How open-loop heat pumps on lakes can help environmental control: an example of geothermal circular economy.

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ABSTRACT

Along Po River (NW Italy), at a few km from Torino (an area of about 1.5 million of inhabitants), many quarry lakes below the water table are present. They are huge water reservoirs with volumes ranging from 0.5 to 12 Millions m^3 and depths up to 45 m. After mining activity, these lakes will be returned to community as natural elements or public parks, but present time experience of reuse is not always positive due to maintenance costs that local administrations cannot afford. By the way, not legal or border line activities are often reported in such areas. Otherwise, many of them result as abandoned.

Aim of the present study is to produce a feasibility project to generate a virtuous cycle using lake’s water as low enthalpy thermal energy source in order to feed open loop heat pump systems for providing low cost energy. In this way, areas nearby the lakes can be exploited to build greenhouses or agro-business factories using lakes as energy source for space heating and cooling, domestic hot water production or food processes requiring heat (e.g. vegetable and fruit de-hydration). In this way, these areas would be again productive and remain under civil society control.

Data from Regional Administration were collected in order to know the thermal and bio-chemical behavior of these lakes during the whole year. In addition, specific measurements were performed on some lakes in order to characterize the entire water reservoir.

A study was then conducted in order to define the best possible position of heat exchangers, pumping rates and critical distances of the final user considering their thermal energy needs.

Moreover, a specific market analysis was carried out in the surroundings in order to define what particular kind of fruit or vegetable can be commercialized in the perspective of zero-kilometer products and sustainable agriculture. Greenhouse conditions will be fitted to optimize vegetable or fruit harvesting and guidelines will be produced to help end-users in this new business.

In the future, a best practice manual will be done in order to give suggestions to private and public stakeholders involved in this circular economy.

1. INTRODUCTION

In Piedmont region there are many quarry lakes located in the Po Plain just close to the river path. Many of them are concentrated south of Torino, in a belt along Po river about 30 km long (Fig. 1). They were mainly born as a consequence of quarry activity of different companies that took a long period (20-30 years) local authorization to excavate gravels and sands below groundwater level (Tab. 1). Some of these authorizations went to the end in the last ten years and several other ones are going to quit in the next decade.

These lakes are big water reservoirs that are returned to the local community after the end of the mining activity. According to national and local legislation, environmental restoration is mandatory and these lakes are always restored by the assessment of vegetal situation consistently with surrounding environment (e.g. planting).

Nevertheless, after this important activity it is up to the local administrations how to use these areas again. Ideas and proposals are therefore welcome in order not to let them go in state of neglect and degradation.

A feasibility study was therefore undertaken based on the idea of exploiting the lakes as source of low temperature thermal energy for whatever final users. Since they are mainly located close to the river path and often a few km far from residential or industrial areas, a possible utilization is for the agricultural sector.

In this paper we try to explain how open-loop heat pumps on quarry lakes can help urban planning and how hydrothermal energy greenhouses as social and environmental restoration can contribute in a virtuous circular economy.

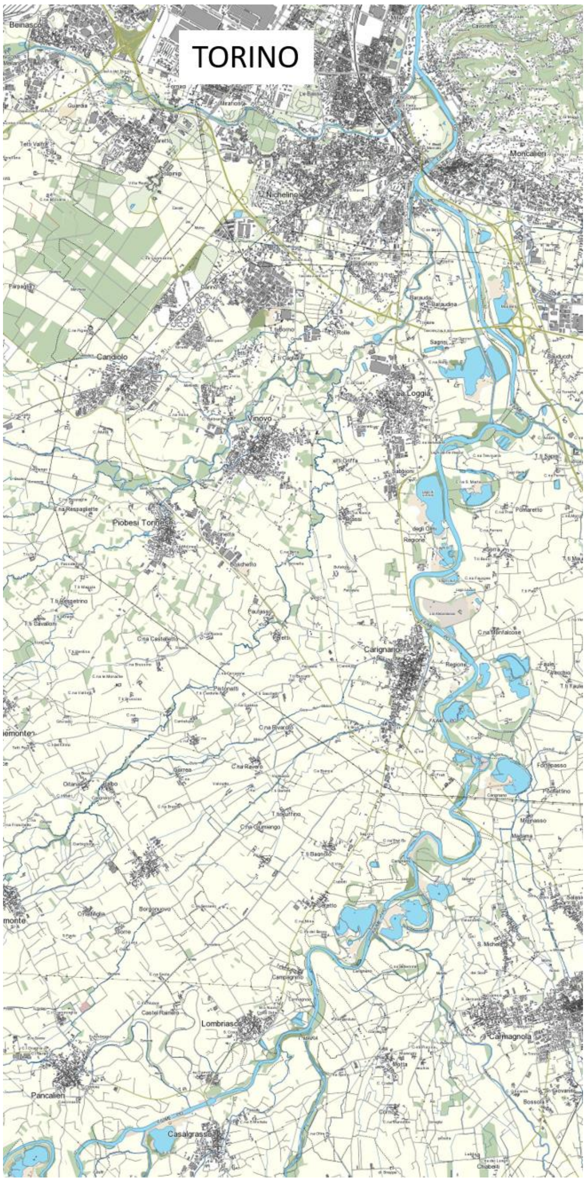

Figure 1: Map of the study area, in light blue quarry lakes along the Po river (scale about 1:30.000).

