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Mini-hydro power plant for the improvement of urban water-energy nexus toward sustainability - A case study

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Abstract

This practical paper presents a required reflection on paradigm shift toward an aware water management in urban context for the provision of renewable energy and for the enhancement of pre-industrial heritage. It investigates the transition toward systemic and ecological approach to face the complexity of urban environment and infrastructures for energy supply. The study investigates the sustainable energy framework in Piedmont Region and in the Municipality of Turin. Especially, it analyses opportunities provided by urban rivers and streams for installing mini-hydro power plants using historical unused infrastructures. The real case study presents the conversion of an historical check dam of Regio Parco canal in a mini-hydro power plant in the city of Turin (Piedmont Region, Italy), and it investigates the "land use-water-energy nexus" from an ecological perspective. The paper considers the *12 principles of infrastructure ecology* in the urban water management to provide innovative solutions for blue-urban infrastructures that increase sustainability in cities. According to the *urban ecological infrastructure*, the project of mini-hydro power plant presents multi-functional features and this method can be replied in other similar contexts. Concerning technical solutions adopted for the mini-hydro power plant, it examines the potential of the green/blue infrastructure approach to integrate the flood risk management and the production of renewable energy. It analyses opportunities provided by low impact development to preserve freshwater ecosystems and to maintain biodiversity using inflatable dam, Kaplan turbine and fish ladder. The "Regio Parco" mini-hydro power plant is designed to provide energy for almost 600 households improving the environmental value and the usability of the area. The paper discusses the adoption of an ecological approach to design multiple functions blue infrastructure that can be implemented on other networks improving the urban landscape.

Keywords

Urban Ecology, Water management, Clean blue energy, Mini-hydro, Urban regeneration, Flood risk management.

1. Introduction

1.1. Global challenges for the use of resources

In the last century, cities have changed their structure moving towards a higher level of complexity to deal the demographic shift from countryside to urban areas. All around the world, the high concentration of population, industries and infrastructures in urban areas have consistent environmental and ecological impact. For the first time in the human history, half of the world's population lives in urban areas (UN-Habitat, 2018). Nowadays the 55% of global population lives in urban areas (Carli et al., 2018) and many projections suggest that the number of people living in cities will grow nearly to 70% in 2050 (Un-Habitat, 2018). Considering the complexity of modern cities is necessary to design proper infrastructures and services. The use of water resources for industry, energy, agriculture and daily consumption, such as drinking and personal cleaning, is one of main issues discussed by the international community (UN Water, 2019). In global panorama of water scarcity (United Nations, 2017), the understanding of the water-energy nexus is relevant for the proper management of basic resources. The increasing demand of water and energy is an important challenge to consider moving toward sustainability, especially in the urban context. The management of rivers in cities should meet the need for multiple functions, including the production of renewable energy through small-mini-micro hydropower technology.

1.2. Opportunities provided by water resource management

Hydropower is considered one of the most ancient type of sustainable, cheap, feasible and clean source of energy. It provides many benefits for local citizens, as reducing water and air pollution and enhancing local resources (Kamran et al., 2019). It covered an important role in the economic and industrial development in Nineteenth century and nowadays it still represents an important factor in the development of low-carbon systems (Harlan, 2018). Hydroelectric power includes both large-scale hydroelectric dams and small run-of-the-river technology. The construction of hydroelectric power stations depends on the topography and geography of the territory. On the other hands, the construction of new hydroelectric facilities, especially large-scale infrastructures, might impact the environment and aquatic wildlife's ecosystems. In some cases, in large artificial lakes with dams the concentration of nutrients and sediments might increase, changing habitats and conditions for animal and plant life and increasing greenhouse gasses emissions (Abbasi & Abbasi, 2011; Wagner et al., 2019). The global future challenge is to provide benefits for humans without affecting natural ecosystems. Referring to the study of Hatata et al. (2019), small-hydropower systems can be installed in run-of-river scheme or implemented in existing river infrastructures as a cost-effective source of renewable energy. The concept of sustainability applied to the network of infrastructures mainly refers to addressing the energy issue, the environmental issue and the socio-technical issue, such as the recovery and renovation of historical facilities. As *blue infrastructure* (Lennon et al., 2014, Kougias et al., 2019), its positive effects on the urban environment are evaluated considering ecological issues and citizens' wellness related to the redevelopment of the degraded area under study.

1.3. Novelty of the study and paper organization

This paper presents a reflection on paradigm shift toward an ecological approach in water management and on benefits provided by small-scale hydroelectric facilities through a real case study designed in the urban context. Before introducing the case study, the article addresses the theoretical framework concerning city dynamics and the ecological perspective to face its complexity. These reflections are further explored (Fig.1) through the project of a mini-hydro power plant constructed in an historical district of Turin. The study analyses the current status of the context, in terms of infrastructures' usability and conditions. and administrative regulations to define the scenario of the city and main requirements.

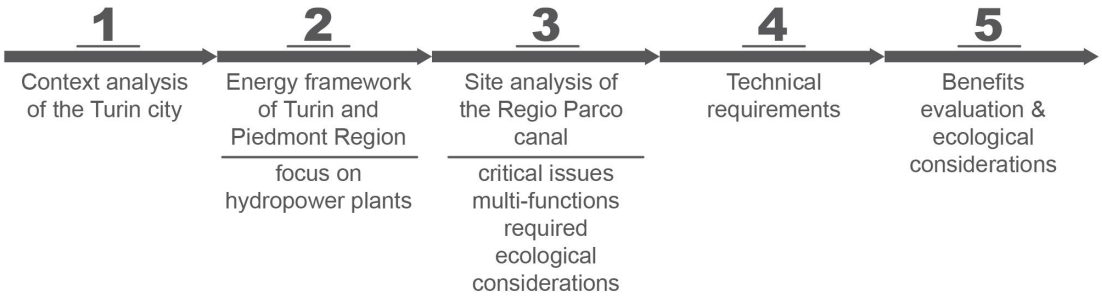

Fig. 1. Organization of the case study analysis.

