A proposed road map to exploit the wastewater treatment, water reuse and resource recovery opportunities in Kanpur (India)

Deliverable D7.1

Develop a road map to exploit the WW treatment, water reuse and resource recovery opportunities for a selected Urban Local Body

Final version (public)
WP7
Task 7.1

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Dissemination level		
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CO	Confidential, restricted under conditions set out in Model Grant Agreement	
CI	Classified information as referred to in Commission Decision 2001/844/EC)	
R	Document, report	X
DEM	Demonstrator, pilot, prototype	
DEC	Web sites, patent fillings, videos, etc.	
OTHER	Software, technical diagram, etc.	
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SUMMARY

Wastewater must be seen as a potential resource instead of a threat and a burden. The roadmap, proposed in this document, seeks for pathways toward sustainable wastewater systems, matching a scenario with a 50 years horizon in the area of the Kanpur Nagar region. The overarching goal aims at determining an ideal scenario for the next infrastructural investments resulting from a careful analysis of the opportunities for recovering energy, materials and nutrients, and providing a sustainable water reclamation service.

The roadmap is structured as a multi-step process requiring preliminarily an accurate screening of the local conditions, the environmental pressures, the stakeholders' interests, the local water resource specificities, subdividing the screening in different sub-steps. In parallel, an evaluation of the actual asset situation is conducted in view of present and planned investments. The information provided above is used as a feed to a methodology meant to select and boost the most adequate circular economy-based solutions. A number of scenarios carefully selected from literature and real world cases, are first analyzed as standalone scenarios. Subsequently, a systemic approach is presented to short-list them and the method is applied to the Kanpur Nagar Region case. An element that was found to negatively impact the choice of the different applications is the impact of the toxicity from the nearby tanneries' cluster and the efficiency of the circularity. The latter indicators drop the circularity potential of specific solutions and this results in a lower environmental attractiveness of single standalone solutions. Finally, the overall information is merged with determining a centralized base-line scenario for the Jajmau STP (sewage treatment plant), around which decentralized solutions are also proposed for other settings. The financial viability of the selected scenarios will be verified in the next deliverable of work-package 7.

Short-listing (Chapter 3) and rejection of standalone scenarios (Chapter 4), results in the definition of a baseline scenario. The proposed base-line scenario foresees a conventional sewage treatment (STP) to produce effluent water, further treated to remove heavy metals and recover chromium solution. The STP effluent water would be reused for industrial applications, and for agricultural applications, giving priority if possible to industrial reuse-opportunities – as this sector has a higher potential to achieve cost recovery than the agricultural sector. However, there is also a strong argument to deliver safe irrigation water as a public good for local farmers.

The energy valorization has a crucial role in the circular approach. The possibility of mixing wastewater sludge with organic material (at high caloric power) is enforced wherever possible (both co-pelletization with farming residues, and primary sludge digestion with other organic sources). Septic sludge and manure have been identified as ideal substrate for primary STP sludge co-digestion. While the primary STP sludge would be treated through digestion, the disposal and the valorization of secondary STP sludge would depend mainly on sludge co-pelletization. Co-pelletized material could be sold to the domestic market or incinerated in biomass power plants as a substitute for coal. It is important to realize that the energy valorization of the wastewater sludge ultimately depends on the incineration of the secondary STP sludge. Moreover, the sludge incineration turns to be the necessary step for a number of powerful circular solutions: the production of fertilizers, as the ashes resulting from the biomass power plants combustion can be further exploited in a high-rate phosphorous recovery process; sludge inertization for construction; substitution of charcoal with a significant contribution to mitigation of global warming.

A high number of attractive solutions is ultimately proposed in the Materials pathway. Yet, for several of them, there has been a discussion on which technology to apply in order to realize sustainable processes. Being Utter Pradesh an area with an important agricultural sector, the production of

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fertilizers is of crucial importance: the latter can be realized from the sludge ashes (as discussed in 3.4), rather than from the liquid-phase of a wastewater treatment plant.

Considering that the production of phosphorous fertilizers from sludge ashes will not fully secure the need for fertilizers, the additional production of compost is an initiative with a secure circular success. Yet, as discussed in 3.4, wastewater sludge should not be used as a fertilizer due to the risks of introducing heavy metals and other emerging contaminants to the local soils (from illegal dumping of tannery wastes into the municipal sewer system or into open drains that are capped and pumped to the municipal treatment plant). As most solutions explored in the roadmap were also aimed at reducing health concerns for farmers, soil and livestock, fertilizer production and use should also try to reduce the cross-links between faecal matter and food-production pathways. For this reason, the production of organic fertilizers in the Kanpur Nagar region would be solely based on the compost production from food waste collection as a parallel activity to the roadmap proposed for the STP Jajmau.

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CHAPTER 1 DEFINITION AND GOALS

The gross domestic production (GDP) data of the world countries for the last few decade offers, amongst the many, two interesting trends. While the western world faces intermittent crises, developing countries show a rising trend that can only be slowed down but not stopped by the events that year by year shake the world. In 2019, the last year before the Covid-19 era, the economic growth in Europe stayed stagnant at 2.4%, while in India it grew by 4.2% (World Bank, 2019). More importantly, the economic leadership is moving from west to east over the next decades. It is no secret that the current economic domination of G7 countries will slowly disappear, and IMF projections for 2050 predict the G7 to be expanded to include China, India, Russia, Brazil, Mexico, Turkey and Indonesia will be part of the future G14. These countries will benefit from low labour costs, technology transfer, population growth, digital transitioning, and resource availability (P.W.C., 2017). Particularly, the forecast for India is that it would become the second largest world economy by 2050 (Hawksworth *et al*., 2017).

The wind of change brings several global shifts that represent remarkable opportunities: technological breakthroughs might offer a chance for a widespread rise in the level of education and social awareness; new economic leadership will tackle poverty, and help find new markets for goods and services. But threats are also going to emerge in the new world order: rapid urbanization creates unequal communities competing for survival and employment; threats of climate change put water supply under great uncertainty, undermining future farming and even the survival of rural populations; resource scarcity sets the end for present business models; and in some countries, the economic uncertainties increase the risk of hyperinflation and a daily struggle with rising food prices. Countries that experience rapid economic growth run a double risk: from an environmental perspective, the risk is to accelerate the rush to exploit resources, failing to align economic growth with long-term environmental sustainability; from a social perspective, the risk is not to redistribute the gained economic benefits across the society, resulting in large disparities between social classes and increased social unrest.

The whole economy of India is rapidly changing. The political powers India has the capacity to maneuver a top-down approach to shape a completely restructured industrial and social system, and the Pavitra Ganga project positions itself as an important research and innovation initiative to demonstrate approaches to promote the sustainability of the water treatment sector, to improve access to reliable, alternative water sources in a changing climate, and to contribute to developing better environmental policies and decision-making.

1.1 THE ROADMAP: PURPOSE AND DIRECTION

The project Pavitra Ganga has been conceived and financed with the purpose of boosting the environmental and economic potential of municipal wastewater treatment and the resource recovery opportunities in the Kanpur Nagar region. The project has the ambition to convey a new approach towards wastewater treatment that finds, in a chosen urban local body, the perfect laboratory to demonstrate innovations. The realization of this ambition requires a plan to overcome the multiple barriers that impede the development, and to unravel the socio-economic local entanglements. Our plan is what we call a *"Proposed roadmap to exploit the wastewater treatment and the resources, water reuse and resource recovery opportunities"*.

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Our roadmap is organised into a logical sequence of steps: steps that illustrate how the local boundary conditions have been defined, how the problems have been identified and approached, and finally how the thinking process and consultations with key experts and stakeholders has resulted in specific solutions and scenarios.

The roadmap primarily requires a number of steps to analyse the boundary conditions of the Kanpur Nagar case area. This is done in the socio-economic screening and the analysis of the current asset situation (Figure 1). The complete roadmap is outlined in Chapter 1. The present document provides in Chapter 2 a description of the area, the outlining of the current existing assets, the state of the art of the water resources in the area. Further details are found in the Annexes and other project deliverables. The circular economy (CE) principles and what they could mean for the Kanpur Nagar region are illustrated in Chapter 3. Chapter 3 analyses the possible solutions as standalone scenarios in the local context (see 'Literature Review Circular Solutions' in Figure 1) being split into three different pathways: water, energy, materials. A decision-making framework for circular solutions selection is then applied in Chapter 4, by evaluating the standalone scenarios against different parameters and framing them subsequently in a systemic approach. The decision-making framework concludes with the proposition of a solution that integrates several processes or stand-alone solutions (base-line scenario in Chapter 5). In Chapter 5, all the technologies tested and exploited in the Pavitra Ganga project are presented and analyzed in a circular approach.

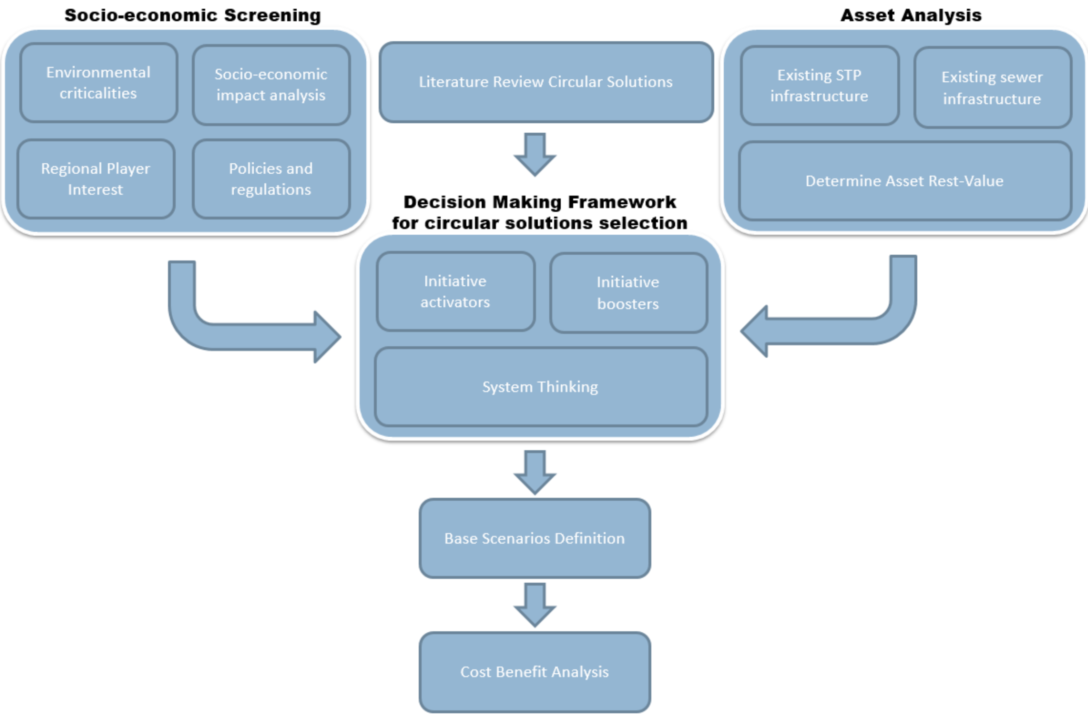

Figure 1: Roadmap scheme.

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The urban area of Kanpur Nagar was chosen as the subject for the roadmap. The decision was based on the peculiarities of the area as well as its potential. A crucial aspect is that the urban area of Kanpur Nagar is already provided with a sewage treatment infrastructure where a multi-step rehabilitation programme has been deployed to improve the situation (the rehabilitation programme is discussed in Chapter 2). The 'rolling out' of the proposed roadmap in Kanpur Nagar is meant to let all deployed efforts converge into implementation, and accordingly map the existing infrastructure and the future financial interventions in a circular economy perspective. The roadmap selects and suggests cost effective and energy efficient solutions for the treatment of (unregulated) drains, the improvement of existing treatment installations, as well as decentralized sewage treatment, that could be proposed for a different urban settings The Kanpur Nagar region can be seen as a laboratory to showcase an economic transition with possible opportunities that are worthy of detailed elaboration.

The roadmap has been developed in cooperation with "UP Jal Nigam", wastewater treatment operator of the WWTP Jajmau, and "Kanpur Nagam Nigam", Kanpur municipal corporation. It will help the local institutions in accellerating the transition towards a circular economy.