Table 1: Characteristics of the most important quarry lakes in Piedmont (from Castagna et al., 2008).

NAME	HYDR. BASIN	AV. DEPTH [m]	VOLUME [Mm^3]
Ceretto	Po river	42	10.1
Germaire	Po river	40	7.0
Germaire-Ianca	Po river	34	3.0
Provana	Po river	42	11.9
C.na Lanca	Po river	30	10.5
Sabbioni	Po river	47	14.6
Santa Marta	Po river	31	4.6
San Michele	Po river	35	3.0
Brusa Vecchia	Tanaro river	8	0.7
Falè	Po river	45	4.5
Fontane	Po river	34	4.5
Revellino	Tanaro river	18	0.5
C.na Guazza	Po river	26	3.2
C.na Altafiore	Tanaro river	28	0.6
C.na Isoletta	Tanaro river	18	1.2
C.na Borio	Bormida river	13	1.5

In this respect, greenhouses were taken as final target in this study and technical, economic, environmental and urban sustainability were evaluated. Quarry lake and greenhouse were initially analysed separately, as two end members belonging to what is however considered a circular model. Both these entities can therefore take advantage from each other.

2. METHODOLOGY

The main activities carried out during this study (Fig. 2) aimed at understanding the possible solutions to exploit these lakes in an efficient way throughout these key-points:

- lake's water temperature monitoring for thermal characterization;
- evaluation of environmental impact and assessment of urban restrictions for greenhouse's construction in these areas;
- evaluation of water's withdrawal modalities and heat exchange techniques, together with

the design and optimization of greenhouse plants fed by surface water open loop heat pump systems;

- market analysis of agricultural products of possible interest for Torino's area.

As an example, the study has been carried out on two lakes: *Cave Fontane* in Faule (Cuneo Province) and *Cave Provana* in Carmagnola (Torino Province). These lakes can be considered as representative of the whole set of Po belt lakes upstream of Torino (about 15). They indeed have different sizes and the first is far away from Torino and the latter is close to the metropolitan area, with consequent different climatic conditions.

3. RESULTS

3.1 Thermal source's characterization

Lakes' thermal behavior has been first evaluated by collecting all available data (databases and archives) from local administrations about both surface water (lakes) and phreatic groundwater, which is in direct connection with them. In addition, two field campaigns (October and December 2015) have been performed in the chosen lakes, by making temperature logs in surface water and monitoring piezometers around these. A monitoring cable equipped with 5m-spaced Pt-100s has been moreover placed in Provana Lake on the experience of silimar project (Giordano et al, 2016).

These results are not discussed here, but it will be a useful monitoring tool over the next years in order to continuously record temperature data and understand in details lakes' thermal behavior over a whole year.

Data processing showed a similar behavior in the lakes under examination (Fig. 3). In summertime (May to September) a stratification is clear, due to air temperature influence. Shallow layers present high temperature values (20-25 °C) while bottom layers (10 m to bottom) are in equilibrium with the groundwater (12-14 °C). This condition does not generate convective currents since high temperature water has lower density than low temperature one. Conversely, approaching to wintertime (October-November) shallow water gets colder and a vertical circulation starts. The final result is the generation of a homogeneous temperature (7-11 °C) within the lake that lasts until the next spring (March-April).

It is worth noting that minimum peak (7-8 °C) usually occurs at the end of the winter (February-March), while in the coldest months temperature stands at 10-11 °C. The bigger the lake the more evident this phenomenon, since, as extensively known, water can act as a huge thermal energy storage thanks to its high heat capacity.