The project has been designed, in collaboration with the Municipality of Turin, to restore an inactive check dam and to convert it in an inflatable dam to produce electricity for citizens use. The additional contribution is to consider the reduction of environmental impact on landscape, on vegetation and noise during design steps. Considering the city as complex system, the study focuses on integrating ecological consideration from the *Urban Ecological Infrastructure* approach during design steps. This case study shows an example how it is possible to produce clean energy in site and reduce ecological footprint of hydropower plants through the restoration of an historical infrastructure inside the urban context. It refers to the concept of microgrids (Khalili et al., 2019b) for the distributed energy generation for local demand with the purpose to reduce costs for energy transportation (Khalili et al., 2019a). In this case, the energy produced in situ is introduced in general electric grid that provides energy for the city of Turin. The project of the infrastructure's renovation is a part of a wider plan to integrate issues focused on energy, water resources, urban land use nexus toward the increasing of urban sustainability. This study suggests to use the ecological approach for the urban redevelopment, because it focuses on creating infrastructures with multiple functions that integrate human requirements and environmental needs.

2. Theoretical framework for urban transition towards sustainability

2.1. Cities as complex systems

Since the 1960s, cities are considered as dynamic and complex open systems and McLoughlin, in 1969, introduced the systems approach applied to urban planning as tool to face many challenges that arise in

urban contexts. Consider the seven features that describe complex systems (Cilliers, 2000), they can be used to describe main characteristics of contemporary cities:

- Cities represents a concentration of high number of elements, that can be read by multidisciplinary perspectives;
- Interactions between these components are dynamics. There are constantly exchanges of information and energy between elements that are essential for the existence of the city itself. The city involves in its metabolism many inputs that come from outside its physical territory and its outputs can affect the external environment;
- There are a lot of direct and indirect feedback loops that give information regard the status of the system itself;
- Cities are open systems because their boundaries are flexible, and they operate around dynamic equilibrium condition;
- Memory and history are important aspects for the behaviour of cities. They aren't located at a specific structure, but they are distributed between components of the system. This feature influences the adaptive ability of the system without central control;
- The behaviour of the whole cities cannot be predicted only observing the behaviour of their elements. Cities operate as a "whole" and their behaviour is emergent;
- Each element has an important role in the self-organizing activities of the whole system because many aspects of cities are defined by bottom-up operations. Top-down decisions aren't enough to describe properly the whole system.

Considering the current environmental crisis, low-carbon strategies toward sustainable transition of our cities are necessary. They should enhance the value of local resources and ecosystem services, especially looking for the energy provision. Sustainable transition of infrastructures in urban context arises discussions at three different levels:

- at the political level that involves local governance, administration, citizens and stakeholders in decision making process;
- at the technical level that includes designer, architects, engineers in projects implementation;
- at the community level that implies that people are aware regard benefits and impacts.

Relationships and connections between these three levels are essential to really deal with transition towards effective and sustainable actions.

2.2. Ecological perspective in city dynamics

Urban Ecology promotes an interdisciplinary approach to investigate interactions between humans living and urban ecosystem (Richter & Weiland, 2011). It addresses the paradigm of *ecology in - of - for* the city (Endlicher et al., 2007), that focuses on biodiversity, on green and blue spaces of urban fabric and on providing the access by citizens to nature (Goode, 2014). This approach is essential in defining new opportunities for decision-making to improve urban resilience and reduce the ecological footprint of infrastructures (Pickett et al., 2016).

Another theoretical lens to read the complexity of urban ecosystems is the Systems thinking (Meadows, 2008). Systems thinking explores opportunities to improve sustainability in urban context, in the framework of innovation for transition of socio-ecological systems (Gaziulusoy et al., 2013). In the sustainability framework, the role of urban infrastructures is essential for the efficient operation and metabolism of complex cities. The concept of *infrastructure ecology* (Brown, 2014; Xu et al., 2012) is included in the theoretical approach of Urban Ecology and it aims to provide essential ecosystem services for wealth that implies less energy, matter and financial investments and increases urban resilience. The ecological approach to urban infrastructure recognizes the importance of relationships and flows between elements of cities and it consists in the consideration of "Materia-Water-Energy-Land-Use-Transportation-Socioeconomic Nexus" (Pandit et al., 2017). The central aspect of this approach is designing interconnected "green-blue" infrastructures of materials, energy and water flows. The 12 principles of infrastructure ecology, proposed by Pendit et al. (2017), focus on increasing the quantity and quality of ecosystem services provided in man-made ecosystems. *Urban ecological infrastructure* (UEI) is defined as the organic integration of blue (water-based), green (vegetated), and grey (non-living) landscapes, combined with "exits" (outflows, treatment, or recycling) and "arteries" (corridors) at an ecosystem scale (Li et al., 2017a; Li et al., 2017b). In the ecological framework applied to the urban context, the network of infrastructures is necessary to be multi-functional and strategically planned to promote healthier environment. Flood risk is a persistent issue in cities crossed by rivers and streams. Blue and green infrastructure should be designed adopting a long-term and ecologically sensitive approach to increase mitigation, adaptation and resilience (Lennon et al., 2014). Meanwhile, they also provide habitat for urban wildlife and they are essential green corridors to maintain or increase biodiversity in the territory. The main challenge in complex urban areas is to integrate in blue infrastructures the water management to preclude flood risk with the provision of basic needs for local community, such as energy, and maintaining or recovering of natural environment. Managing local resources and providing benefits for the whole context is important to promote sustainable urban metabolism, through the application of the holistic viewpoint. Optimization of resources and energy investments, minimization of impacts and maximization of comfort and wellness are the main actions to pursue for the creation of more sustainable urban areas (Pandit et al., 2017).

3. The study area: characteristics and trend of Turin (Piedmont, Italy)

3.1. Overview of the urban context

With its population of 878.074 habitants (ISTAT, 2018), the city of Turin is the third largest economic-productive complex in Italy. The city is characterized by a rich historical, industrial and cultural heritage and by many parks (there are 21,37 km^2 of green areas in the city) recognised in 2016 by the UNESCO "Man & Biosphere" program. Turin is also called as "The city of four rivers" (Lanzardo, 1995), because it rises in the plain delimited by rivers of Stura di Lanzo, Sangone and Po and in addition the river Dora Riparia flows across the middle of this plain, near the historic centre. The project "Turin Water City", which is approved in 1993 (n.d., 2001), provides the recovery of riverbanks,

the increasing of urban green areas and the improvement of riverine parks through bike lanes, pedestrian areas and naturalistic itineraries. This project, that is supported by the administration of Turin, shows the importance of restoring urban riverine environment to enhance the naturalistic heritage of the city. Until the middle of XX century, the flourishing industry of the city was marked by the presence of rivers, especially in the north area and in Borgo Dora and Vanchiglia districts (Parodi, 2017). Historical canals, industrial archaeology and old riverine infrastructures next to the Dora Riparia river are witnesses of its importance as engines of local economy.