1.2 The Roadmap: outline and reference to the information contained in the Pavitra Ganga project deliverables

Identification of the environmental criticalities related to wastewater management

Improper wastewater management is known to have a devastating effect on the environment. Destruction of biodiversity, aquatic ecosystems depletion, surface bodies eutrophication, food chain contamination, potable water shortage are all very clear consequences of the necessity of addressing the wastewater management in a precise and structured manner. The task of designing and detailing a master plan to address the wastewater pollution in a wide area can only arise after the identification of the specific environmental criticalities. There is a need for an articulated inventory that can distinguish the problems and quantify the impact of the wastewater emissions. Data about wastewater streams and surface bodies is generally inventoried and outlined in master plans, archives of environmental national institutions, water utilities, sanitary institutions, academic institutions. The present roadmap made use of the Deliverable 4.1 of the Pavitra Ganga project, in order to detail an articulated environmental screening of the Kanpur Nagar region. More details, are found in Chapter 2, the ecohydrological assessment; in Chapter 3, the geohydrological aspects; in Chapter 4, the climate and the metereological data; in Chapter 5, land use and topographical data; and in Chapter 6, the assessment of the local water quality. The improvement of the actual wastewater conditions, according to specific technological solutions with the evaluation of the ecological impact has been presented in "Deliverable D3.1: Identification of the boundary conditions for technology development under Indian conditions, including factsheets of PAVITRA GANGA benchmark technologies and innovations".

Review of the catchment socio-economic situation

The present roadmap recommends a "Socio-economic impact assessment" (SEIA), as a comprehensive methodology for impact assessment in a specific area. It is good practice to evaluate the potential socio-economic and cultural impacts of a proposed development on the lives and circumstances of people, their families and their communities. If such potential impacts are significant and adverse, this element should lead the decision makers to find ways to reduce, remove or prevent these impacts from happening.

Due to a lack of data, a SEIA was not conducted. The present roadmap evaluated the socio-economic situation of the Kanpur Nagar region by means of workshops whereby different stakeholders and involved actors, carefully selected, were invited to interactively express their views and their specific interests with regards to the wastewater situation and perspective. The workshops allowed to select

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and elaborate the identified problems, with intrinsic evaluation of the impacts to the proposed solutions. This information is reported in the "Pavitra Ganga: Workshop Summary: Kanpur Co-creation Workshop I" (Saharan T. *and* Scholten L., 2021) and summarised in Deliverable D2.3 (Multi-criteria decision analysis (MCDA) and portfolio models to support regional wastewater management).

<u>Analyse regional players interests (private stakeholders and public institutions)</u>
In this section of the roadmap, the intention is to review the cross-links between wastewater exploitation, resource recovery, and the local economic sectors, possibly identifying potential projects partners. The local economic sectors include all relevant actors, and dimensions to implement, demonstrate systemic solutions. Examples of local economic sectors are: public administrations and utilities, private sector services, including SMEs. The "Stakeholder engagement and responses" have been probed and described in Chapter 3 of Deliverable D2.1 "Policy brief on determinants of successful and unsuccessful urban wastewater treatment, water re-use and resource recovery models".

<u>Policies and regulations</u>
Additionally, the present section aims at analysing the environmental and legislative regulatory framework pending in the local area and structuring the local economic activities. Policy and regulatory interventions can create successful business models for wastewater treatment and resource recovery but need effective monitoring, enforcement and follow-up at all governance levels (central, national and local governing bodies). The present roadmap elaborates its information based on the local regulatory framework. A summary of "Water and wastewater policy interventions and the regulatory framework" is covered in Chapter 2 of the Deliverable D2.1 "Policy brief on determinants of successful and unsuccessful urban wastewater treatment, water re-use and resource recovery models".Review the existing assets under operation

<u>Review actual environmental performances of the existing infrastructure in static and dynamic operations</u>
Existing facilities are a crucial asset for each urban local body active in water management. The performance of its assets determines amongst other parameters the actual working efficiency of its company. Simultaneously, this performance is a main driver for its operational cost. Asset management also enables an organisation to examine the need for assets and asset systems at different levels. Additionally, it enables the application of analytical approaches towards managing an asset over the different stages of its life cycle (which can start with the concept of the need for the asset, through to its disposal, and includes the managing of any potential post-disposal liabilities).

The environmental performances of the existing infrastructure have been reviewed in Chapter 2 of the Deliverable D3.1 "Deliverable D3.1: Identification of the boundary conditions for technology development under Indian conditions, including factsheets of PAVITRA GANGA benchmark technologies and innovations". Additional information has been collected in Annex 1-2 of the present document.

<u>Determine Asset Health Indices under operation, Asset Rest Value and related life-span horizon.</u>
The assessment of the remaining effective life of an asset is a crucial step in the reinvestment process, as part of an asset management plan. The main purpose of asset condition assessment is to detect and quantify the remaining asset life, and as such determine the actual health index of the asset. The result of assessing the remaining life is based on the prediction when an asset will likely fail, and it's favourably based on the actual condition. As suggested above, in the scope of a roadmap, it is strongly advised to prepare a condition score card to rank the actual condition of each asset based on a health index. By definition, the determination of the health index is thus closely related to the determination of the remaining lifetime, the replacement value and the residual value of the equipment. The scale of the health index is set from 1 to 5, with 5 being an unserviceable asset.

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Due to the complexity derived from the Covid period, and the difficulty in collecting full-scale data, the Asset Health Indices of the existing infrastructure under operation could not be fully validated but are viewed as suitable indicators.

1.2.1 DECISION MAKING FRAMEWORK FOR CIRCULAR SOLUTIONS SELECTION

The information provided in the socio-economic screening and the asset analysis is used as a crucial background information to further analyse and boost the circular economy based solutions according to the specificities of the area.

The different sub-steps that compose the circular economy screening have been discussed in Chapter 3-4 of the present document. In sections 3.3, 3.4, 3.5, the authors screen the state of the art of research literature in search of possible standalone solutions that can represent a potential answer to the opportunities and the challenges demanded in the Kanpur Nagar context. The standalone solutions are projected into their local context, and are subdivided into the the three pathways, *i.e*. the sections 3.3, 3.4, 3.5 respectively discuss water, material and energy re-use standalone scenarios.

After having performed the analysis of the local boundaries, as in

Figure 1, and sought for eligible standalone scenarios (as in Chapter 3), the short-listed scenarios are analyzed in view of some specific criteria in a circular oriented philosophy: the analysis of demand and supply (section 2) and the assessing of circularity and economic potential (section 4.2 and Annex 3). The scenarios are then analyzed in terms of their interaction with the broader context (section 4.3). In section 4.5, the standalone scenarios are rejected or accepted on the base of elements discussed in 4.1-4.2-4.3.

Finally other legal, commercial, and management based aspects are discussed (section 4.4).

1.2.2 DEFINITION OF THE BASE-LINE SCENARIO AND COST-BENEFIT ANALYSIS

The roadmap scheme in Figure 1 converges towards the definition of a centralized/decentralized base-line scenario (Section 5, Figure 15-16). The base-line scenario proposed in section 5 represents an integration of different technological solutions that must interact together. The financial feasilibility of the short-listed and stand-alone solutions has not been discussed until the solutions have been selected on the base of a complex circular approach and coupled together. In the present document, the cost effectiveness of the single short-listed solutions has notbeen assessed. The reason for a later involvement of financial factors is due to: (i) generally, the literature already indicates the economical attractiveness of specific solutions; (ii) the complexity of the circular economy philosophy that often gives priority to ecological and socio-political aspects, social acceptance, and local context factors that would not easily find space in a cost-benefit analysis but that are crucial in the circular economy approach; (iii) the cost-effectiveness of a stand-alone solution may not be valid when the latter solution is interacting in a wider process.

The base-line scenario implements the options that become profitable or will be realized against a certain cost. The definition of the base-line scenario must be followed by a cost-benefit analysis (CBA). The latter is the process used to measure the benefits of a decision or taking action minus the costs associated with taking that action. A CBA involves measurable financial metrics such as revenue earned or costs saved as a result of the decision to pursue a project. Cost effectiveness comprises all costs covering the *Total Cost of Ownership* for certain interventions.

This step will be carried out in Task 7.2 of the Pavitra Ganga project.

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CHAPTER 2 KANPUR

Kanpur is the largest city of the state of Uttar Pradesh in India. Nested on the banks of Ganges River, Kanpur is one of the major financial and industrial centres of North India with nearly 800 industries (Singh *et al*., 2001). The city is famous for its leather and textile industries. It is a multifaceted economic entity, hosting very productive sectors and promising technological hubs. According to the results of 2011 census, Kanpur urban area has a population of 2.927 millions inhabitants (Office of the Registrar General & Census Commissioner, Government of India, 2012). Kanpur's urban population for the year 2021 was estimated at 4.581 millions, with an estimated annual compounded growth rate of 0.94% which is expected to rise to 2.21% by 2030. In 2018, Kanpur, was considered by the World Health Organization as the city with the worst air quality (Dasgupta *et al*., 2018), due to the excessive amount of particulate matter of size under 2.5 micrograms found in every cubic meter of air.

While the Ganga river flows through the northern part of the city, the Pandu river, a tributary of the Ganga, flows to the south of the city and joins Ganga river downstream of the city. The Kanpur sewerage system has discharge points into the Ganga and the Pandu rivers. The sewerage works are subdivided in 4 districts. District I, which constitutes the older part of Kanpur, discharges its wastewater into the Ganga river, whereas the other districts discharge their wastewater mainly or completely into the Pandu river.

Unfortunately there are a number of shortcomings that impede sustainable development. The main aspect that hinders sustainability and prosperity is the inadequate infrastructure, including that for public water services.

1.3 Existing Sewerage and treatment facilities in Kanpur City

The sewerage system in the Kanpur city was first introduced in the year 1904 (National River Conservation Directorate, 2009) (Kanpur Nagar Nigam, 2013) (Department of Namami Gange and Rural Water Supply, 2019) through the construction of underground sewage network and a trunk sewer which had its outfall near Sidhnath Temple on river Ganga. The sewerage system was further extended in 1920 to cover a larger area and the trunk sewer was extended up to Jajmau in the downstream of Kanpur. Since 1952, there has been a fourfold increase in the city's population. In response to this, the Kanpur Development Board formulated and implemented a plan for re-organization of the sewerage system. New sewers were added including intermediate sewage pumping stations at Parmat Ghat and Jajmau (Figure 2). Aiming to address the pollution of the river Ganga from sewage discharge, a plan was formulated to utilize the wastewater on the sewage farm in Jajmau, in an area of about 3080 hectares.

Over time there was a consistent increase in water consumption and sewage production. The existing sewage systems suffered from blockages, which resulted in unsanitary conditions with wastewater overflowing into the road-side stormwater drains and ultimately into the several storm water canals of the city. The sewage pumping capacity at Jajmau is inadequate, and most of the sewage is discharged into the Ganga through bypass channels, rather being used for irrigation in the sewage farm.

With the objective of controlling pollution to improve the river water quality and to arrest the environmental degradation, Ganga Action Plan (GAP) was launched in 1985 by MoEF (Government of India). The sewage treatment plants (STPs) completed under GAP in the district of Kanpur city (Jajmau)

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are summarized below (Figure 3-4-5): 5.0 MLD UASB (based on an up flow anaerobic sludge blanket process) with its treated effluent discharged into river Ganga; 130 MLD ASP (based on an Activated Sludge Process) with its treated effluent used for irrigation; 36 MLD UASB (Common Effluent Treatment Plant (CETP), to treat industrial waste with domestic waste after mixing in 3:1 ratio) with its treated effluent used for irrigation. A separate sewage collection system of 12 Km was also constructed for conveying the wastewater from industries to the 36MLD CETP.

In order to encourage cities to take up initiatives to bring about improvements in the existing service levels in a financially sustainable manner, Jawaharlal Nehru National Urban Renewal Mission (JnNURM) was launched in December 2005 by the Government of India. The primary objective of JnNURM was to create economically productive, efficient, equitable and responsive cities. With reference to Kanpur city, the following mentioned works were sanctioned under JNNURM Part I, II & III for improvement of the sewerage infrastructure of Kanpur city.

