dam. Due to the rapidly increasing water demand, less predictable precipitation patterns and limited dam capacities, additional water resources are required. Transformation at farm level can take place either by specialising whole farms on, e.g. strawberry production as suggested here, or by complementing existing rainfed agriculture with further water reuse. Producers in the region are already experienced in soil-based greenhouse cultivation. For them, it would be desirable to enhance the proportion of processing and hence generate additional benefit for the region. Again, agricultural cooperatives might lead sale alliances supported by their long-standing experience in the field of food conservation. In particular, berries are very suitable for the production of jams, juices and syrup, as well as frozen and dry products. A market entry for strawberries produced in the outlined novel technical approach is possible, combining direct and regional marketing for the case of raw consumption. Exports to the northern EU, where year round production is much more energy demanding, should also be considered (see Fig. 4).

State infrastructure investments improve the scope of action

A clarification of procedures and requirements for water reuse depending on the product type in the national legislation adopted in August 2019 (Portaria n.º 119/2019 and 226/2019) creates new windows of opportunity for water reuse from the perspective of the water sector, as well as legal certainty. However, cooperation between public and private actors is still in need of approval by the national level (ERSAR). The scope of action this legislation creates can only become reality if crop production can count on necessary improvements of wastewater infrastructure. The same applies to research facilities and the logistics of cooperatives. They require state investments in transport infrastructure and in the region's scientific facilities. Better transportation to urban areas and more efforts for research in rural areas can contribute to structural planning to support civil society in its efforts to stop migration away from rural areas.

5. Parameters for an economic example calculation

At the current state, a robust estimation of the economic feasibility of the described system in Albernoa is hampered by a lack of relevant data. For future considerations, the most important parameters for such an analysis are discussed in the following. Benefits and costs are equally considered.

Income from products

In general, the main source of income will be generated through marketing of the products of the hydroponic system. This depends on the crop, and vice versa, the crop can also be chosen based on economic considerations. Questions to be discussed in this context are the market access for these products (Alentejo, Lisbon, other European countries or beyond), and product price fluctuations within the year. Another issue is the long-term stability of the prices, which are difficult to foresee, but should be considered in a risk analysis. Also, the question of how the products will be marketed has to be considered. Marketing options include direct marketing by the producer or indirectly via retail partners. Careful thinking about the product choice should also include product processing and finishing of the raw products to achieve more revenue within the region and to increase shelf life to lower the impact of price fluctuations.

Benefit for wastewater treatment

A further cash flow can be expected from savings where the wastewater infrastructure has to be upgraded or implemented anyway. The size of the additionally necessary wastewater installations will be smaller, less complex and expensive if the HypoWave concept is applied. This is mainly due to the fact that the plants growing in the hydroponic system will take over parts of the nutrient removal. This is especially of advantage for smaller settlements, where conventional solutions to fulfill the increasingly stringent effluent quality requirements for save disposal are very costly on habitant basis. The organization responsible for upgrading or building the wastewater treatment can reinvest the savings into the construction and operation of the hydroponic system. Without this transfer of opportunity costs, chances are high that other water sources, where available, will be used for the hydroponic system. The need for upgrading or establishing wastewater treatment facilities capable of nutrient elimination usually arises from requirements for the quality of receiving water bodies based on the Water Framework Directive. Therefore, a comprehensive overview of the local surface and groundwater quality is essential.

Cost for water and nutrients

If the costs for water and nutrients are relatively high (which usually in Europe is not the case), it might make economic sense to use treated wastewater and thus save these costs for the operation of a hydroponic system, even if the above mentioned need for upgrading the wastewater infrastructure is not given.

Cost for additional wastewater treatment

As the effluents of the ponds cannot directly be used for the production of high-value crops, additional treatment processes are necessary. Depending on the requirements of the chosen product, these processes can be more or less complex and thus expensive. A membrane filtration process e.g. might fulfill more stringent regulations, but is also more expensive than UV radiation in regards to investment as well as operation.

Cost of land and labor

These are specific costs for a certain region, which can have a strong impact on the feasibility of this solution, as a certain area of land as well as workforce is needed.

Cost for selling and marketing of products

Marketing and selling the products might be too costly compared to the potential income. Also, in this case the overall solution can only be economically feasible if savings through cheaper wastewater treatment installations and operation will support the hydroponic producer.

Interest rate

Usually, the investment for such a solution has to be taken as a loan from a bank. Depending on the current interest rates, this can involve high costs.

Energy demand for heating and lighting

The production has to continue throughout the year, as the water has to be treated and the nutrients eliminated continuously. In addition, the market or retail sector might demand a continuous product supply. Depending on the local climatic conditions, heating and artificial lighting may be required. Even though the demand for both will be lower than in northern Europe, the installation and energy consumption can increase the operation expenditure significantly.

6. Conclusions and way forward

The HypoWave concept bears significant development potentials for small settlements such as Albernoa in the Alentejo Region of Portugal. Direct advantages are lower costs for the establishment and operation of wastewater treatment plants, unburdening of natural water bodies and production of valuable crops. Beyond these direct and measurable effects, the concept offers indirect positive effects, which are related to the growing demand for specialized labour and infrastructure. The labour demand will not only be limited to the area of plant production, but also encompass service providers and the retail sector. Furthermore, crop production for regional markets reconnects regions and brings urban and rural areas closer together. Thus, the concept contributes to sustainable regional development.

Sustainable economic operation requires that the further treatment of wastewater for hydroponic crop production is acknowledged, and that the service provided is financially compensated. This in turn relies on the readiness of the local and national stakeholders and their willingness to invest into the improvement of existing and establishment of new wastewater and water reuse infrastructure. The readiness will depend on the national and regional regulative framework and the transparency of the information database that supports application of regulative measures.

Usually, the effluent quality that wastewater treatment plants of small settlements have to comply with is defined by the chemical and ecological status of the receiving water body downstream of the plant. Currently, the existing level of information on the water quality of streams and rivers appears insufficient (Cipriano, 2019). Therefore, we suggest that in an initial step, the status of the streams is assessed and the efficiency of existing wastewater treatment plants in the region is studied.

In a second step, the shared needs of the different actors regarding advanced treatment of the irrigation water (e.g. required quantity and quality) should be clarified to figure out costs and benefits of establishing such a concept. A third step should focus on the joint tendering for the service provider in particular and the relationship between the actors involved in wastewater treatment and plant production (e.g. cooperatives). Being part of the suggested 'future alliance', potential associations or cooperatives can attract interested farmers and train them with the support of the local agricultural research centres. Beyond a reliable operation of established wastewater treatment, the capability to build this 'future alliance' at the regional level depends on the support of national organisations and institutions (e.g. AdP & EPA – Portugal Environment Agency). This is, in particular, necessary regarding the knowledge on the quality of surface water, but also in view of investment programs as part of structural policy focusing on transportation and wastewater infrastructure for rural areas.

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