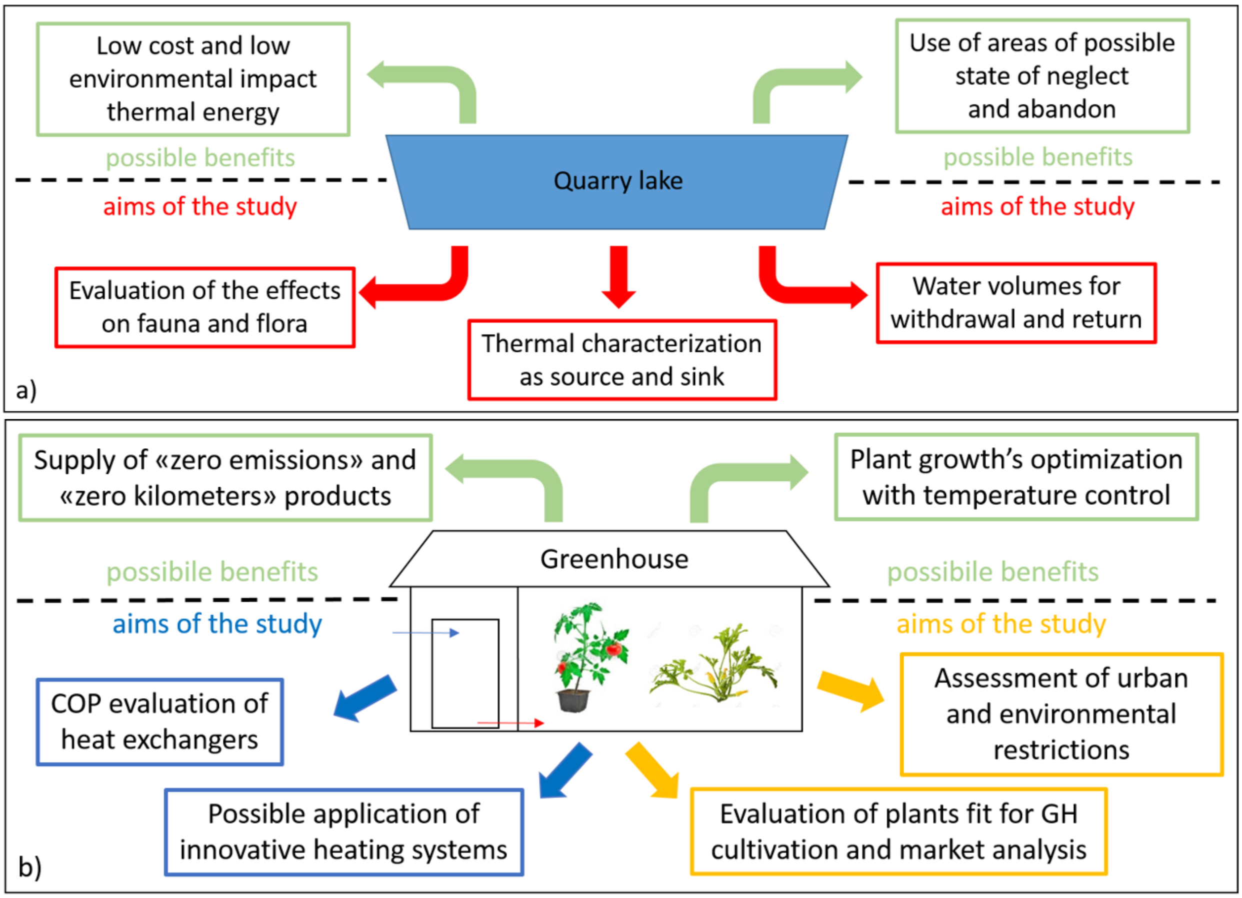

Figure 2: Sketch of the whole feasibility study, divided in quarry lake (a) and greenhouse (b) end terms.