Projects approved under JNNURM (Part I)

- **Renovation/Rehabilitation of existing Common Sewage Pumping Station (CSPS);**
- **Renovation/Rehabilitation of existing 5 MLD & 130 MLD sewage treatment plants and 36 MLD tannery waste water treatment plant (Jajmau STP1 & STP2) (Figure 3-4-5);**
- **Renovation/Rehabilitation of existing 7 Nos. intermediate sewage pumping stations;**
- **Renovation/Rehabilitation of existing 4 Nos. tannery sewage pumping stations;**
- **Renovation/Rehabilitation of existing rising mains of 4 Nos. tannery waste water pumping stations;**
- **Laying of 350 mm to 2000 mm diameter trunk sewers of 69 km in core area of the city;**
- **Augmentation of 130 MLD capacity Jajmau STP by constructing another STP unit of 43 MLD based on ASP technology;**
- **15 MLD capacity MPS and STP at Baniyapura in sewerage District III based on the topography of this sewerage district. As per projections, 124 MLD STP shall be required for sewerage District III. As a 15-MLD STP has already been sanctioned, the proposal for the balance requirement of 109 MLD is under preparation;**

Projects approved under JNNUM (Part II)
Sewage treatment plant of 210 MLD at Bingawan. New DPR for balance requirement of 105MLD STP and MPS are under sewerage system.

Project approved under JNNURM (Part III)
Comprehensive proposals have been made in this project to provide sewerage facilities in sewerage district IV of Kanpur for four wards. Works include:

- **Intermediate sewage pumping stations of 14 and 40 MLD respectively;**
- **42 MLD main sewage pumping station and a STP of 42 MLD capacity & laying of 130.90 km reinforced-concrete sewers and other allied works.**

This ultimate objective of the sewage management plan in Kanpur is to ensure that flow of untreated sewage from the city into the Ganga and Pandu rivers through storm water is completely stopped. For this to become a reality, sufficient sewage collection and treatment infrastructure must be developed. Considerable progress has been made in these areas, through further works remain ongoing. Operation and maintenance of the created infrastructure remains a great challenge.

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Further insights regarding the actual situation of sewerage infrastructure and the STPs in Kanpur are described in Annex 1 and Annex 2.

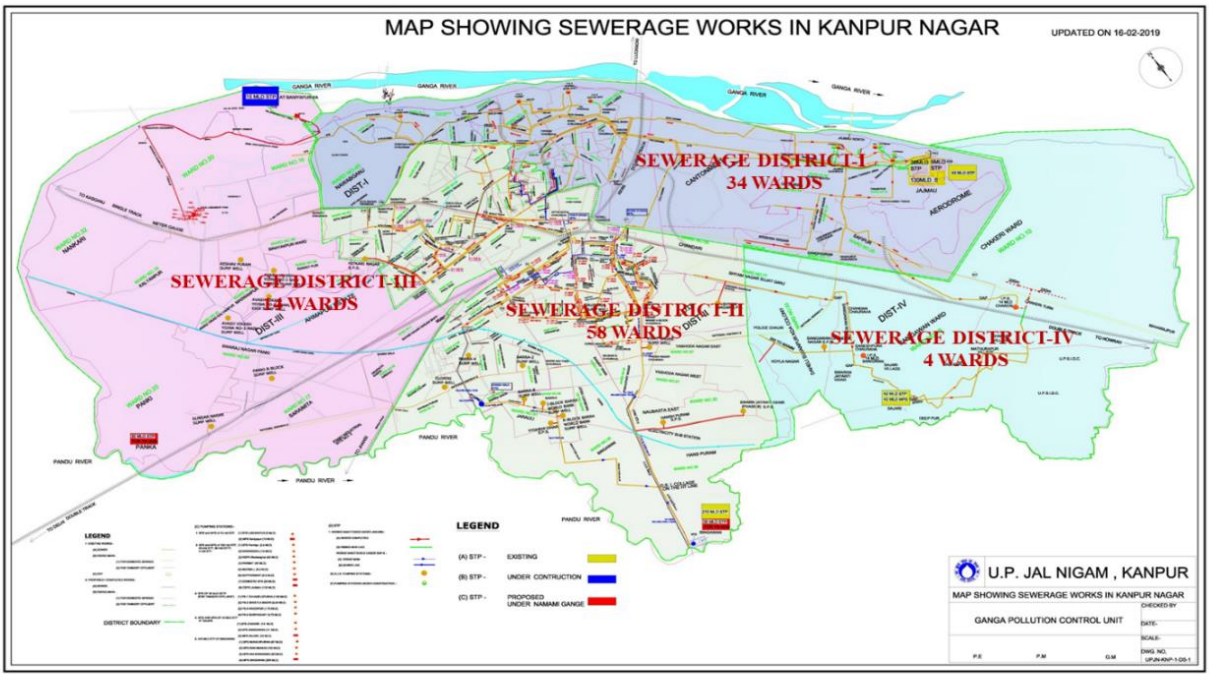

Figure 2: Map showing sewerage works in Kanpur Nagar.

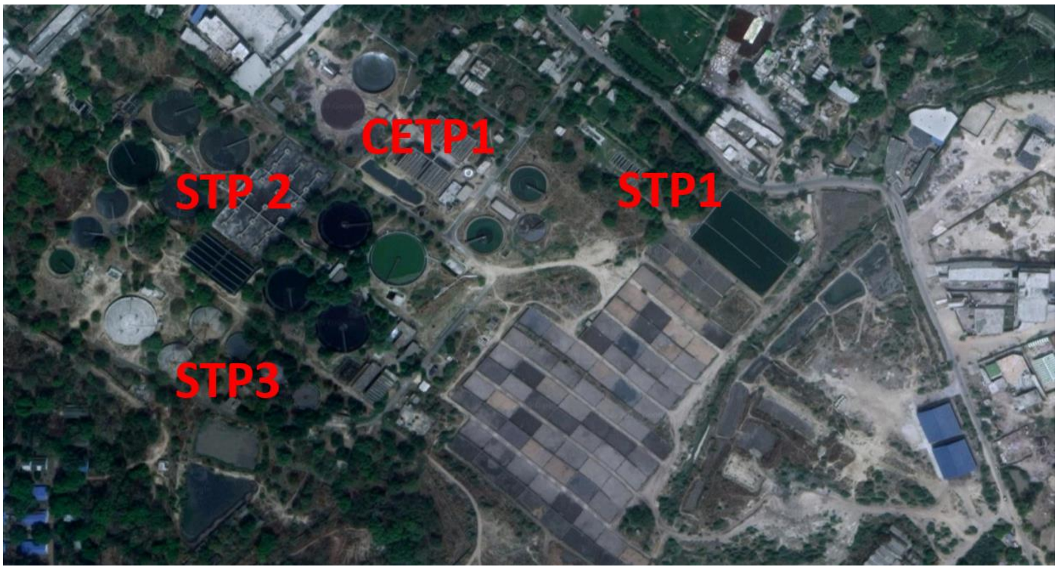

Figure 3: Layout Plan of STPs & CETP Jajmau, Kanpur

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Figure 4: Photographs of various units of STP 1

Figure 5: Photographs of various units of STP 2

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1.4 WATER RESOURCES OF KANPUR NAGAR REGION

India has 18 per cent of the world's population but only 4 per cent of the global water resources. India is undergoing the worst water crisis in its history and nearly 600 million people are facing high to extreme water stress (NITI Aayog, 2018). Households of rural territories do not have piped or potable water and have to rely on sources that pose a serious health risk. The water shortage problems have reached Indian metropolitan areas as well. NITI Aayog estimates that 21 major cities, including Delhi, would run out of groundwater by 2030 (NITI Aayog, 2018).

Everywhere, rural communities have responded to water scarcity and insufficient water supply for irrigation purposes by uncontrolled and widespread extraction of groundwater for private use. More than 20 million bore wells pumping out groundwater are reported across India. The uncontrolled exploitation of groundwater wells has inevitably led to a decrease in groundwater tables. As many as 256 of 700 districts have reported 'critical' or 'over-exploited' groundwater levels (Central Ground Water Board, 2017).

Contrary to popular belief, it is neither domestic use nor industry that guzzles India's water resources but agriculture which consumes over 80-85 per cent of water consumption in India (Figure 6) (C.W.C., 2015). With only 40 per cent assured irrigation, farmers depend heavily either on rains or on groundwater for their needs. And yet, India's agricultural sector accounts for more than 90 % of total water drawn but contributes only around 14 % to the GDP (C.W.C., 2015).

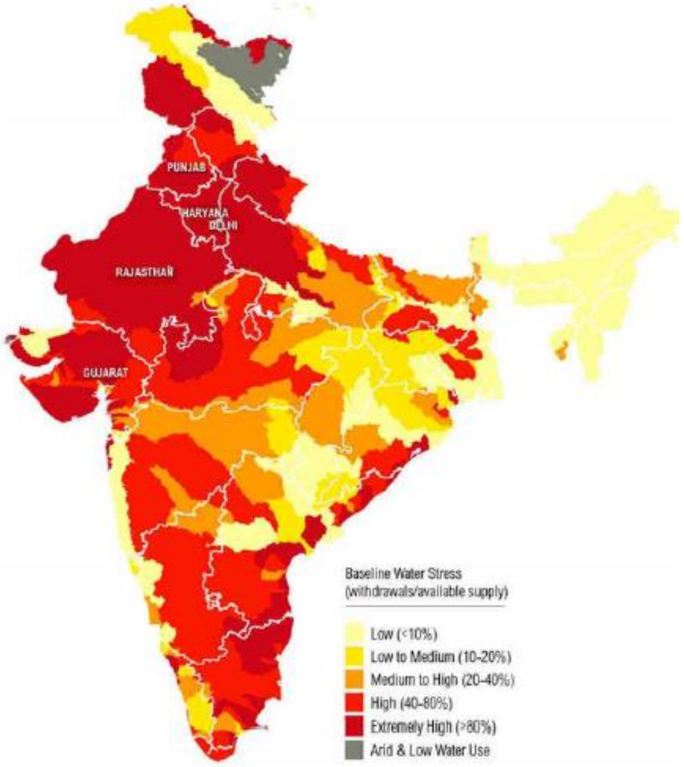

Figure 6: Baseline water stress in India (2010).
The base-line water stress measures the total annual water withdrawals (municipal, industrial, and agricultural) expressed as a % of the total annual available flow for 2010. Higher values indicate more competition among users (Ministry of Statistics and Programme Implementation, 2018)

The background information above fits only partially the reality of the Kanpur Nagar region. The Kanpur Nagar region and more in general the state Uttar Pradesh has, to date, sufficient water resources. As on 2020, the total annual groundwater extraction in HAM (Hectare meter) is 62833.44 *i.e.* 628.33 MCM

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(Million Cubic Meter) for Kanpur Nagar (Central Ground Water Board, 2021). The Central Ground Water Board, confirms in 2020 the abundance of groundwater in this region (Central Ground Water Board, 2020): the total Annual Ground Water Recharge amounts to 89398.87 MCM, against a total current annual groundwater extraction of 65225.16 MCM. The stage of groundwater extraction is 76.06 %. Yet, the 54.55% of the assessed groundwater bodies is considered in a semi-critical state, where by “semi-critical’’, one defines a body with a groundwater extraction between 70 % and 90 % (Central Groundwater Board, 2020). And 18.18 % of the assessed groundwater bodies is in a critical state where by “critical’’, one defines a body with a groundwater extraction between 90 % and 100 % (Central Groundwater Board, 2020).

NITI Aayog established a Composite Water Management Index (CWMI) for the whole country (NITI Aayog, 2018). This Index established a national platform in the public domain which provides information on key water indicators across states. This platform helps in monitoring performance, improving transparency, and encouraging constructive competition amongst states. The Index comprises nine themes covering groundwater and surface water restoration, major and medium irrigation, watershed development, participatory irrigation management, on-farm water use, rural and urban water supply, and policy and governance. *Based on Water Index composite scores, yearly evaluated from 2015 to 2018,* Uttar Pradesh is one of the bottom-performing states. Worryingly, most low-performing states bear the largest burden of national population and economic production.

It is crucial to realize that almost half of the index scores is directly linked to water management in agriculture. Lack of improvement in water management in all these states can have a national-level impact, given their substantial contribution towards India’s food production and economic output, apart from being home to substantial proportion of the country’s population.

Most of the irrigation water demand is met from groundwater. In the rural areas of the Kanpur Nagar region, in 2005, canal irrigation is employed in the 40.4% of the net irrigated area (Umar, 2018). Irrigation by tube-wells was found mostly used in urban areas (25.8%). Other sources of irrigation are used in the rural areas in the 19.9% of the net irrigated area (Umar, 2018). The prevalence of canals as the main irrigation source is explained by the type of crops that are being widely cultivated in the area: rice in the autumn-winter season, and wheat in the winter-spring season. There are no wide-spread agricultural products in the area that could use drip irrigation.