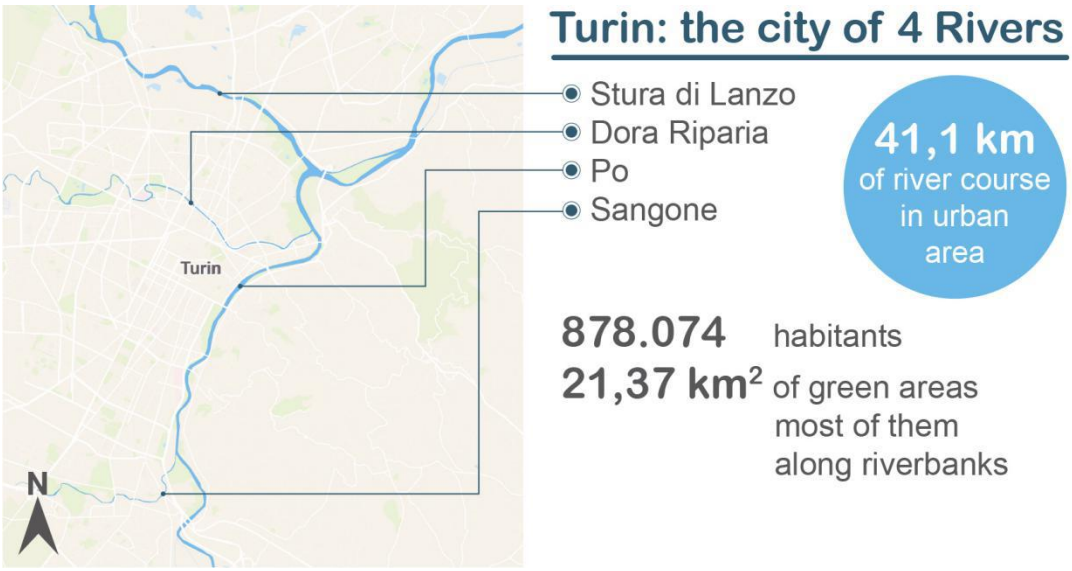

Fig. 2. Summary of data that refer to the main features of Turin's rivers.

3.2. Energy framework analysis in the city of Turin and Piedmont region

Considering data of the 9th Report on Energy (Provincia di Torino, 2014) and of Arpa Piemonte (2017), the energy consumption for industry purpose grew substantially from 1983 to 2007, with a collapse in 2008 mainly due to the economic crisis and the closure of several businesses. Since the end of the last century, the local economic identity is transforming itself as the result of massive de-industrialization process. Looking at the allocation of total energy consumption (Fig. 3), the most significant items are industry (49.1%), the tertiary sector (30.9) and the domestic sector (18.6%). On the other hand, the local energy policies follow the guidelines provided by the European Union regarding the reduction of 20% of total energy consumption and the increase of 20% of the contribution of renewable energy. In last years the production of renewable energy is constantly increasing and this trend contributes to reduce the dependence of the region by abroad energy supplies. It is required to invest in the transition towards production and consumption of renewable energy and towards the reduction of CO_2 emissions. At regional scale, the production of renewable energy is accounted by 39% (Terna, 2016) and, also at local scale, the hydropower production is the largest contributor, with 7,83 TWh of energy production (Arpa Piemonte, 2017).

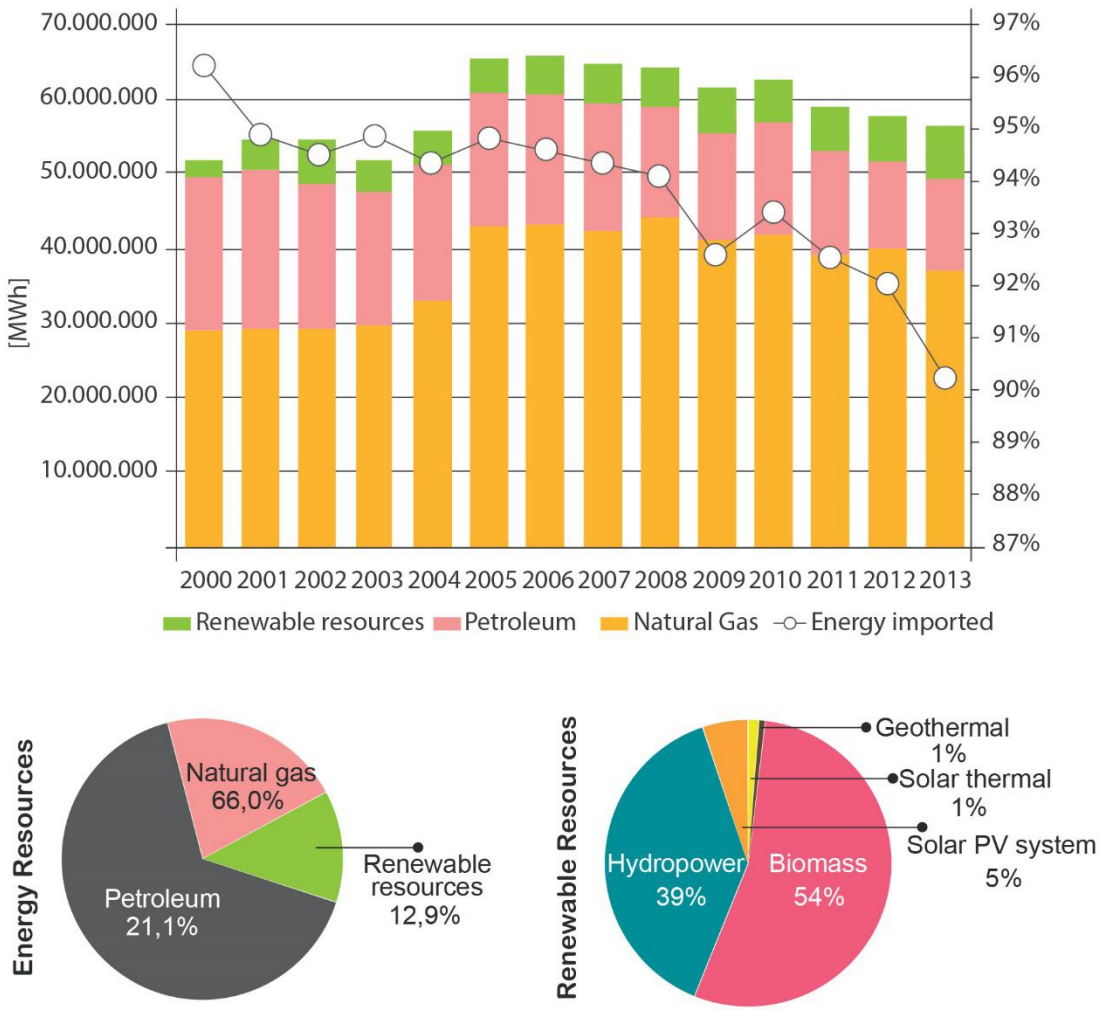

Fig. 3. Energy framework data concerning the Province of Turin (Provincia di Torino, 2014).