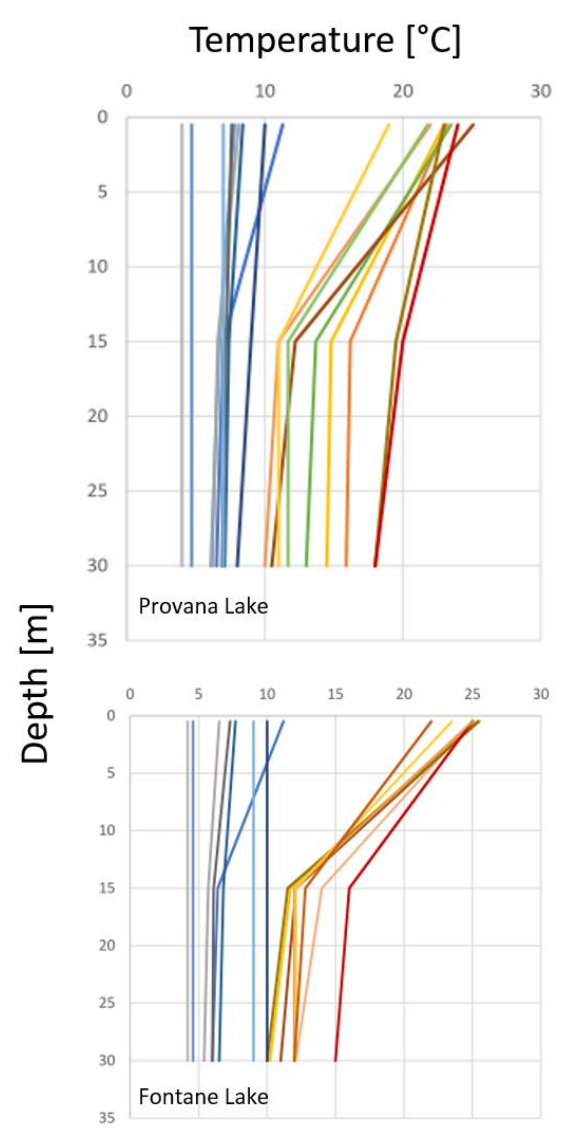

Figure 3: Temperature in Provana and Fontane lakes. Cold and warm colors refer to wintertime and summertime measurements respectively (data from 2004 to 2011, Arpa Piemonte).

It is also important to highlight that temperature values registered over the years show a high variability from one year to another. As mentioned, air temperature is the main influencing factor and weather conditions can therefore define very different thermal situations between consecutive years, with even 4-5 °C differences.

Field campaigns carried out in autumn-winter 2015 presented a homogeneous temperature condition in both lakes but with high differences between the two surveys. In Fontane lake, end of October's measurement recorded about 15 °C in the whole volume compared to 10 °C in Christmas's acquisition. Provana lake had 14 °C and 10.5 °C respectively. No other surveys could be made afterwards, but the end of December's values appear to be far away from minimum peaks recorded by local administrations.

3.2. Environmental and urban regulations' assessment

In depth analysis about environmental and urban restrictions ended up with the fact that greenhouse plants are not even mentioned as permitted or illegal in those areas. It is nevertheless clear that the location of such building constructions have to be evaluated from several points of view. Main restrictions can be summed up as follows:

- urban restrictions given by *"Piano Regolatore Generale Comunale"* (PRGC), a technical-administrative planning instrument adopted by each Italian municipality to regulate urban development planning. Lake areas are commonly split up in two or more territories, making things sometimes difficult due to important differences among different PRGC's restrictions. Provana Lake is subdivided in three municipalities (Carignano, Carmagnola, Villastellone) belonging to Torino Province, Fontane Lake in two municipalities and two provinces (Faule, (Cuneo Province), Pancalieri (Torino Province));
- hydrological restrictions due to the close location to Po river. Three levels of hazard are defined by the *"Piano di Assetto Idrogeologico"* (PAI), dividing the area along the Po in three different zones, A, B and C, from most to least dangerous;
- environmental and landscape restrictions defined by *"Parco del Po"*, a local reserve along the river, and other parks or national laws protecting natural environments.

Greenhouse plants considered in this study are permanent structures that cannot be removed seasonally as those made by single-chapel plastic films. Their construction needs therefore to be planned properly, taking into account the definitive modification caused on the landscape and the geomorphologic/hydraulic context, raising the geological hazard. Nevertheless, the agricultural purpose of the structure lets one thinking positively about the feasibility of the project, since agricultural activity is widely permitted in the areas close to the river path.

The analysis ended up with the result that greenhouse plants are compatible with national and local laws and regulations, at least in the two outer river zones (B and C). Here, it is however mandatory to develop detailed studies about the influence of the new structure on the local geologic and landscape context. Conversely, we consider inappropriate the use of the Zone A, which is characterized by too high hydraulic hazard.

The methodology adopted to highlight the areas around the lakes suitable to the construction of greenhouse plants has been therefore based on the following criteria:

- 100 m is the maximum distance from lake's coastline for putting in place heat exchangers (as described in section 3.4);
- 150 m is the minimum distance to Po river (urban restriction);
- 3 m is the minimum elevation difference with respect to river's water elevation (based on most recent DTM from *Regione Piemonte*), in order to avoid even low energy water floods;
- location out of the Zone A.

Suitable areas have been then highlighted with an additional buffer of 200 m from the first criterion above described. Heat exchangers can indeed be placed at 100 m from the lake's coast, but after the work of the heat pump, heating water can be delivered to greenhouses placed up to 200 m. Results on the two examined lakes showed how suitable areas in Provana and Fontane (Fig. 4) lakes have a size of 86.4 ha and 12.7 ha respectively.