There is no problem with water scarcity as such in the Kanpur Nagar region, as neither drought nor lack of rainfall threaten it. The priority consideration is the pollution of the surface water and groundwater bodies.

A report from the CGWB (2011) indicated in the groundwater of Kanpur Nagar, presence of salinity above 3000 µS/cm (at 25 ° C), lead above 0.01 mg/l, cadmium above 0.003 mg/l, chromium above 0.05 mg/l. More recently, a recent sampling campaign performed by Gupta et al. (2019), the groundwater reported pollutants with the following maximum concentrations: 3735 µS/cm (at 25 ° C), 84 mgNO_3/L, 345 mgSO_4/L, 3.2 mgF/L, 0.1 mgCr/L, 345 mgSO_4/L, 8 µgAs/L, 8 µgPb/L.

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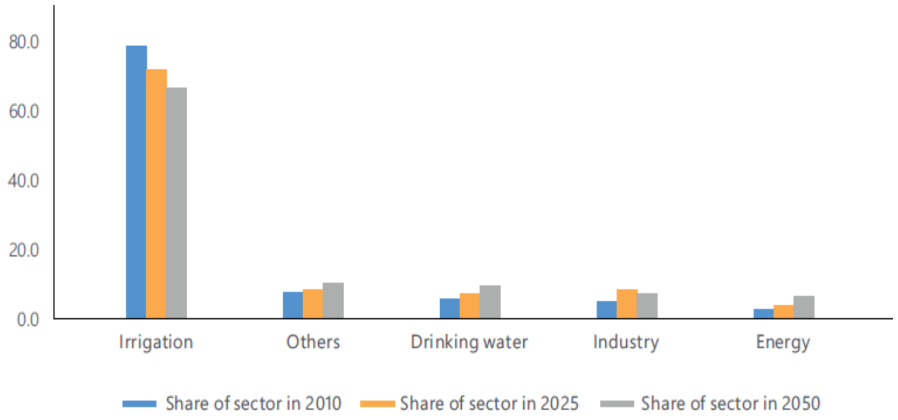

Figure 7: Share of water consumption per economic sector in Uttar Pradesh (C.W.C., 2015)

The available literature leads to the conclusion that the Ganges River is highly contaminated by dichlorodiphenyltrichloroethanes, hexachlorocyclohexanes, and heavy metals (Ravindra *et al.*, 2015). This is partly due to the mixing of industrial and municipal sewage water (Singh *et al*., 2001). The illegal discharge of industrial water causes the intrusion of several pollutants including As, Cr, Cd, Cu, Fe, Hg, Pb and Zn in the surface water body (Singh *et al*., 2001). The presence of various ions, such as Fe^{2+}, Ca^{2+}, Mg^{2+}, Cl^- and $SO_4{}^-$, significantly change the water composition, including its ability to stain, its hardness and salinity (Singh *et al*., 2001). Gupta *et al.* (2018a, 2018b) have measured through grab samples the sulphate and sulphide concentrations in the Kanpur Nagar STPs effluent, in 2016-2017. During the winter season, sulphate and sulphide were respectively measured to be 3430 ppm and 75 ppm in the tannery effluent, 891 ppm and 186 ppm in the UASB effluent, 672 ppm and 62 ppm in the mixed effluent used for irrigation. In the summer season, sulphate was 2644 ppm in the tannery effluent and 416 ppm in the mixed effluent used for irrigation, while the maximum sulphide concentration was 159 ppm. The effluent consent of Sulphide allows a maximum of 2 mgS/L (CPCB, 2020). According to Gupta *et al.* (2018a, 2018b), the characteristics of effluents are not suitable for irrigation purposes. The discharged sulphate and sulphide loads directly affect the groundwater, the surface water quality and the irrigated crops.

With all evidence, the avoidance of industrial illegal discharge into the water bodies is not a part, but the unavoidable premise to achieving the roadmap to exploit wastewater treatment in the Kanpur Nagar region.

The impact of micropollutants and heavy metals is relevant in view of setting up a circular economy, becase the STP effluent water toxicity, described above, does not allow to unbridle the full potential of water reuse resources in the area.

Similarly, the sludge produced during STP operations, is expected to sorb most of the heavy metals, and it would thus still contain toxic substances. Consequently, the use of sludge as farms fertilizer would pose an environmental risk to the agricultural lands. In order to safely enable all possible circular economy routes, the separation of industrial effluent and municipal sewage water is crucial. To date, the Kanpur Nagar urban local body have strongly taken this aspect into consideration, and the construction of the CETP plant to handle the tannery effluent clearly indicates the efforts dedicated to the pollution’s problem (Annex 2).

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1.5 State of the art of the use of resources in the KANPUR NAGAR region

The Ganga Action Plan-I led to the construction of three wastewater treatment plants in Jajmau, Kanpur (Annex I & II). The design of the infrastructure did not consider the long-term development of the area, and the excessive increase in wastewater volume has led to the poor performance of the STPs. The performance of the treatment plants are affected, on the one hand, by the unplanned loading; on the other hand, sewage water entering the STPs contains in fact a mixture of toxic discharges from industries. As a result, both STP effluent water and disposed STP sludge are in fact hazardous waste.

In the absence of any standard or guidelines for irrigation with reused-water, untreated wastewater is still used for irrigation by farmers located downstream of Jajmau STP, since 1989. Deeper bore wells are installed to pump water due to shallow groundwater contamination. Likewise, wastewater reuse is also being promoted in tanneries to reduce the financial burden for extracting groundwater (in terms of electricity fee). Similarly, the sludge disposed by the STPs is used as fertilizer and spread to the soil, raising the concerns of soil and crops heavy metals contamination.
The option of improving the STP effluent water before reuse is meanwhile frozen: due to the high cost of operation and maintenance, the proposal for zero liquid discharge in the CETP-STP was not implemented.

Having a look at the stakeholders perspective, as resulting from D2.3 (Multi-criteria decision analysis (MCDA) and portfolio models to support regional wastewater management), the farmers, currently using partially treated wastewater, have expressed the following concerns: 1) there is no willingness to pay for use of treated wastewater, but farmers would still like to receive it, 2) health effects on farmers and livestock.

Root-causes of these issues expressed by the farmers during the co-creation workshops (Saharan T. *and* Scholten L., 2021) are: the limited awareness of systemic long-term effects of poor quality effluent water used for irrigation; lack of alternative water sources; high levels of toxic metals in the delivered wastewater effluent; varying effluent quality discharged into drainage channel; history of the area that led to free use of partially treated wastewater.

From the perspective of the industries, as resulting from D2.3 (Multi-criteria decision analysis (MCDA) and portfolio models to support regional wastewater management), some of the key challenges that emerged during the co-creation workshops (Saharan T. *and* Scholten L., 2021) were the increased discharge from tanneries to be treated at CETP, limited use of primary treatment plants, low adoption of green technologies for leather production within tanneries, insufficient skills for primary effluent treatment plant operation, and no remedy for disposal of salt or hazardous slurry. According to the results of the co-creation workshops (Saharan T. *and* Scholten L., 2021), the underlying causes for these issues are the non-compliance with criteria set by the authorities, low capacity building, increasing cost of operation, lack of market and profitability of the tannery business, and lack of solidarity in capacity building.

The scenario faced in the Kanpur Nagar region indicates on the one hand, the will of the local productive sectors (farmers ad tanneries) to start up a circular economy with reuse of effluent water and fertilizers. On the other hand it indicates the difficulty in securing the circular pathways for which a demand already exists, meanwhile leading to deterioration of the quality of soil and groundwater, and the widespread use of harmful health practises for farmers and livestock.

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CHAPTER 3 THE DEPLOYMENT OF CIRCULAR ECONOMY IN INDIA

3.1 CIRCULAR ECONOMY IN A NUTSHELL

The concept of circular economy is rather opposite to the traditional concept of economy. An economy answers three questions: what to produce? how to produce it? who gets the benefit? It has in general three main components: flows of material; flows of energy; and flows of information (*e.g*. money). In this general context, raw materials are collected, then transformed into products that are used until they are finally discarded as waste, where the waste has, as end-products, a marginal economic value. Such a vision of economy is conceived as linear in the sense that it follows the "take-make-dispose" approach. The global value of a linear economic system is created by producing and selling as many products as possible. As the disposal routes of the used products are not sufficiently capable to readdress the value of discarded materials, the result is the continuous introduction of new resources while the world is increasingly becoming resource-scarce. In the present economic framework, in the near future, this may lead to an economic paralysis (Klare, 2012) (Lampert, 2019) (Umweltbundesamt, 2020).

Conversely, in a circular economy, the lifespan of the produced goods is not conceived linearly but in closed loops. In a sense, raw materials, components and products lose their value only marginally, because the circular economic system engineers the products to last as long as possible. The design of products seeks to attain durability, reuse, remanufacturing, and recycling keeps products, components, and materials circulating in the economy. As a consequence of what is described above, the circular economy "designs-out" waste and pollution meaning that the negative impacts of economic activities that cause damage to human health and natural systems are also framed out: the release of greenhouse gases and hazardous substances, the pollution of air, land, and water, as well as structural waste disposal in landfills and or incinerators are largely avoided; the traditional energy sources are also discouraged in favour of renewable energy sources. This new economic framework provokes a deep re-thinking process of economy creation. In its principles, the exploitation of energy sources should respect the regenerative capacity of the energy source and should reshape production systems to maintain their capacity. The circular economy is in a way restorative and regenerative in its primordial conception. Opposite to a "take-make-dispose" approach, where the path of the market products is not looked at in relation to the environment and their disposal, the products in a circular economy are instead conceived on the base of this relationship. As everything becomes interconnected, the level of complexity rises, and a change is only possible when the effect of it on the overall economy is understood. In the current *status quo*, all business models, product and service design, legislation, accounting practices, urban planning, farming practices, materials extraction, manufacturing, and more, have undesirable qualities from a circular perspective. Therefore, there is no simple fix and no stones can be left unturned in the pursuit of system change. Shifting from linear to circular requires systemic solutions.

The potential benefits of shifting to a circular economy extend beyond the economy and into the natural environment. By avoiding waste and pollution, keeping products and materials in use, and regenerating rather than degrading natural systems, the circular economy represents a powerful contribution to achieving global climate targets: lower carbon dioxide emissions; reduction in exploitation of primary resources; and, in the context of the Pavitra Ganga project, the provision of water reuse and resource recovery.

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3.2 Circular economy for wastewater: the three pathways

In the linear economy principle, wastewater is something which is handled in wastewater treatment plants (WWTPs) before it is disposed off. Provided that a wastewater treatment effluent quality meets the regulatory conditions, water is finally discharged into surface water bodies. But in fact being a WWTP a crossing point of micro and macro materials and substances at the end of life, a WWTP is a perfect environment to elaborate a circular solution for many resources that make up the municipal influent flow. The circular economy potential of WWTPs has become a central issue in recent literature research, seeking and investigating the high resource recovery potential of this strategic infrastructure (Kalemba, 2020) (Gherghel *et al*., 2019) (Van Der Hoek *et al*., 2016).

An enlightening report from the International Water Association (2016) proposed a framework to support the identification of circular economy opportunities for wastewater by subdividing the means to make the most of these opportunities using three interrelated pathways: the "Water Pathway"; the "Materials Pathway"; and the "Energy Pathway", (International Water Association, 2016).
In sections 3.3, 3.4, 3.5, the authors screen the state of the art of research literature in search of possible standalone solutions that can represent a potential answer to the opportunities and the challenges demanded in the Kanpur Nagar context. The standalone solutions are projected into their local context, and are subdivided into the the three pathways. The standalone solutions are further screened in Chapter 4, being then metricized by specific indicators, and confronted with a more systemic approach.

3.3 The three pathways of Pavitra Ganga: Water Pathway

The Kanpur Nagar is not a water scarce region, but an optimization in the use of the water resources is possible and appropriate. The major critical issues that emerged from the CWMI report (NITI Aayog, 2018) summarize well a suboptimal water resource management in the state Uttar Pradesh:
- Groundwater restoration: Uttar Pradesh has ~17% of the country's groundwater. There is no laid plan to optimize the use of the groundwater resources as well as no recharge infrastructure.
- On-farm use: the Uttar Pradesh has negligible micro-irrigation coverage.

In a circular economic approach, the first approach to avoid water resources depletion is to pursue an efficient use of the available resources. Supply and demand for reused water represent both the core of the problem as well as the chance for solution (Figure 8). From the **demand side**, the major aspects to serve as potential leverage are: the efficient use of the water resources (the irrigation technique and the type of crop); the regulatory enforcement to restrict groundwater use; the introduction of a smart water pricing tariff. From the **supply side**, the major aspects to serve as potential leverage are: water reuse practises need to be enforced and advertised; major efforts are needed at the regulatory level concerning quality standards for water reuse; the pollution reduction of surface water bodies, groundwater bodies and STPs' effluent water.