Urban rivers and streams naturally flowing towards existing and historic check dams provide sites suitable for hydropower generation. In recent years, the trend is to restore historical and idle dams located along the rivers in the urban and sub-urban area of Turin and to use them to produce electricity through mini-hydro power stations, with an installed power less than 1.000 kW. Mini-hydro power station is included in the category of small-hydro power station/plants that have output up to 25 MW. Small-hydro is considered more environmental-friendly than large-hydro and it is also considered a cleanest substitute for large-hydro (Abbasi & Abbasi, 2011). Some example of these interventions of requalification in the Metropolitan City of Turin are (Fig. 4):

- along the Pellerina Canal on the Dora Riparia River, which is located within one of the biggest urban parks of the city;
- along the Meana Canal on the Dora Riparia River, in the framework of the urban regeneration of the post-industrial area of Spina 3 (Environment Scientific and Technological Park);
- along the Po River in the sub-urban area of La Loggia (Moncalieri, Turin);
- along the Ceronda stream in the Municipality of Venaria Reale (Metropolitan City of Turin).

Fig. 4. Distribution of mini-hydro power systems in the urban and suburban area of Turin.

Generally, these interventions are considered good practices of integration between urban and suburban river and water infrastructures. Especially the mini-hydro power plant installed into the Pellerina Park (Fig. 5) is considered as virtuous example by environmental organisations. In Piedmont, another important initiative is the recovery of historical architecture in contemporary mini-hydro power station, as the watermill in the Municipality of Crescentino (province of Vercelli). The objective is to enhance the existing hydraulic head (2,6 m) of the mill on the canal of the Canal Roggia Camera for the electricity production (expected average annual productivity of 283 MWh/year) (SRIA, 2019). In the same Municipality, in 2013 another micro-hydro power plant was constructed on the Roggia Camera canal, recovering an historical watermill, that expects it to produce approximately 215 MWh/year.

Fig. 5. Mini-hydro power plant installed in the urban park of Pellerina (Authors, 2018).

3.3. Environmental issues linked hydroelectric production in Piedmont Region

Mini-hydro is a well-established technology to convert energy in rural and urban areas. Its application refers not only to the technical approach, but also to the environmental and social issues. It is considered as one of the most environmentally friendly solution for energy conversion, because it generates low impact in the river flow than large hydropower plants, but some conflicts in decision-making still remain. The debate on the environmental impact of hydropower is ongoing in Italy as well as in Europe (Bracken et al., 2014), especially because its importance for contributing to the production of energy from renewable sources. Some potential impacts of mini-hydro infrastructures mainly concern transformations of freshwater habitats by barriers in riverine ecosystems. Barriers are responsible of changing flow velocity, habitat fragmentation, sediment transfer that could affect wildlife and biodiversity. They could also increase flood risk and contribute to noise pollution, some important issues in urban areas. Freshwater ecosystems, which are important for biodiversity, should be protected from further anthropic pressures, as they are among the ecosystems that suffer most from environmental stress. Sociotechnical and ecological needs should be taken into consideration for the proposal of technical solutions for the use of water resources for the energy production. Technical solutions must ensure good health status of the watercourse in both urban and rural environments (Commission of the European Communities, 2000).

4. The project: design considerations of mini-hydro power plant

4.1. The case study of Regio Parco Canal (Dora Riparia River)

This study presents the project of historical checkadam of Regio Parco Canal's recovery along the Dora Riparia River and inside the district of Borgo Dora (in the middle of the city of Turin) (Fig. 6).

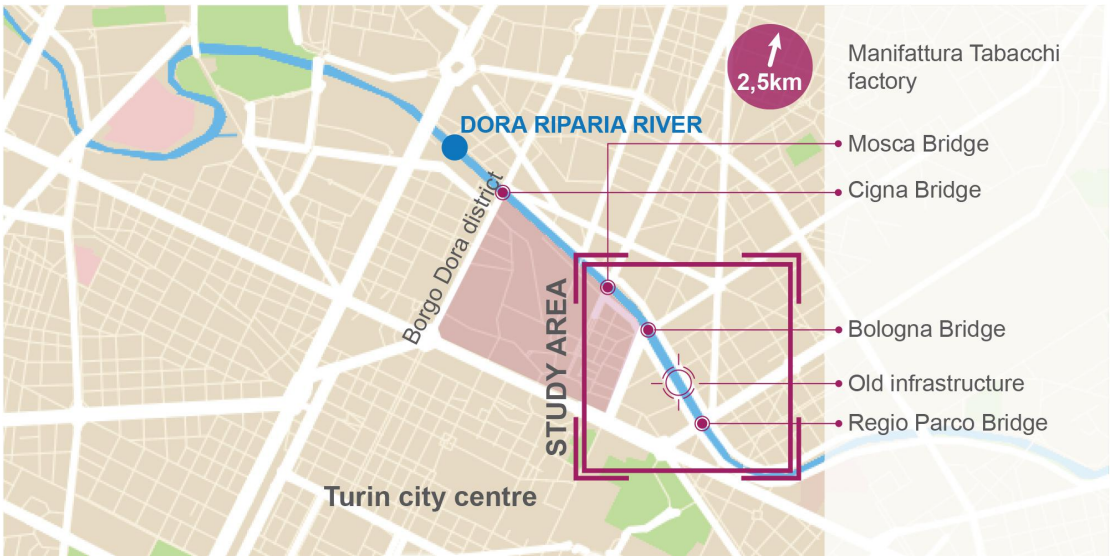

Fig. 6. Map of study area with indications of the main landmarks.