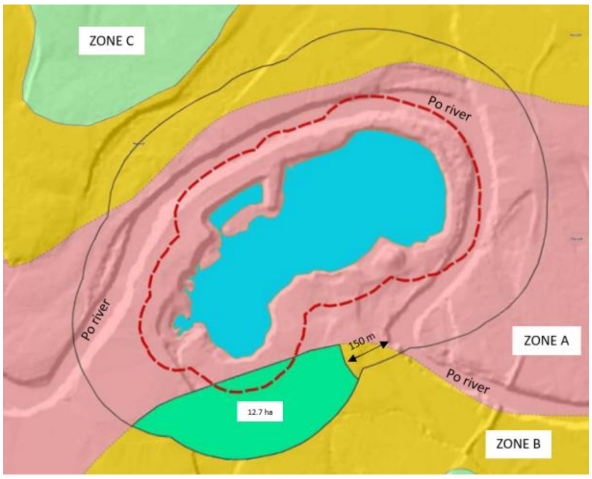

Figure 4: Suitable areas in Fontane lake (green). Red dashed line represents the limit of 100 m from the lake's coast, the black line a 200 m buffer from the latter.

Taking in mind what above mentioned and that each study is site-specific, the feasibility study of a greenhouse in these areas should involve: environmental, geological and landscape evaluations, as well as lake's thermal behavior and estimates and considerations about possible effects on fauna and flora species into and around the lake.

3.3. Impact evaluation on lake's water

Recent studies on rivers and lakes have highlighted that significant drifting events occurred with sharp temperature changes (> 3 °C). TETRANER project (Viquerat, 2012) studied heat pump systems on lakes and possible effects on surface water and biological activity. Influence of re-injection of water at different temperature values has proved to be limited on microbiological community and fish fauna as well.

No Italian regulation defines a limit of temperature difference between withdrawal and re-injection in surface water for whatever use. Nevertheless, a comprehensive environmental law (D. Lgs. 152/2006) regulates industrial waste water discharge in lakes, stating the limit to 30 °C, being anyway aware that the temperature increase must not overcome 3 °C at a distance of 50 m from the injection point.

On the basis of the thermal characterization performed on the two lakes under examination, it can be said that the influence of abstraction-injection cycles on these reservoirs should be very limited. First of all, water volumes involved are small enough compared to those of the entire lakes. Secondly, since during wintertime no stratification has been highlighted, a valid water mixing can easily erase every local temperature decrease due to re-injection after heat extraction. Plant activity is expected to produce 1-2 °C temperature differences, avoiding to overcome the 3 °C threshold stated by D. Lgs 152/2006.

3.4. Energetic evaluation and cost estimate

The study of the thermal needs of a greenhouse plant should involve the following estimates: heat pump efficiency (related to source temperature), heat losses due to the structure type, average air temperature, volume and exchange surface of the greenhouse, indoor air temperature and relative humidity (based on the chosen plant).

Currently in Italy, greenhouse design is regulated by technical laws UNI 13031-1:2004 *"Serre: progettazione e costruzione. Parte 1: serre per produzione commerciale"* based on european standard EN 13031-1 (2001) and UNI EN 13206:2002 *"Film termoplastici di copertura per uso in agricoltura ed orticoltura"*.

After data collecting from several existing greenhouses in Torino area, simulations have been performed with a C.T.I. (*Comunità Termotecnica Italiana*) certified code EDILCLIMA – EC700 v. 6.2.1. It has been also stated that the critical distance of the plant from the lake is 100 m. Further distances indeed would have a big influence on the costs due to the excessive length of the pipelines, which on turn would increase the heat losses.

The base case plant has the following characteristics:

- structure type: conventional iron and glass;
- greenhouse dimensions: surface of 8000 m^2 and volume of 44,000 m^3;
- indoor temperature (based on the chosen cultivation, as described in the following section): 18 °C;

- ventilation: 1 air change per hour;

From this background simulation, some other calculations have been carried out by modifying some features of the structure, e.g. by introducing energy efficiency improvements (Tab. 2).

Finally, the case study plant has been chosen to have a valid thermal efficiency with a total rated thermal input of 500 kW. On the basis of the above presented results, source temperature from the lakes in winter can range between 7 and 10 °C. Rated C.O.P. (coefficient of performance) calculated for the example greenhouse above described turned out to range between 7.5 up to 8.1.

Table 2: Greenhouse's characteristics of the simulations carried out.

TYPE	THERMAL INPUT [kW]	SPECIFIC ENERGY CONSUMPTION [kWh/m^3]
Iron and glass	2500	8300
Enhanced cover	870	2400
Enhanced cover + heat recover (70% eff.)	520	1050

Table 3: Total costs of the plant.