The first way to reach an efficient use of the available water resources is a wise selection of the planted crops. As in section 0, the major agricultural products in the Kanpur Nagar region are rice and wheat. On average, about 2500 liters of water need to be supplied (by rainfall and/or irrigation) to a rice field to produce 1 kg of harvested rice, *i.e.* these 2500 liters account for all the outflows of evapotranspiration and percolation (Bouman, 2009). Micro-irrigation techniques, such as drip irrigation, can decrease groundwater usage by around 20% annually (NITI Aayog, 2018). Sprinkler irrigation uses 30 to 40 % less water, while drip irrigation uses about 40 to 60 % less water as compared to flood irrigation. Correspondingly, 40 to 50 % gain in crop yield can be achieved. But to date, the potential area that can be brought under drip irrigation in Kanpur Nagar is only 7.9 m.Ha out of the 65

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m.Ha of irrigated area in the country. Therefore, a selection of the planted crops should be considered in view of enforcing micro-irrigation practises.

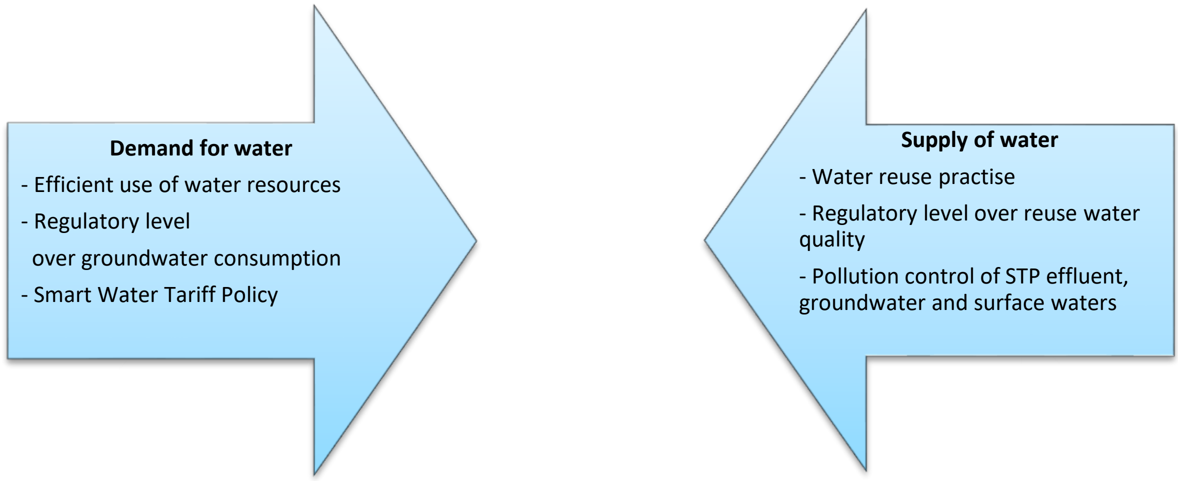

Figure 8: Demand versus supply of reused water in Kanpur Nagar region.

A second way to achieve an efficient use of the available water resources is by acting upon the regulatory system on deep-wells and private groundwater extraction. The widespread use of deep-wells in this region shapes and limits the possibilities of establishing a circular economy in the Kanpur Nagar region. If groundwater is accessible by means of deep-wells at a low cost, in rural communities and services, it is difficult to strengthen water reuse practises for irrigation. Therefore the opportunities created by potential grey water reuse, even at affordable treatment costs, may not be well perceived in communities. This topic will be further discussed in the section 4.4.

Incentives capable to force big water consumers, farms and industries, towards water reuse practise should legislatively discourage deep-wells exploitation on the one hand, and on the other hand, elaborate strategic water tariff policies. The possibility of acting on the water tariff would consider then industry as a more elibigle target: farmers have limited means to stand pressures on prices, and are more ready to accept any source of water, *e.g.* it is common practise to irrigate fields with raw or partiallly treated sewage water (Kumar Kesari *et al.,* 2021).

A good reason to push consumers and industrial companies towards water reuse practise could be the higher reliability in accessing water of warranted quality. Reused water could assure a stable water supply in dry months, when the water table significantly drops. The stable supply should be accompanied by a sufficient water quality capable to compete with shallow groundwater quality.
To date, water effluent from Kanpur Nagar STPs reports high metal concentrations and an elevated microbial risk. That is why water reuse practises require primarily a sufficient capital investment to raise the WWTP effluent performances, upgrading them with robust post-treatment facilities. Capital cost for post-treatment can be assured only by investments from large industrial clusters whereby water reliability is of extreme importance to keep continuous industrial processes on the run. The cost of the water service is also partially balanced by the cost of the groudwater extraction, and for this reason the cluster of tanneries of Kanpur Nagar already use treated effluent.

A valuable example of integration between the industrial services and water reuse projects is the case of Nagpur where reused water is now used to cool a powerplant. Water reuse implementation avoided massive deep-well intake and disfunctionality in the summer months as a result of water scarcity. The Tariff Policy (2016) by the Ministry of Power mandates the use of treated sewage in thermal power

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plants which are located within 50 km radius of an STP. The keys of this success story are discussed in the golden box below. More information can be found in the Pavitra Ganga Deliverable 2.1 (Cuadrado Quesada *et al*. ,2021). As of now, no thermal power plants are using treated wastewater in Kanpur region. However, Panki Extension Thermal Power Station being developed in Kanpur will use treated wastewater from Bingawan STP.

From Waste to Resource – The Case of Nagpur (World Bank, 2019)

The investment project included: a raw wastewater intake facility with a pumping station of 130 million liters per day; a 2.3-kilometer pipeline to the wastewater treatment facility; a wastewater treatment plant with secondary and tertiary treatment to meet MahaGenCo's water quality requirements; a 16.2-kilometer pipeline from the wastewater treatment plant to the power plant; a one-day reservoir of treated wastewater at the Koradi Thermal Power Plant for back-up.

Recipe for success

MahaGenCo was the only wastewater end-user. This element ensured strong project ownership and management, which were facilitated by regular communication and coordination with the municipal authority. There was no bidding process, because the MahaGenCo directly approached the tendering station (NMC) and selection was done on a sole-source (nomination) basis (FICCI Water Mission and 2030 WRG 2016). The collaboration between NMC and MahaGenCo ensured that the synergies of wastewater treatment and reuse were fully exploited through the contractual arrangement. An important aspect of this project is that MahaGenCo did not undertake the transport and treatment of the wastewater but instead selected an engineering, procurement, and construction (EPC) contractor and an operations and maintenance (O&M) operator through a single-stage competitive tender (FICCI Water Mission and 2030 WRG 2016).

Lesson learned

A well-designed contractual arrangement facilitated clear project ownership and management by the end-user and the urban body. The main driver of the project was the end-user's need to obtain secure sources of water at an affordable cost.

As mentioned in the CWMI report, large scale water supply presses and subtracts resources from groundwater bodies. No infrastructure for recharge is available, and this marks the future of the groundwater resources in the Kanpur Nagar region towards a possible decline. Artificial recharge would however require sufficient water quality of the injected water flows. Even more, being the effluent water of Kanpur Nagar WWTPs water with higher salinity, also salinity would need to be removed. High water quality and salinity removal to a certain degree can be only assured by filtration processes. The capital investment and operational cost of such initiative would be significant and not directly chargeable to a customer. Indeed, Khumar *et al*. (2008) concludes that artificial recharge systems in natural water-scarce areas in India are economically unviable.

The strength of the circular economy lies in acknowledging and enforcing the capacity that nature has to self-regenerate itself. The estimate area of wetlands in district Kanpur Nagar is around 14770 Ha, and this surface area is severely restricted when compared to the past (NGRBA *et al*.). Wetlands are the repository of vital ecosystem information services. They perform many functions and provide many ecosystem services, such as maintenance of the food web, providing habitats to aquatic flora and fauna, as well as numerous species of birds, including migratory species, filtering of sediments and

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nutrients from surface water maintaining of nutrients recycling, purification of water, controlling of flood, recharging of groundwater, providing drinking water, fish, fodder, fuel and providing source of livelihood and recreation to local people (NGRBA *et al*.). We firmly believe that the wetlands restoration and safeguard should be short-listed as a potential scenario as a tool to guard the water resources in a circular approach.

SHORTLISTED STANDALONE SCENARIOS:

- **STP water reuse for drip irrigation;**
- **STP water reuse for paddy rice fields;**
- **water reuse solutions for industries;**
- **grey-water separation and subsequent reuse in rural or urban communities;**
- **wetlands restoration;**
- **artificial groundwater recharge.**

The suitability of the selected standalone scenarios will be further screened in Chapter 4.

3.4 The three pathways of Pavitra Ganga: Materials Pathway

Besides water and energy there is a wide variety of possible alternatives to harvest materials from a wastewater treatment plant. In the context of effectively implementing circular economy objectives, particular importance should be attributed to sludge management, due to the possibility of recovering valuable raw materials from sewage sludge and the use of its energy potential.

A first classification could be made amongst solutions that use sludge and sludge water as a waste product, and solutions that instead use sludge and sludge water as a process to achieve other end-products. In the first category is the recovery of the sludge as an end-product: compost for land fertilization (Warman *and* Termeer, 2005); sludge co-pelletization blended with coal as a solid fuel feedstock (Hossain *and* Haij Morni, 2020) or with agricultural products (Yilmaz *et al*., 2018); recovery of inert material for construction of roads (*inter alia* Lin *et al.*, 2012; Sayed *et al*., 1995; Lucena *et al*., 2014). In the second category is the recovery of products produced by processing the sludge or the sludge water: cellulose fibers from sludge water filtration (Ruiken *et al*., 2013); biopolymers (Tamis *et al*., 2014); bioplastics (Kleerebezem *et al*., 2007); phosphorus recovery both from centrate (Cardoso Chrispim *et al*., 2019), digestate (Cardoso Chrispim *et al*., 2019), or sludge ashes (Tan and Lagerkvist, 2011).

The unique set of socio-economic conditions of specific products is decisive in the flourishing of specific circular implementation scenarios and in the rejection of others. This is for instance the case of the chromium recovery in the CETP in construction whereby this process was enforced from the Kanpur tanneries effluent (Annex 2). Considering that the chromium level is significant also in the effluent of the Jajmau WWTP, this might be a possible scenario also for the Pavitra Ganga project. Case per case, it will be necessary to select the most cost-effective process according to the chromium concentrations: a sorption process based on structured adsorbers developed by Vito (Seftel *et al.*, 2018) is modified to act on low chromium concentrations; a precipitation based process (golden box at page 26), being efficient on higher chromium liquid phase concentrations in the WWTPs effluent.

The local boundaries also have an influence on the scenario that would enforce compost production. Compost production from sewage sludge is not likely to be a favourable solution for the Kanpur Nagar region. A ministerial report (Government of India - Ministry of Urban Development, 2017) indicates a general hesitancy towards the use of products that derive from faecal matter. Stakeholders' consultations that took place within the Pavitra Ganga initiatives highlighted a strong hesitancy towards practises that can pose health concerns to farmers, soil and livestock. Moreover, it is crucial

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to look into the heavy metals content of the sludge (Singh *et al*., 2001), and their long term eco-toxicological impact. The sludge sorbs the heavy metals contained in the sewage water and it would be finally disposed on the soil where plant roots are growing. There is a concrete possibility that the sludge of Jajmau STP would not meet the criteria for sludge disposal in soil. Also from a microbiological point of view, the avoidance of any microbial contamination in food production industry would still require laborious controls and protocols.

Chromium recovery in the 20 MLD CETP (Pattanaik, 2015)

A common Chrome Recovery Unit (CCRU) with capacity of 300 KLD (x 3 modules) has been designed for the treatment of the tannery effluent (in the CETP) to achieve 98-99% recovery and reuse. Spent Chrome liquor collection from each Tannery unit is transported by tankers to CCRU & the recovered chrome is stored in drums or sold. This is to ensure that all tanneries treat the chrome liquor uniformly and are not encumbered in operating such systems in their own premises. It involves various unit operations such as collection tank, reactor, chemical dosing system and chrome regeneration tank and supernatant collection tank. The tenderer should give the following assurance in Chrome Recovery Plant. Depending on the site condition about 80% of fresh basic chromium sulphate and 20% of recovered chrome can be used for chrome tanning. The whole process can start afresh from here.