The check dam of Dora Riparia River and the Regio Parco Canal were very important infrastructures for one of the oldest factories in Turin, the Manifattura Tabacchi. The factory was in the Borgo Regio

Parco district, in the north of the city, and it was dedicated to the activity of packaging cigarettes and tobacco. The urban area along the Dora Riparia River is the zone of first subalpine industrial development, thanks to the presence of the nearby waterway. Waters of the river provided the hydraulic energy necessary for the energy supply of mills, sawmills, military industries and silk twisters. The "Regia Manifattura Tabacchi" was designed in 1758 and the "Regio Parco" artificial canal was considered as strategic infrastructure for water provision. The tobacco factory and the canal were in operation until the second half of the 20th century. Afterwards, the Regio Parco canal lost its function for the provision of engine power and water for the industrial production. The abandoned and completely dry canal was degraded and characterised by the presence of spontaneous vegetation. Launched by the Municipality of Turin, the project focused on the recovery of the historical infrastructure for:

- the adaptation of the fluvial crossbar, between the Bologna Bridge and the Regio Parco Bridge (also known as the Benne Bridge), to reduce water level of the river in flood condition and to limit the flooding risk, following the indication given by the River Po Basin Authority in the document "Variant to the 2007 PAI (Piano stralcio per l'Assetto Idrogeologico - Hydrogeological Structure Excerpt Plan)";
- the production of electricity through a mini-hydro power station on the right bank of the Dora Riparia River using the existing hydraulic head created by the check dam. It is identified by the Municipality of Turin as historical infrastructure to enhance using it for the electricity production without altering the qualitative and quantitative characteristics of the water body;
- the requalification of the surrounding area to improve the quality of river waterfront for recreative and educative purposes.

Dora Riparia River has a torrential course and it is subject to strong flood risk, being a security problem for citizens. In recent years, the need to secure the area (Table 1) has also increased as the result of critical conditions of flood risk, in 2000 and 2016, presented especially in the previous section between the Mosca Bridge and the Bologna Bridge (Vv.Aa, 2016). In this section, riverbanks and the Bologna Bridge are quite low and exposed to flood risk. Moreover, the surrounding area presents a critical social condition and it is necessary the upgrading of degraded buildings and of the Torino-Ceres railway station.

Table 1: state assessment of the infrastructure before the intervention and interrelations between different functions that it must consider for avoiding environmental impacts.

Current state assessment	Proposal of intervention	Multiple functions required
High flood risk during intense precipitation	Adaptation of the river diversion crossbar	Produce energy by run-of-river system using urban water flow
Historical infrastructure in state of deterioration	Construction of a mini-hydro power plant	Reduce flood risk
		Consider preservation of

		freshwater habitat for wildlife
Surrounding area not enhanced	Upgrading of the right riverbank	Enhance historical and urban landscape
		Improve green spaces providing new facilities

During preliminary steps, site analysis focuses on environmental issues related to surface of freshwaters. It is necessary to predict potential impact of the infrastructure and to establish the monitoring assessment procedure after the installation of mini-hydro power facility. The flow regime of the Dora Riparia river (Fig. 7) has been elaborated using data provided by Arpa Piemonte (Regional Agency of Environmental Protection) concerning the average annual rainfall trend (1991-2013). The average natural discharge of Dora Riparia, calculated at the intake section of the mini-hydro power plant, is 23,31 m^3/s. This analysis is useful to calculate the environmental flow of Dora Riparia, to set parameters of the Regio Parco power plant and to define turbine's characteristics.

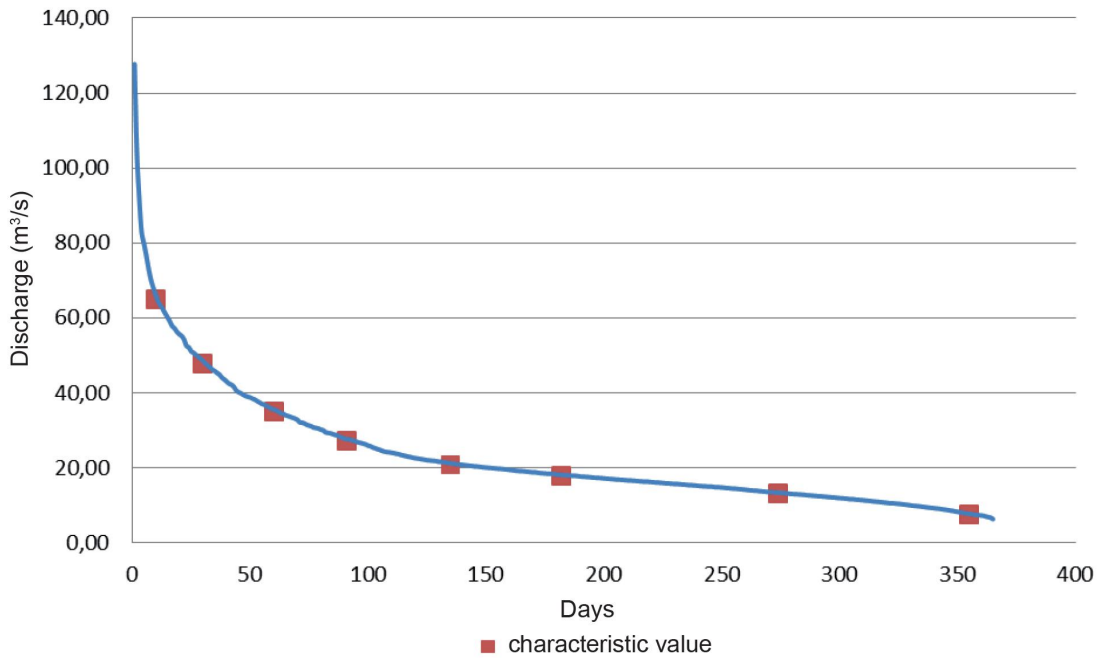

Fig. 7. Duration curve of the natural discharges of Dora Riparia river during the average hydrological year. The curve is calculated at the intake section of the power plant and it is representative of a period of about 23 years.

Hydraulic model of functional detail, obtained by Hec-Ras software, are used for assessing the extension of upstream backflow. According to the last monitoring conducted by Arpa Piemonte (2017), the section of river under consideration presents some criticalities due to water extraction for agriculture and to pollution for civil discharges. The introduction of the Framework Directive 2000/60/EC requires to reduce the harmful pressure on watercourses and to improve their chemical and ecological status reaching the "good" one by 2021. The analysis of the project does not predict negative

impacts on freshwater ecosystem because it interests a limited reach of the watercourse where there is an existing an old check dam infrastructure.