COST TYPE	COST [€]
Heat pump (2 x 200 kW)	45,000
Heat exchangers	15,000
Hydraulic pump and circuit	18,000
Installation	30,000
Pipelines	5000
Excavations	10,000
Design	10,000
Total costs	**133,000**

On these considerations, a cost estimate has been performed in order to assess the economical sustainability of a greenhouse plant in those areas, supplied by surface water open-loop heat pump system. The total cost of the heating system amounts to 133,000 € (Tab. 3) and assuming a duration of 15 years the annual energetic cost would be around 68.4 €/MWh (Tab. 4). It is also worth pointing out the economy of scale as a function of the size of the heat pump system (Fig. 5).

The costs of the described system are competitive with respect to traditional fossil fuel supplies: natural gas (80 €/MWh), diesel oil (85 €/MWh) and LPG (117 €/MWh) (Francescato, 2012). Nevertheless, some critical points arise:

- significant initial investment;
- lower efficiency with respect to groundwater heat pump systems (in these areas groundwater temperature is 14 °C);
- other green alternatives are cheaper, e.g. a similar calculation for a biomass plant (strongly incentivazed) resulted in about 50 €/MWh.

It is however true that currently biomass plants in Italy are strongly incentivized and, not less important, biomass supply is nothing but simple and involves other direct costs such as storage buildings and manpower for transport and movement.

Table 4: Annual energetic cost, considering the initial investment.

COST TYPE	COST [€]
Equity share	2200
Mortage payment	8994
Maintenance	5320
Electric energy cost	63,473
Total costs	**79,987**
Energy costs	0.068 €/kWh
	68.42 €/MWh

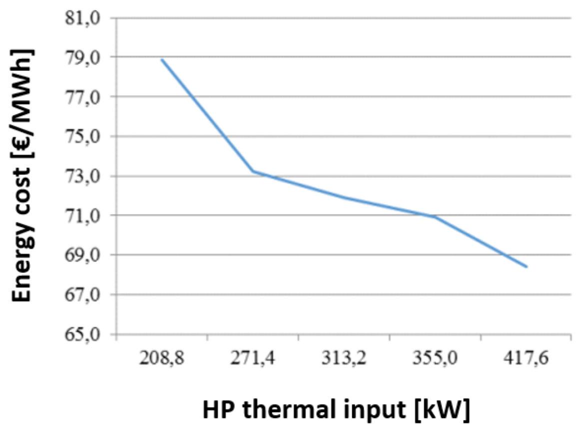

Figure 5: Energy cost as a function of heat pump thermal input.

A groundwater heat pump system would take advantage of constant and higher source temperature, but, on the other hand, flow rates would be lower (even if transmissivity in these areas is high) and re-injection in groundwater would require detailed hydrogeological studies and long administrative procedures rather than surface water discharge.

3.5. Market analysis

Several agro-businesses in Torino area have been analyzed, in particular those involving greenhouse production. 18 firms adopt greenhouse production and they are divided in: floriculture (8), horticulture (5), plant nursery (4), herb farming (1). Number of months when heating is necessary usually ranges between 4 (nursery) and 8 (horticulture), but this strongly depends on annual weather conditions. Interestingly, it turned out that heating during coldest months (December and January) provides a limited contribution to production, since reduced sun-light is the most influencing factor. It is however useful for protecting plants from too low outdoor temperature.

Four specific products have been pointed out for having a valid greenhouse productivity and market value in Torino area with respect to what exists nowadays. These are: tomatoes, zucchini, strawberries and basil plants. Generally, the best opportunity is to sell early products (February, March), when Italian products are usually not present and foreign ones can have significant costs even compared with greenhouse's high production expenses.

4. DISCUSSION AND CONCLUSIONS

The feasibility study here presented aimed at defining a possible circular economy linking actions for exploiting local natural resources, actions for re-using areas probably going to be abandoned after mining activity (with doubtless landscape and social degradation) and actions towards a local-based sustainable agricultural production chain.

Main outputs of the activity developed by a 4-partner local consortium can be summed up as follows.

A. From database and archives of local administrations and field campaigns carried out, it turned out that lakes in Po river belt upstream of Torino behave as temperature-homogeneous reservoirs in wintertime, while they show stratification in summer. The main key-factor is atmospheric temperature, that strongly influences shallow water. Hence, in winter water temperature ranges between 7 and 11 °C, the minimum occurring at the beginning of spring (February-March). Groundwater seems not to be affected that much by lake (and thus atmospheric) temperature, apart from areas next to the lake, in particular those downstream.