Recipe for success

Long-term rejuvenation of the river Ganga will have significant social and economic benefits on the lives of the 500 million people living along its basin. For this purpose, in May 2015, the GoI approved the flagship Namami Gange programme for cleaning, rejuvenation, and protection of the river Ganga. A correct socio-economic impact analysis is a recipe for success.

Lesson learned

A group of 175 tanneries united in form of a cluster and took active participation in the project proposal and in the reclamation of the tanneries' combined effluent. The tanneries pledged to participate to maintenance and operational costs for the extent of the 60% of the total.

Compost production in Amberpet STP (Sourav Mohanty, 2019) (Bachan Jeet Singh, 2018)

The wastewater sludge is sold to external agencies for compost production. The company "Vinuthna Fertilizers" processes it further in various stages to form compost. This compost is being marketed by "Rashtriya Chemical Fertilizers" through a network of distributors and retailers. This final product named as "RCF City Compost" is being purchased by farmers and used for agricultural purpose. The crop yield has increased by using the city compost, especially for cultivating vegetables.

Recipe for success

The central government provides a Market Development Assistance (MDA) of Rs.1500 per tonne of compost under the Swach Bharat Mission. The token is provided by the Department of Fertilizers to the marketer of city compost. This assistance lowers the market cost that farmers would pay but also scales up production and consumption of city compost.

Lesson learned

The farmers lacked a clear understanding of the usage of the city compost. In addition to the existing set of promotional measures, awareness programmes must be organised by government agencies to explain the benefits of compost.

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Despite the compost production case could stand robustly in the market, as the Amberpet STP case tells (golden box at pag. 26), the matter of the social acceptance and that of the toxicological impact of the sludge in the green fields would suggest to discourage this path. The circularity capacity of composting is higher if the compost is attained from non-faecal organic sources, typically food-waste and agricultural residues.

As the Kanpur Nagar region is an economical area with a strong agricultural component, the production and supply of fertilizers is a relevant aspect. Plants require macronutrients and micronutrients for their growth and fertilizers are the source of these nutrients, which not only enhance the plant growth but also maintain soil fertility. The State of Uttar Pradesh uses 16621 kilotonnes of fertilizers per year (Usama *and* Monowar, 2018), which is the largest amount in India. Rice and wheat are the major crops which are consuming 37% and 24% of the total fertilizers consumed in India. For this reason, sewage water in Kanpur Nagar region is used as source of nutrients. To date, many farmers are irrigating with raw sewage, a practice that poses severe risks to human health and requires a smarter approach to nutrients. Also the sludge disposed from the STP Jajmau is taken by the farmers and spread in the fields with the function of fertilizeing the soil with nutrients. It is therefore necessary in the context of this roadmap to redirect the production and the consumption of fertilizer towards safe practises.

Fertilizers should be used in a balanced manner through integrated management of nutrients, involving the use of chemical fertilizers, biofertilizers, compost and vermicompost (Usama *and* Monowar, 2018). Balanced use of fertilizers reduces the harmful effects of chemical fertilizers on the environment and helps in making agriculture sustainable. To the state of the art, most of the fertilizer formation processes in WWTPs are based on crystallization or precipitation from the digester supernatant. But the recovery rate of phosphorus from the liquid phase is lower (10–60% from wastewater treatment plant influent) than from the sludge (35–70%) and from sludge ashes (70–98%) (Cardoso Chrispim *et al*., 2019). Phosphorous recovery from the ashes therefore allows the highest recovery. Noteworthy, optimal phosphorous recovery from the ashes would require a centralized sludge incinerator, and in that case such process has been estimated to cover up a significant fertilizers demand: in Sweden, for instance, Kalmykova *and* Karlfeldt (2013) estimated that the phosphorus extracted from the municipal sludge water residues, could meet the 30% of the annual demand for mineral phosphorus fertiliser in Sweden, given a recovery rate of 70%. The specific costs per kg P recovered by ashes (4 to 10 EUR/kg P) are in general higher than conventional fertilizer production (1.6 EUR/kg P), found Nättorp *et al.* (2017). However, annual costs per PE represent less than 3% of the total costs for wastewater disposal. Other European experiences (Remondis TetraPhos®-process (2019)) indicate that the process is economically efficient, but – as for every P-recovery process – dependent on the P-load of the ashes as well as the global market price for phosphoric acid.

Sludge incineration in Kanpur Nagar region could be a favourable solution in the case of a biomass based power plant where secondary sludge could be conveyed, as advocated by Purohit *and* Vaibhav (2018) (cost-effectiveness of the latter solution is discussed in the next section). This option would allow to combine energy valorization from the dried sludge, disposal of the agriculturale residues, and phosphorous recovery from the ashes of Jajmau STP. In substance, the phosphorous recovery from the ashes would well combine with the sludge pelletization or co-pelletization, the sludge disposal and the subsequent energetic valorization in an already existing infrastructure.

As an alternative to phosphorous recovery from the sludge ashes, the phosphorous recovery could be deployed from the liquid phase of the sludge water. However the latter step would require the biological water line to store enough phosphorous in the sludge, by empowering the biological phosphorous removal (BPR) as a part of the activated sludge process in Jajmau STP. Having to comply with an efficient BPR process, is always a complex constraint to meet in an STP. The problem is rather

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constituted by the BOD balance. A process that would separate primary sludge for electricity valorization, would also reduce the BOD content in the water line necessary to guarantee an efficient BPR process. It is also true that one condition that underpins the BPR process would already be met in Jajmau STP: temperatures should be above 20°C to have an established BPR process. However, to the knowledge of authors, there is no existing wastewater treatment plant operated with a BPR process in India. The operation of such a plant is complex and may not deliver the expected output. In a sense, being the BPR a multi-parametric process, it is not easy to operate, even in Europe. Therefore having the phosphorous recovery to depend on the BPR efficiency is a risky scenario. Moreover, a subsequent problem may come from the struvite quality hampering its commercial viability: as reported by Hutnik *et al.* (2012), in the presence of salts and heavy metals, their hydroxides may also be formed, remaining in the final struvite product.

Encouragingly, examples of materials reuse have started to build up in India. This is for instance the case of the compost production at Amberpet STP presented in the golden box at pag. 26. Another good example is the chromium recovery in the 20 MLD CETP at Kanpur. What the examples in the golden boxes show is that:

- the primary problem for setting up an active implementation of material reuse practise is not the availability of technologies for resource recovery, but the lack of a social-technological planning to deploy the most sustainable solutions in a given geographic and cultural context (Van der Hoek *et al.,* 2016);
- a possible way to unlock a circular implementation relies always on unique business model cases.

SHORTLISTED STANDALONE SCENARIOS:

- **Chromium recovery by adsorbers or precipitation in the 43 MLD Jajmau III STP;**
- **nutrients-based fertilizers production from solid-phase (sludge ashes) ashes rather than from the liquid-phase;**
- **Rehabilitation of the existing infrastructure;**
- **bioplastics;**
- **sludge inertization for the construction industry;**
- **composting from food-waste rather than from wastewate sludge.**

The suitability of the selected standalone scenarios will be further screened in Chapter 4.

3.5 THE THREE PATHWAYS OF PAVITRA GANGA: ENERGY PATHWAY

Wastewater contains significant quantities of chemical energy which can be converted to electrical energy or heat. For example, primary sludge contains approximately 66% of the energy entering the treatment plant, with the rest entering secondary treatment. The energy available in a typical municipal wastewater exceeds the energy required for treatment by a factor of 10. It should be noted that not all available energy in wastewater can be harvested in a beneficial form. However, an understanding of the available energy in the wastewater is a critical step toward developing energy and resource recovery schemes in wastewater treatment plants.

It should be noted that anaerobic treatment processes avoids the need for aeration and may reduce the specific energy consumption for overall treatment. Anaerobic digestion is one of the methods of generating energy from bio-waste. It involves the transformation of organic matter into biogas in an anoxic environment when acted upon by anaerobic bacteria. Biogas consists of 60–67% methane, 30–33% carbon dioxide, 1–2% hydrogen and 0.5% nitrogen, by volume and can mitigate greenhouse gas (GHG) emissions to the atmosphere. There is an enormous untapped potential for converting sludge

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and waste into energy through biogas (Betsy *et al*., 2020). However, if more of the energy contained in the wastewater were captured for use and even less were used for wastewater treatment, then the wastewater treatment plants may become net energy producers rather than consumers.

When looking at the Kanpur Nagar region, the approach described above opens up interesting scenarios. But in truth, as described in Annex 1 and 2, the digestion facilities have been abandoned and not properly maintained in the last decades, as they were not proven to be cost-effective solutions. This fact could be explained by the attempt of exploiting digestion from secondary sludge with very low residual caloric power. Additionally, electricity in India is produced for a large majority from fossil fuels (Electrity Utilities, 2021) where coal and lignite represent 55% of the whole electricity generation in 2021. In addition to the huge carbon footprint, household electricity remains extremely cheap at around 0.08 USD per kilowatt hour, whereas in 2020, the average residential consumer's electricity price in Europe was 0.25 USD (Eurostat, 2020), and in Germany the price of household electricity is 0.36 USD per kilowatt hour (Statista, 2021). There is however still the possibility that the digestion of primary sludge could be a more cost-effective solution, especially when the primary sludge clarifiers are already available in Jajmau STP. In order to assure the cost-efficiency of the anerobic digestion facility operations, a good selection of the organic streams to co-digest is advised. In this sence, the co-digestion of agricultural residues would not produce sufficient methane, due to high content of cellulose and lignine of the residues. Instead, septic material and manure could be efficiently conveyed to the digestion facility for energetic valorization.

Several studies have been conducted on the increased methane production by co-digesting different organic streams. In a recent study, sewage sludge (SS), maize straw (MS) and cow manure (CM) have been used as feeds, and the effects of the mixing ratio and C/N ratio of the substrates were analyzed in detail. Interestingly, the co-digestion of SS/CM/MS performed better than the individual digestion of the components because of the balanced C/N ratios and supply of carbon (Wei *et al*., 2019).
Urban waste streams could also be co-digested, as a similar solution has been implemented in Nashik (Yadav *et al*., 2014) (see golden box). However in the Pavitra Ganga project, the urban food waste streams could be alternatively used for compost production, by-passing in this way social and environmental concerns that arise when producing compost from secondary sludge.

If secondary sludge would not be digested, an eligible destination for dried secondary sludge appears to be the sludge pelletization to be used as solid combustion fuel. The current market price of biomass pellets in India is €0.17 to €0.21/kg (Jain *et al*., 2015). These pellets are mainly used for cooking applications in the commercial sector (Jain *et al*., 2015). A recently published paper evaluated the techno-economic feasibility of biomass pellets for power generation in India (Purohit *and* Vaibhav, 2018). The study infers that surplus biomass availability from the agricultural sector (123 Mt in 2010–11) alone is sufficient to substitute 25 % of the current coal consumption in the power sector. Pelletized biomass can potentially produce 6 % of India’s total electricity in 2030/31 (Purohit *and* Vaibhav, 2018). Large amounts of agricultural residues are available especially in Northern states such as Punjab, Haryana, and Uttar Pradesh. The pelletization of secondary sludge can therefore be strenghtened with agricultural residues.

Power generation from co-pellets could be decentralized (cooking application ot others), or centralized in power plants. The upscaling of the co-pelletization for a biomass power plant is a giant opportunity ahead of India: the associated carbon dioxide mitigation potential resulting from the substitution of coal is estimated at 205 Mt in 2030–31 if the entire biomass surplus is diverted to power generation (Purohit *and* Vaibhav, 2018). The combustion of the pellets in an existing power plant, besides the advantage of the charcoal substitution would also avoid the necessity of building an ad-hoc infrastructure for sludge mono-incineration. Additionally, such projects will generate employment for

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more than 200000 full-time employees in the operation and production of biomass pellets (Purohit *and* Vaibhav, 2018).

The capacity of an Indian WWTP (Jajmau STP in this specific case) to penetrate this market with the dried secondary sewage sludge depends on some crucial factors: sludge drying beds must fully substitute industrial drying processes to strongly reduce the energy bill of the co-pelletization process; sludge drying beds should efficiently operate and assure the necessary moisture requirement; the sewage sludge must still have sufficient caloric power after treatment for energetic exploitation, and therefore digested sludge might not be favourable; pellet production should happen on site, and close to the sludge drying beds. In fact this process is becoming widespread in Germany, where more municipal WWTPs have already been equipped with compact containerized solutions. Considering that examples of co-pelletization of secondary sludge are already upscaled (Yilmaz *et al*., 2018) (Hossain *and* Haij Morni, 2020), this might turn into a very interesting end-route scenario for secondary sludge.