4.2. The design process and technical aspects for construction

Works for the recovery of the historical check dam and for the construction of the mini run-of-river hydroelectric power plants started during the summer 2017. Installations for hydroelectric facilities usually require an environmental impact assessment under the European Directive 2014/52/EC. Environmental impact assessment is also necessary to comply with the Framework Directive 2000/60/EC that impose to reduce the hydromorphological alteration of watercourse and to preserve a good status of freshwater ecosystems. In the framework of this specific case study, the environmental impact assessment was not required because it is an infrastructure already present in urban area. Nevertheless, the project of intervention has been subject to a review stage to assess the technical feasibility and potential impacts. The project was also presented to citizens and it remains available for public consultation for 45 days. At the end of this consultation period, no negative comments were received. The period of the construction site has been estimated at 10 months and the mini-hydro power plant has started its activity in the end of 2017. The area under study is inside the urban context, near the city centre, and the construction site has been designed to slightly affect regular road practicability. Figures 8 and 9 summarize the overview of project's interventions.

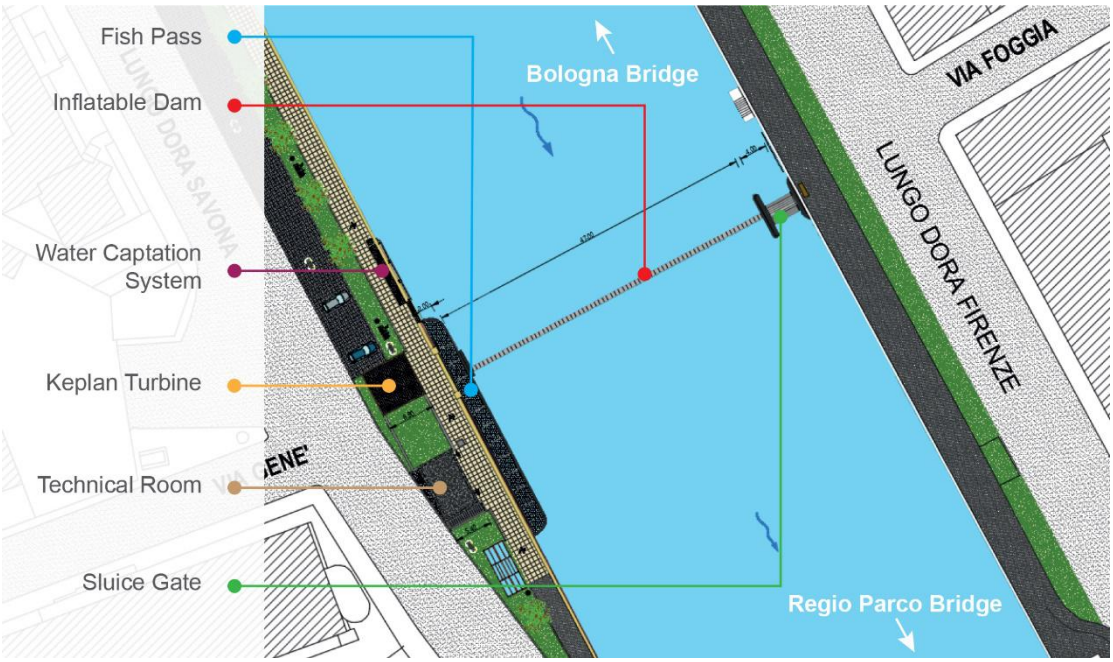

Fig. 8. The technical map shows an overview of interventions for the mini-hydro power plant in the study area.

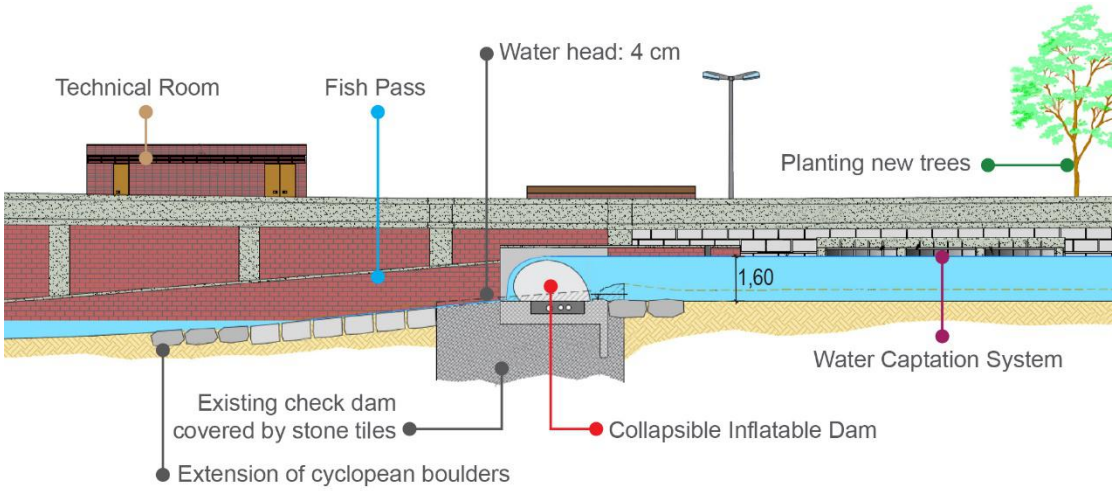

Fig. 9. Profile of the mini-hydro power plant and profile view of right riverbank along to Lungo Dora Savona.

Most interventions have been made during periods of lean river as the construction of provisional infrastructures and the realization of the collapsible inflatable dam. The design solution provided partial lowering (0,70 m) of the check dam and the installation on the lowered structure of a fully collapsible inflatable dam (1,60 m high and 47,5 m width). The collapsible inflatable dam (Fig. 8) artificially increases the hydraulic head for hydroelectric purposes and, when collapsed, it permits to reduce flood risk during the peaks discharge of the Dora Riparia River. In this way, the mini-hydro facility follows goals established by the variant of PAI project. A flap gate on the left edge of the check dam permits the adjustment of the levels upstream improving the regulation of the derived flow when the flood river discharge increases (Table 2). The inflatable dam is always covered by a water nappe that also ensure the Environmental Flow to maintain biocenosis of freshwater ecosystem and wildlife.

Table 2: Water flow rate management of the mini-hydro infrastructure.