B. It can be said that energy cost deriving from the calculations of a quarry lake open-loop heat pump system with a temperature source of 7 °C and a thermal input of 500 kW is competitive in respect to traditional fossil fuel supplies. Money savings amount to 15%, 20% and 42% in comparison to natural gas, diesel oil and LPG respectively. However, initial investment is significant and annual cost is higher than that of a biomass plant (+36%) and the system suffers of low heat pump efficiency due to small source temperature in respect to groundwater source heat pumps (7-8 °C against 13-14 °C). Even if biomass supply can be difficult and involves other direct costs, some technical-economical limitations about the quarry lake plant arise. These are essentially related to air temperature at these latitudes, which strongly influences heat pump efficiency and thus total costs. In order to improve heat pump efficiency, it can be however considered to drill one or two wells for groundwater abstraction and using the quarry lake for the discharge. It is important to point out that in Piedmont discharging water in surface bodies is far less expensive from a procedural point of view, with faster authorizations and simpler reports to submit. It is anyway restated the importance of detailed studies on the effects of water discharge on local fauna and flora. But in this case, the injection temperature would be more or less the same of the lake, being hypothetically 4-5 °C lower than that of the groundwater after the work of the heat pump.

C. The environmental and urban restrictions' assessment turned out to be quite complex and often different for the same lake, due to diverse urban planning in nearby municipality territories. For this reason, each case is extremely site-specific and a generic feasibility study of a quarry lake greenhouse plant in these areas should involve: environmental, geological and landscape evaluations, as well as lake's thermal behavior and estimates and considerations about possible effects on fauna and flora species into and around the lake (Fig. 6). The suggested methodology to identify areas suitable for hosting greenhouse plants consists of measuring 100 m from lake's coast, 150 m from river path and 3 m in height from river's water elevation, being aware to be out of the too dangerous Zone A.

D. Tomatoes, zucchini, strawberries and basil plants resulted to have a good greenhouse productivity and a valuable market value in Torino area. Production should however be set up for selling early products in February and March, when foreign products have higher prices even in comparison with greenhouse's significant production costs. It is moreover worth highlighting an aspect resulting from several interviews to farmers and small businessmen. The location of the greenhouses next to quarry lakes brings itself the problem of fog and high relative humidity. These issues are seen as negligible only in case of a sharp reduction of annual energy production costs.

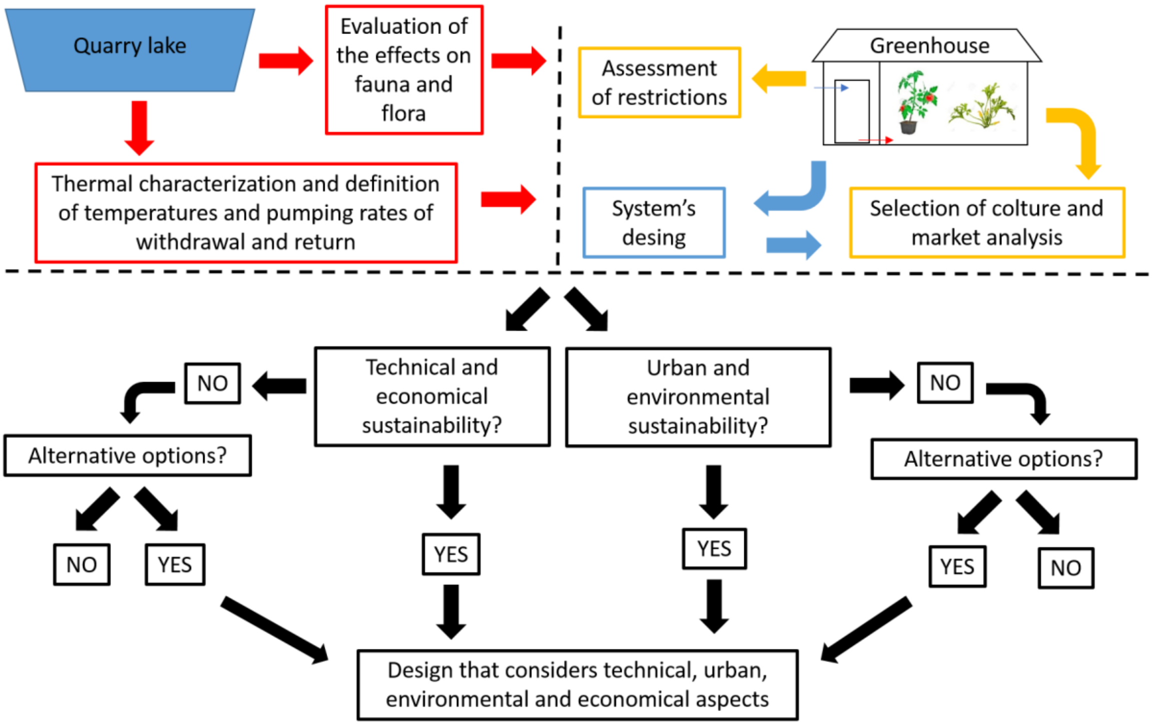

Figure 6: Flow diagram of a possible feasibility study to be submitted to local authorities.