SHORTLISTED STANDALONE SCENARIOS:

- **co-digestion of organic streams and primary sludge in the 130 MLD Jajmau I STP;**
- **co-digestion of organic streams and secondary sludge in the 130 MLD Jajmau I STP;**
- **secondary sludge co-pelletization with agricultural residues.**

The suitability of the selected standalone scenarios will be further screened in chapter 4.

Organic waste and septage co-fermentation in Nashik (Yadav *et al*. 2014)

A pilot project in the city of Nashik offers another model to manage wastewater streams particularly useful for smaller Indian cities using a circular approach. This project manages about 10 to 15 tons of organic waste in municipal solid waste (MSW) and 10-20 tons of faecal sludge for this unsewered town. The process involves co-fermentation of the organic MSW and faecal sludge to generate energy and farm fertiliser. The energy is sold to the power grid and the farm fertiliser is sold in agricultural areas in the vicinity, creating an urban-rural circular economy loop.

Recipe for success

The involvement of multiple stakeholders in operation and maintenance of the plant from collection to final disposal of products lead to persistent project failures. The key to success was a viable business model for implementation of waste to energy projects through a Public Private Partnership (PPP). The adopted formula was a "Design, Finance, Built, Operate and Transfer" (DFBOOT) model: the contractor operates the plant for a period of 10 years and NMC will pay monthly tipping fees for collection and transportation of 30 TPD of waste flows from city to the site and the operation of the plant. In return the plant operator guarantees the supply of daily minimum of 1150 KWh electricity to NMC free of cost through supply to the grid. In return NMC gets rebates on monthly electricity bills. Any additional power generated by operator is a source of additional revenue for the operator.

Lesson learned

Firstly a very close coordination between collection-transportation, plant operation and disposal of the products is required. Secondly, a reliable access to the materials flows requires a well operated logistics system in order to ensure undisturbed supply to the plant.

CHAPTER 4 A DECISION-MAKING FRAMEWORK FOR CIRCULAR SOLUTIONS SELECTION

In a complex and multifaceted area like the Kanpur Nagar region, the screening of circular economy opportunities would require simultaneously modelling a large number of products, technologies, and sectors, including their interaction within a broad economic context, also out of the water context. The Pavitra Ganga project has a well-defined boundary of intervention of how to shift the actual economic vision: the circular valorisation of the local wastewater sector. This sector has always revealed its multidisciplinary capacity of cross-linking different economic sectors and the social activities.

There is not a single initiative that can successfully enable the virtuous path towards the circularity of a complex socio-economic situation. Several limiting factors entangle the positive forces that would lead to significant changes in the economy. In this sense, a decision-making framework is elaborated further below aiming to interact according to the different key enabling steps (Figure 9). The framework also aims at reorganizing the different enabling aspects, and especially valorise their contribution in a systemic approach.

As suggested in Figure 1, the first step is the analysis of the background conditions. This information is summarized in Chapter 2, but in section 1.2 the reader can find the reference to the involved project deliverables of the other work packages. In the second step, the eligible standalone scenarios have been selected and shortlisted at the end of every section (3.3, 3.4, 3.5). In the upcoming Chapter 4, the short-listed scenarios are analyzed in view of some specific criterias: the analysis of demand and supply (section 2) and the assessing of circularity and economic potential (section 4.2). The scenarios are then analyzed in terms of their interaction with a broader system (section 4.3). Finally other legal and management based aspects are evaluated (section 4.4). The summary of the rejected scenarios is provided in section 4.5.

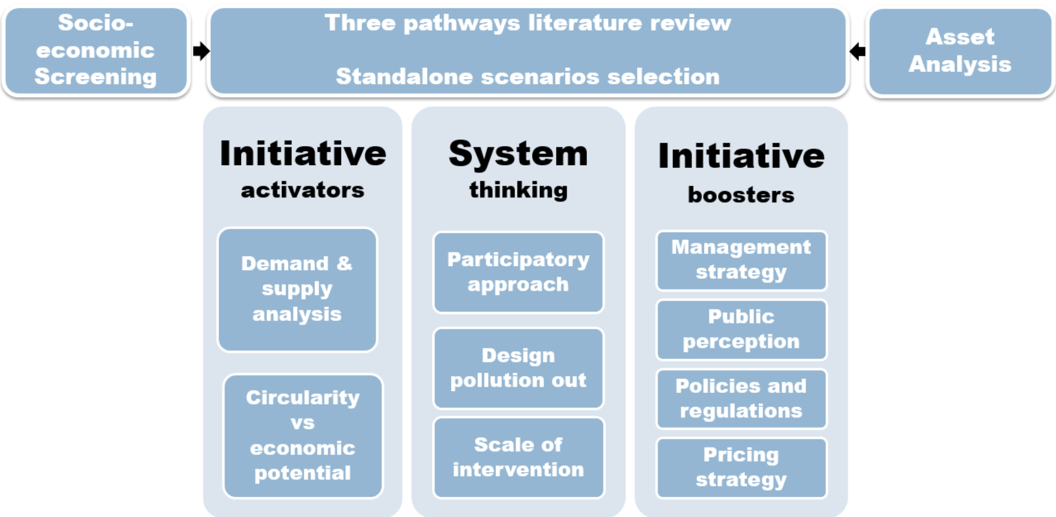

Figure 9: Sketch of the decision-making framework for circular economy solutions

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4.1 INITIATIVES ACTIVATORS: MATCH DEMAND AND SUPPLY

Through research and investigation, the scientific community has produced a number of technological alternatives that can be the target of a circular activity in the wastewater field. In the previous section, by subdividing the framework into three circular pathways, we have introduced a number of eligible scenarios that need a further look in relation to their feasibility. Despite apparently appealing ideas, only the actual socio-economic boundaries can ultimately distinguish real opportunities from academic endeaviours.

After short-listing of a number of scenarios (section 3.3, 3.4, 3.5), for each of the scenarios, the product flows must be looked at in terms of input and output, that is to say as *Demand* and *Supply* of a specific standalone scenario (Table 1, 2, 3). By *Supply*, the authors mean the supply of the main product which is linked to the scenario*, i.e.* in case of water reuse scenario, the supply of water. By *Demand*, the authors check if there is a demand of the main scenario's product*, i.e.* in case of water reuse scenario in industry, the demand of water from industrial sites. Demand and supply are estimated as in 2021. Demand and supply are estimated for the Kanpur Nagar region, including the impact of the existing infrastructure.

Table 1: Supply and demand of Water Pathway standalone scenarios.

Water Pathway	Supply	Demand
STP water reuse for paddy rice fields	There is already water supply by use of the canals. The WWTP effluent water is not of the necessary quality. The planted crops could be selected in views of their irrigation requirements.	The market demand is high, as the paddy rice fields require extensive amount of water.
STP water reuse for drip irrigation	There is already water supply by use of the canals. The WWTP effluent water is not of the necessary quality. The planted crops could be selected in views of their irrigation requirements.	The demand is low, as the crop fields requiring drip irrigation, in the surrounding of the STP, are very limited. There are limited range of crops that are best suited for drip irrigation
Water re-use solutions in industries	The supply of effluent water is potentially already available. Yet most industries access water resources through deep-wells. Post-treatment processes might be necessary to improve the STP effluent up to the necessary quality.	The demand for water is at the moment not present, but the potential is there as tanneries and other industrial sectors need process water. Both a suitable pricing strategy and a regulatory system for groundwater extraction permits and control constitute strong enabling keys.
Grey water reuse in rural or urban communities after source separation and "helophyte" treatment.	At the state of the art, there is no supply of reused water in rural communities. In perspective of supplying technologies to foster local reuse of water, investment and operations may result cost ineffective.	At the state of the art, the demand for this action is scarce. Water resources are generally accessed through deep-wells.
Wetlands restoration	At the state of the art, wetlands are present. Wetlands need to be restored / maintained.	At the state of the art, the demand for this action is scarce.
Artificial recharge	The capital investment necessary to inject water of the due quality in groundwater bodies is extremely high. Nonetheless, there are numerous artificial groundwater recharge interventions across the country.	At the state of the art, the demand for this action is present at a ministerial level and embedded in water policy and programs of the central and state governments.

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Table 2: Supply and demand of Energy Pathway standalone scenarios.

Energy Pathway	Supply	Demand
Co-digestion of 2° sludge and other organic streams with reuse of energy & heat	There is supply of secondary sludge streams. The secondary sludge is dried in sludge drying beds from which it can be harvested. There are other organic streams to be valorized with digestion processes.	At the state of the art, there is a demand for energy and heat. But secondary sludge has a low methane yield, and the cost of electricity outcompete the cost of biogas driven electricity. Digesters are not well maintained. Demand for biogas driven electricity is poor. Demand for secondary sludge digestion is not present.
Co-digestion of 1° sludge and other organic streams with reuse of energy & heat	There is supply of primary sludge streams as primary settling is present in WWTP Jajmau, but the system is not working efficiently. There are other organic streams to be valorized with digestion processes.	At the state of the art, there is a demand for energy and heat. Primary sludge has a high methane yield, and it might be able to compete with the cost of the electricity. Demand for primary sludge digestion is, at the moment, not present.
Sludge for co-pelletization	There is available supply of secondary sludge as raw material.	There is already demand for pellets as solid fuels.

Table 3: Supply and demand of Material Pathway pathway standalone scenarios.

Material Pathway	Supply	Demand
Rehabilitation of the existing STP infrastructure	The supply would be constituted by the existing STP infrastructure.	The demand is represented by utilities needing new infrastructure.
Fertilizers production	At the state of the art, it would need to be performed from sludge ashes or digestate. There is enough dried sludge but fertilizer supply from wwtp is at the moment non existent.	There is a demand for fertilizers. The fertilizer would need to comply with the environmental regulations for products quality.
Bioplastics	At the state of the art, the sludge that would be source of bioplastic requires another specific process. The supply is non existent.	There is at the state of the art limited demand for bioplastics.
Chromium recovery (precipitation/filtration/ structured adsorbers)	There is potential supply of Cr in sewage water.	At the state of the art, there is a demand for chromium in tanneries .
Composting from wastewater sludge	Technically the supply is present, but the product quality is potentially harmful. Two problems affect the supply: the problem of the mixing of faecal sludge with nutrition and food routes in terms of sanitation risk; the heavy metals contamination of the sewage sludge.	The farmers need for fertilizers is high.
Composting from food waste	The supply is present. Composting from food-waste routes is more indicated than from wastewater sludge.	The farmers' need for fertilizers is high.
Sludge as inert material for construction industry	The sludge of the STP Jajmau I is dried in sludge drying beds. There is enough raw material but the sludge incineration process is missing.	The demand is represented by the construction works companies. This solution could stand higher metal and organics micropollutant standards.

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Often the supply or demand are not activated as capital investment is not there to produce the necessary sub-products, *e.g.* the supply of fertilizers is active only after a struvite reactor is built and operated. For consistency of the exercise, this lack of supply or demand is always considered as such, even when a capital investment would be sufficient to directly enable the market without other obstacles. Capex and Opex cost of the interventions that would enable the supply of such products is taken into consideration in Tables 1-2-3.

Similarly, often both supply or demand are not activated as political or social consensus is not there to allow substantial market, *e.g.* sludge composting has a market, but people are reluctant to mix faecal sludge with food production pathways. When the two market routes are matching for a specific scenario, qualitatively and quantitatively, the eligible scenario would seem to be directly applicable, but yet it may not be a favourable option, *i.e.* there is both supply/demand for water for rice, and yet industry might generate more economy with the same water supply. When neither demand nor supply of a specific product/technology is present, the standalone scenario reaching a certain product/technology is rejected.

REJECTED STANDALONE SCENARIOS ON THE BASE OF DEMAND-SUPPLY ANALYSIS

After demand-supply analysis, it shows how the following scenarios have neither demand nor supply perspectives:
- Bioplastics
- Grey water reuse in rural or urban communities after source separation and "helophyte" treatment.

The above listed standalone scenarios are considered not interesting for deployment in the Kanpur Nagar Region. The final rejection/acceptance of the standalone scenario's is summarized in the tables of the section 4.5.