Guaranteed water flow rate	
On the top of inflatable dam	750 l/s
Sluice-gate drainer	300 l/s
Fish pass	450 l/s

The sediment transport in front of the intake is removed by scour channel with sectioning gate. A fish pass, vertical slot typology (Fig. 9), on the right side of the dam allows the fish species to overcome the existing hydraulic difference in elevation during their upstream migration. The aquatic wildlife in the section of river under consideration is mainly composed of *Barbus plebejus, Leuciscus cephalus, Leuciscus souffia and Salmo trutta marmoratus* (Piedmont Region, 2009). The fish pass is composed by 10 subsequent ponds (0,24 m high, 2 m depth and 2,5 m length) and the depth of water in each pond is almost 1,4 m. A fraction of the water flowing in the river is diverted through a channel and it put in rotation a horizontal axis bi-regulating Kaplan turbine (Fig 10).

Fig. 10. The first picture show the positioning of Kaplan Turbine, the second one shows vertical slots of fish pass and the third one shows the inflatable check dam (Authors, 2017).

The Kaplan turbine can process a maximum flow rate of 21 m^3/s (Q_{max} = 21 m^3/s), while the minimum flow rate is the 20% of the Q_{max} (Q_{min} = 4,2 m^3/s). The Kaplan turbine works only if the difference in upstream and downstream head is bigger than 2,0 m. Otherwise, the mini-hydro power plant stops, and the natural Dora Riparia flow rate isn't exploited for energy purposes. The derivable average discharge (Q_{avail}) is calculated following this relation:

$$Q_{avail} = Q_n - Q_{enf\text{-}basic}$$

Q_{avail} is the available rate flow derivable;

Q_n is the natural rate flow of the Dora Riparia river;

$Q_{enf\text{-}basic}$ is the environmental flow of the Dora Riparia river.

Table 3 shows rules for calculating the derivable discharge (Q_{der}) for the mini-hydro power plant's operation, while the Table 4 resumes main characteristics of the Regio Parco plant.

Table 3: management of derivable discharge for mini-hydro power plant's operation.

Rules for the management of the Dora Riparia's water flow	
If $Q_{avail} < Q_{min}$	$Q_{der} = 0$
If $Q_{min} < Q_{avail} < Q_{max}$ and $H_{net} > 2{,}0$ m	$Q_{der} = Q_{avail}$
If $Q_{avail} > Q_{max}$ and $H_{net} > 2{,}0$ m	$Q_{der} = Q_{max}$
In any case, if $H_{net} \leq 2{,}0$ m	$Q_{der} = 0$

Table 4: main characteristics of the Regio Parco mini-hydro power plant.

Main concession parameters of mini-hydro power plant	
Maximum derivable discharge (Q_{max})	21 m^3/s
Minimum derivable discharge (Q_{min})	4,2 m^3/s
Average derivable discharge	10,56 m^3/s
Nominal difference in upstream downstream head	2.40 m
Nominal power	248.6 KW
Base environmental discharge	5,430 l/s
Medium annual power plant production	1,660 GWh/year

The mini-hydro power plant is watertight, and it is built completely underground on the right bank of Dora Riparia River without any negative visual and vehicular traffic consequence. In fact, the inflatable folding barrier is constantly masked by a water blade of 0,14 m and it also provides the environmental flow of the river. Moreover, floating waste barriers have been installed at the entrance of the leading canals to mini-hydro power plant. Building materials used for the structure were chosen considering technical and structural needs and proper landscape integration with the existing materials (Fig. 11). Bricks, local stones and concrete were chosen to facilitate the integration of the new infrastructure with existing ones. The project also considered the redevelopment of the pedestrian pathway next to the riverbank wall until the Regio Parco Bridge. Downstream of the inflatable dam, some large boulders have been used for the reinforcement of the riverbed. With the same technique, the bottom of water restitution canal and the outlet of fish pass have been protected from erosion.

Fig. 11. The status of the Regio Parco check dam and the pedestrian sidewalk before and after the installation of mini-hydro power plant. The intervention includes also the requalification of the right riverbanks (Authors, 2018).

4.3. Benefits produced

Interventions of recovery of existing unused infrastructures and the area's requalification provide many environmental benefits and the mini-hydro power plant can produce an amount of energy of almost 1,6 GWh/year, completely fed into the national electricity grid. This energy production contributes to fulfil the need for electricity of almost 600 households, reducing the emission of CO_2 almost of 900.000 tons.

The nominal power of the mini-hydro power plant has been calculated using the analysis of data of the average turbine discharge and the total difference in head:

$$P_{NOM} = 9{,}81 \text{ x } Q_{media} \text{ x } H_{tot} = 9{,}81 \text{ x } 10{,}56 \text{ x } 2{,}40 = 248{,}6 \text{ kW}$$

While, the energy production of the mini-hydro power plant has been calculated using the net difference in head, the year runtime and the efficiency of the turbine-generator unit.
Regarding the management of flood risk in the area, the modelling of the flow in critical conditions, highlights that the check dam before the intervention causes the flooding of the surrounding area. The power plant construction lowered the check dam of 70 cm, reducing consistently the water surface level during critical conditions (almost 1 m in correspondence of the inflatable check dam). Positive effects of this intervention are also observed almost 1 km upstream (in correspondence of Cigna's bridge) (Fig. 12).

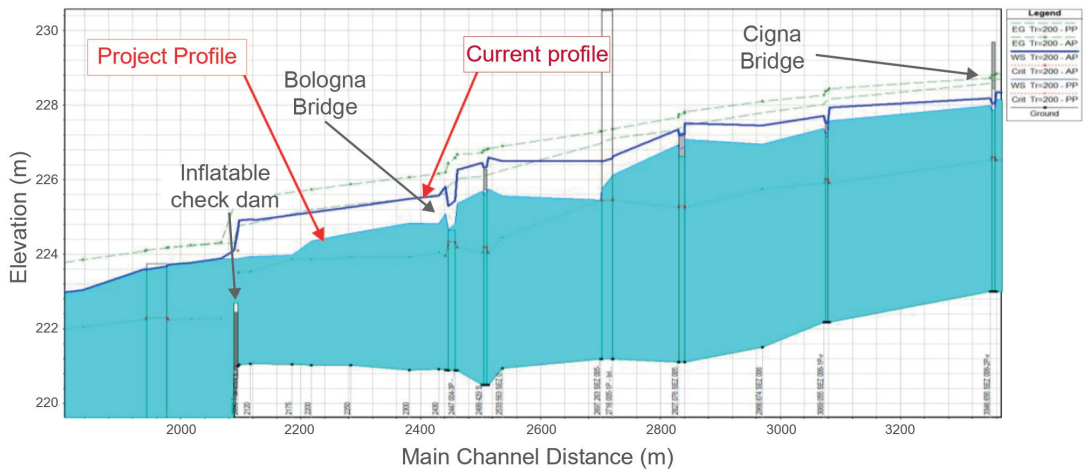

Fig. 12. Results of HEC-RAS modelling that compares the "current profile" before the intervention and the "project profile" after the requalification of the river crossbar and the installation of the inflatable check dam.