E. In the end, we would like to point out that the whole sustainability of the project can only be reached by taking into account also the social benefits that would arise from the establishment of a productive infrastructure in areas at the risk of being abandoned and degraded. Both local administrations (*Comune*, *Parco*) and public community would take advantage of these benefits. The first would save money for maintenance and would not have the problem to establish a whatever activity. The latter would have access to a local-based food chain also in late winter – early spring. All together, they would not have to face social degradation or illegal waste disposals' problems in these areas.

The proposed actions, in our opinion, can contribute to closing the loop of product lifecycles through greater recycling and re-use, and bring benefits for both the environment and the economy (fig. 7).

It goes in the direction suggested by the European Commission that adopted an ambitious Circular Economy Package, which includes revised legislative proposals on waste to stimulate Europe's transition towards a circular economy which will boost global competitiveness, foster sustainable economic growth and generate new jobs.

The Circular economy offers an opportunity to reinvent economy, making it more sustainable and competitive. This will bring benefits for businesses, industries, and citizens alike. With this new plan to make economy cleaner and more competitive, the Communities are delivering ambitious measures to cut resource use, reduce waste and boost recycling.

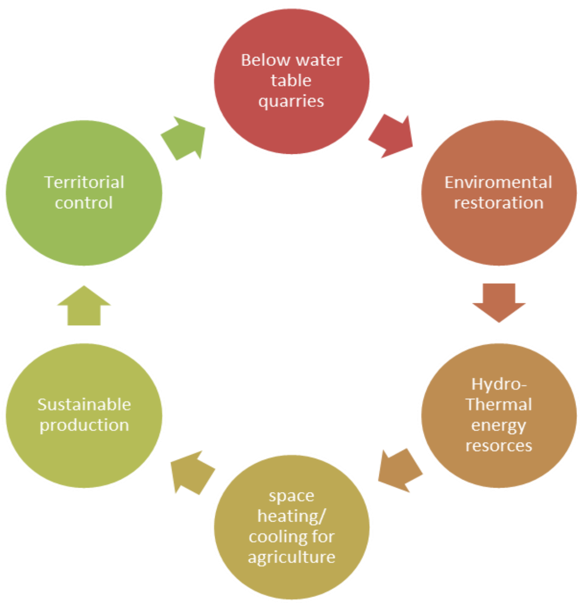

Fig. 7 Flow chart highlighting our idea of circular economy path.

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REFERENCES

Castagna, S., De Luca, D.A., Fornaro, M.: Eutrofizzazione dei laghi di cava: principali fattori condizionanti e stima del livello trofico di bacini di cava piemontesi. *Atti del 84° Convegno Nazionale della Società Geologica Italiana*, Sassari, 15-17 Settembre, (2008).

European Commission: Communication from the commission to the European Parliament, the Council, the European Economic and social committee and the committee of the regions. Closing the loop - An EU action plan for the Circular Economy. COM/2015/0614 final (2015)

Francescato, V, Berno, F., Negrin, M, Bertone, M., Zanetti, G.: Risparmio energetico e biomasse agroforestali per il riscaldamento delle serre. *ENAMA (Ente Nazionale per la Meccanizzazione Agricola) e AIEL (Associazione Italiana Energie Agroforestali)*, (2012), 32 pp.

Giordano N., Comina C., Mandrone G.: Borehole thermal energy storage (BTES). First results from the injection phase of a living lab in Torino (NW Italy). *Renewable Energy*, (2016), 993-1008.

Giordano N., Comina C., Mandrone G.:The First Italian Experience of Ground Thermal Energy Storage: an Integrated Approach for Design and Monitoring, from Laboratory to Field Scale. *Proceedings World Geothermal Congress*, 19-24 April 2015, Melbourne.

Giordano N., Comina C., Mandrone G. - Laboratory scale geophysical measurements aimed at monitoring the thermal affected zone in Underground Thermal Energy Storage (UTES) applications. *Geothermics*, (2016) 61, 121-234

Viquerat, P.A.: Utilisation des réseaux d'eau lacustre profonde pour la climatisation et le chauffage des bâtiments; bilan énergétique et impacts environnementaux: Etude de cas: le projet GLN (Genève-Lac-Nations) à Genève. *Thèse de doctorat, Univ. Genève*, (2012), 269 pp.

UNI 13031-1: Serre: progettazione e costruzione. Parte 1: serre per produzione commerciale (2004) based on european standard EN 13031-1 (2001).

UNI EN 13206: Film termoplastici di copertura per uso in agricoltura ed orticoltura (2002).