This intervention responds to the requests of the River Po Basin Authority (PAI) to secure the area from flooding risk and to reduce the Dora Riparia's thrust on masonry riverbanks. Fig. 13 shows that the balustrades on the riverbanks were reinforced by metal sheet to avoid floods, but this solution is considered inadequate to secure the area.

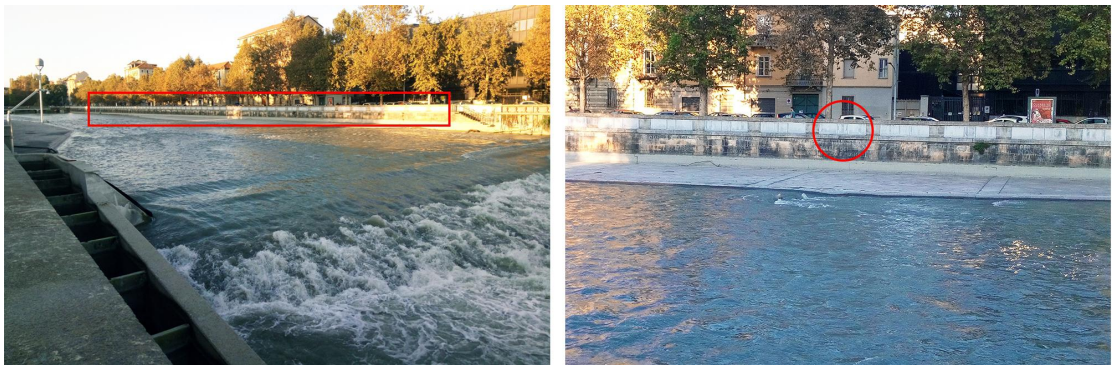

Fig. 13. Balustrades of riverbanks reinforced by metal sheet. The picture on right shows the detail of metal sheets. In the picture on left, the inflatable check dam is deflated due to the flooding condition of Dora Riparia river.

Nevertheless, the installation of inflatable check dam reduces the water level in that river reach. The restoration of historical canals is also important to preserve the paleo-industrial memory of Turin and to make the area agreeable and accessible by citizens thanks to compensation and greening works. Compensation works include the provision of urban furniture and the ordinary cleaning of sluices and canals by waste. The compensatory greening works include the management of green areas and the planting of new plane trees, 3 in situ and 51 in the urban area of Turin. A communication and educative board are installed along the sidewalk to give information regarding the environmental footprint of the mini-hydro power plant and the management of renewable resources.

5. Urban ecological perspective of the intervention

Renewable energy provision, urban regeneration and reduction of environmental impact are some important issues in the redevelopment process of disused industrial areas in the urban fabric of Turin. Many interventions regard the requalification of post-industrial sites and green areas have had a positive impact on the inhabitants' perception of city liveability, but many other actions can be undertaken to improve the quality of infrastructure (SWG, 2015). The transition towards sustainable cities consists of moving away from the traditional engineering paradigm, that consider the maximization of single infrastructure separated from the urban context, to an integrated approach. The recovery of Regio Parco historical check dam expresses some of the 12 principles of infrastructure ecology (Pandit et al., 2017), especially following ones:

- The I principle: the project is not an isolated case of mini-hydro power plant in Turin. The infrastructure is a part of a mini-hydro network in the urban and suburban area of Turin.
- The II and XII principles: the adaptive reuse of Regio Parco dam integrates and optimizes water and energy flows for the production of electricity for local use in urban context. Electricity production through this renewed infrastructure contributes to develop the use of renewable flows rather than depleting stocks. The energy is produced close to the site of use reducing costs for transportation;
- The VII and IX principles: the new “blue infrastructure” was designed to integrate engineering function, for electricity production and control of water level, with environmental one. The recovery of historical dam has taken into account the needs of the fauna living in that stretch of river. The requalification of surrounding area was done with the purpose to increase the integration of the blue infrastructure with green corridors. The entire project proposes to minimize intervention’s environmental impacts and to improve the well-being and comfort of residents in that urban area, first by acting on flood safety;
- The VIII principle: the design process of blue infrastructure is not the result of technical implication, but the project was discussed with citizens and it was built in collaboration with local governance.

6. Conclusions

This paper addressed the opportunities provided by the installation of a mini-hydro power plant with re-development purpose in urban area of Turin. The project's novelty is to provide an urban infrastructure with multiple functions: the requalification of historical check dam, the energy supply and the enhancement of the Dora Riparia riverfront banks. These multiple functions are designed according to the purposes of improving the ecological status of the river and reducing the flooding risk. Small-scale hydropower systems, that use existing structures, present less environmental impacts than large-scale systems. Mini-hydro power presents many advantages as the dependence by natural flow of watercourse, the low relative cost of the system and possible applications in remote areas. It creates new opportunities for rural and isolated communities but also reduce the environmental impact for electricity production in urban and suburban areas (Nasir, 2014; Harlan, 2018). Mini-hydro power, that uses already existing difference in head, is a solution for energy request that continues to grow in urban and rural areas. In the framework of small-scale run-of-river systems, the UEI provides an interesting approach to design infrastructures that interact with river and urban ecosystems in a complex way. The ecological approach applied to urban infrastructures considers a holistic view that integrates planning, engineering, local policy, innovation and ecosystems needs. This approach should be implemented in other case studies to verify the usefulness in producing synergic solutions for urban infrastructures. Since the early 2000s, the redevelopment of the city focuses not on single buildings, but on wider areas considered as systems (Dansero et al. 2001). The network of infrastructure plays an important role in quality and results of redevelopment interventions. The ecological approach needs to be validated as method that improve the sustainability in urban areas, strengthening relations between local administrations, technical figures and citizens. In the transition towards urban sustainability, mini-hydro power infrastructures, widespread at local scale, represent a valid alternative to convert electricity in situ, improving microgrid networks. The UEI approach should be more investigated to estimate its potential in redevelopment processes. Moreover, it is an opportunity to enhance industrial history and the urban landscape and to reduce the flood risk. This case study enhances the "land use-water-energy nexus" adopting a reinterpretation of Low Impact Development (LID) techniques to improve the environmental resilience in urban areas. At the end, this study suggests considering the approach of UEI for a more synergic development of grey, blue and green infrastructure in urban context.

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