4.2 Initiatives activators: assess circularity potential vs economic potential

For every scenario resulting from the literature survey, supply and demand of a certain circular pathway have had their first assessment (Table 1, 2 and 3). The standalone scenarios are then confronted with the potential to generate a circular path (circularity potential indicator), and the economic impact produced from this implementation (role in the local economy).

The circularity potential is an indicator that rates how effective a product is in realizing the transition from a linear to a circular mode of operation. In order to further outline its relevance, several authors (Ellenmacarthurfoundation, 2015) have articulated the circularity potential into a number of sub-parameters:

- *Input in the production process*: how much input is coming from recycled materials and reused components?
- *Utility during use phase*: how long and intensely is the product used compared to an industry average product of similar type? This takes into account increased durability of products, but also repair/maintenance and shared consumption business models.
- *Destination after use*: how much material goes into landfill (or energy recovery), how much is collected for recycling, which components are collected for reuse?
- *Efficiency of recycling*: how efficient are the recycling processes used to produce recycled input and to recycle material after use?

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- *Complementary risk indicators*: material price variation, material supply chain risks, material scarcity and toxicity.

The circularity and the economic potential of the Water Pathway standalone scenarios is evaluated in Annex 3 (table A3.1). Water reuse for industry appears from a financial perspective as a very interesting scenario although, to date, a number of enabling factors is lacking to fully activate the supply and demand market flows. Conversely, irrigation from WWTP effluent is directly possible, but it does not output a high economic value, and its use poses significant health concerns to farmers, crops and livestock (this is metricized with a low mark in the "complementary risk indicator" in table A3.1).

The circularity and the economic potential of the Energy Pathway standalone scenarios is analyzed in is evaluated in Annex 3 (table A3.2). As analyzed in section 3.5, digestion of primary sludge, eventually coupled with the co-digestion of other organic streams, might represent a cost-effective solution. Sludge co-pelletization is financially interesting, and environmentally strategic in terms of fossil fuels substitution.

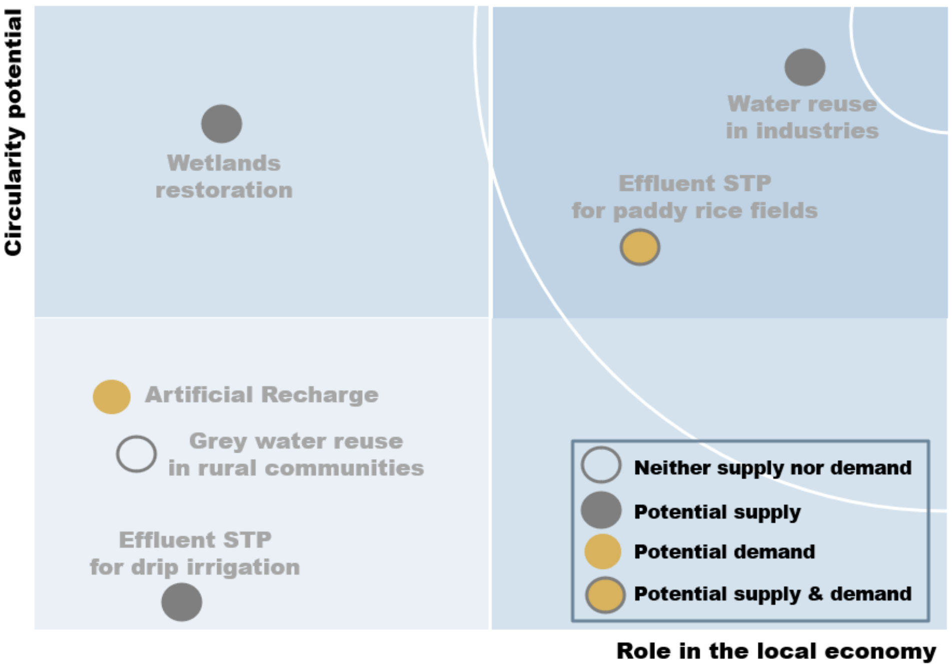

Figure 10: Circularity vs economic potential of the Water Pathway standalone scenarios.

The circularity and the economic potential of the Material Pathway standalone scenarios is analyzed in Figure 12. The circularity potential of the standalone scenarios described in the Y-axis of Figure 12 is evaluated in Annex 3 (table A3.3). As analyzed in section 3.4, sludge composting would be an interesting end-route for sludge, but it encouters a social acceptance barrier and a sanitation problem related to microbial risk and heavy metals contamination (this is metricized with a low mark in the "complementary risk indicator" in table A3.3). Fertilizer production is also an interesting route, as it complies with a strong market demand, and yet technical issues and contamination may affect the commercialized product: the health-related hazard is likely not avoidable when the fertilizer is produced in form of struvite, but the problem can be mitigated when the fertilizer is produced from ashes after incineration (this is metricized with a middle mark in the "complementary risk indicator" in table A3.3). Chromium recovery appears immediately possible as a certain degree of circularity applies to it, and both supply and demand are directly available, but technical feasibility at low incoming

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chromium concentrations is to be further tested. The rehabilitation of infrastructure appears to be a necessary action to boost circularity.

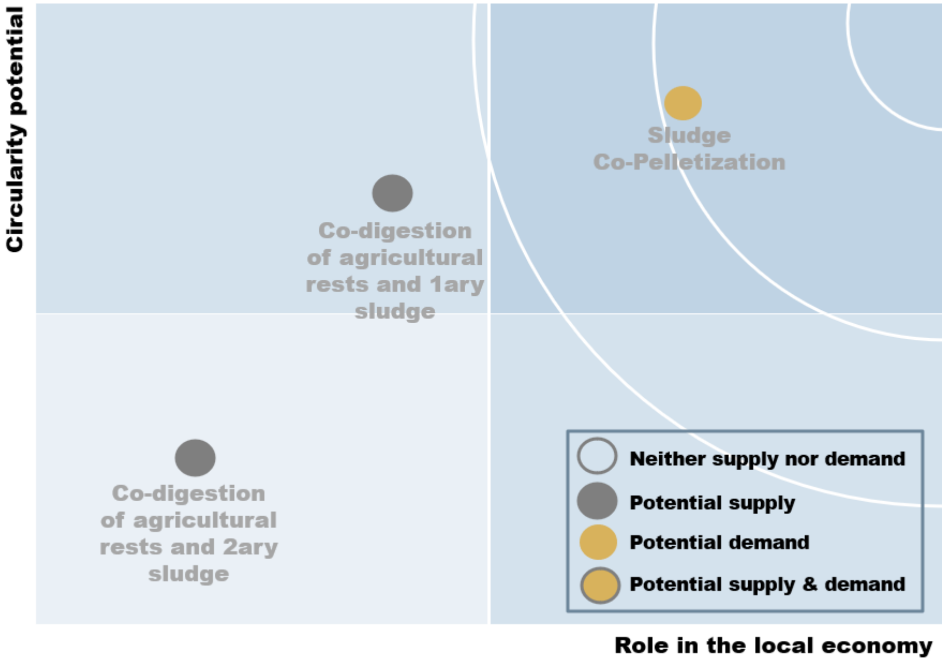

Figure 11: Circularity vs economic potential of the Energy Pathway standalone scenarios.

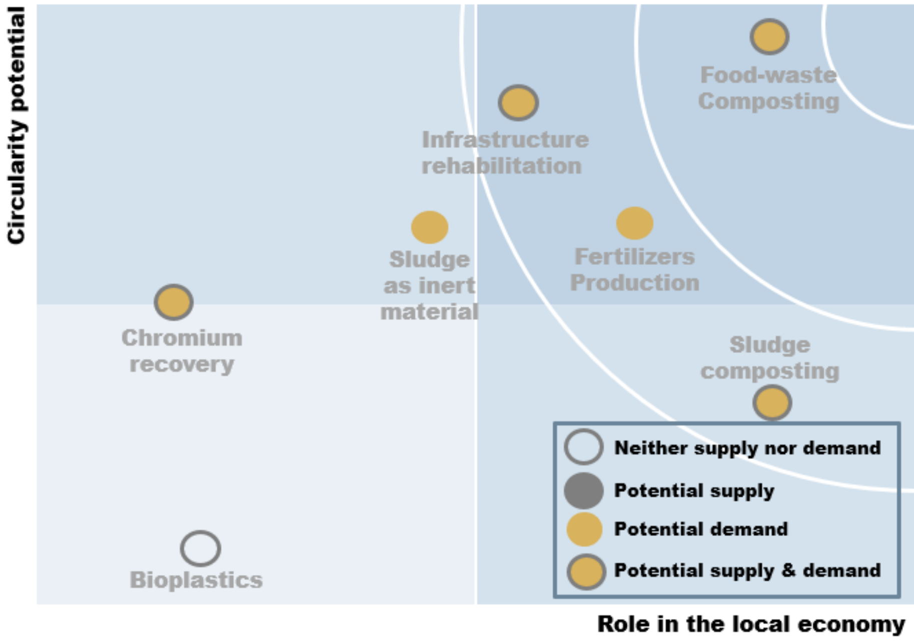

Figure 12: Circularity vs economic potential of the Material Pathway standalone scenarios.

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REJECTED STANDALONE SCENARIOS ON THE BASE OF CIRCULARITY AND ECONOMIC POTENTIAL

- Bioplastics
- Co-digestion of agriculturale rests mixed with secondary sludge
- STP water reuse for drip irrigation
- Grey water reuse in rural or urban communities after source separation and "helophyte" treatment.
- Artificial recharge

The above listed standalone scenarios are considered not interesting for deployment in the Kanpur Nagar Region. The final rejection/acceptance of the standalone scenario's is summarized in the tables of the section 4.5.

4.3 Systemic thinking effect

Once the prioritization of the different scenarios is outlined and potential circular economy cases are selected, it is required to step from standalone scenarios to a systemic approach. This aspects articulates amongst: the definition of the scale of intervention; the definition of the interactions of the material flows with the disposal routes; the engagement with potentially interested parties, adopting a participatory approach; and exploring options to design out pollution by identifying low value residues, pollution, and emissions.

Scale of intervention: the definition and delineation of rural and urban jurisdictions could dictate which sorts of technologies are suitable for different areas, *i.e.* which communities should be connected to sewers centralised systems and re-use, and which communities need decentralised treatment and re-use. Currently, most institutions in India express a preference for sewers as the only sanitation option and often see on-site sanitation as a temporary solution (Peal *et al*., 2014). And in fact, the Government of Uttar Pradesh has started a scheme to connect every house to the sewerage network, (Anshuman and Campling P., 2021).

Decentralised wastewater systems are currently popular amongst practitioners as they are detached from governance, regulatory, and political complexities. Setting up decentralised systems in regularized settlements or housing complexes could be seen as a currently viable opportunity, especially where mandating wastewater reuse and fixing a rational tariff is feasible. In new housing complexes, for instance, such systems could be made an integral part of the building designs. This has already been done successfully in Bengaluru. In 2004, the Karnataka State Pollution Control Board (KSPCB) issued a Zero Liquid Discharge mandate after which about 2000 buildings adopted decentralised wastewater treatment and reuse by 2014 (Karnataka State Pollution Control Board, 2019). In the Pavitra Ganga project, several technologies have been developed and proposed that are suitable for a decentralised approach (Chapter 5).

While on the one hand, India is moving towards a better sanitation including decentralised wastewater systems as a complementary solution, the application of decentralised wastewater systems represents as well a challenge. Reymond *et al.* (2020) showed that the standards prescribed by the Central Pollution Control Board (CPCB) and applicable throughout the country, are too stringent for most small sanitation systems to comply. Consequently, standards that are realistically difficult to meet combined with a weak monitoring framework, leads small utilities operators to focus on circumventing the monitoring system in place rather than investing in improving the performance of their plant (Reymond *et al.*, 2020). India presents a set of conditions for small-scale wastewater treatment systems to take a very significant role in increasing sanitation coverage and water security: fast urban

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growth, large middle- and high- income housing areas, water scarcity and urgent need for water reuse. The political drive is there, but hierarchical governance alone cannot work. The scaling up of a decentralized policy requires market governance to enable the scaling up process, and a high degree of coordination between government agencies for a hierarchical governance approach to be effective (Reymond *et al.*, 2020).

Despite the problem of decentralized sanitation systems governance, the problem of water scarcity or access to water in the Kanpur Nagar Region is not yet at the point of forcing the rural communities to choose for locally based water separation and purification means. The financial resources and economic means are also not present to embark on this approach. In this sense, the proposed roadmap strives to elaborate an urban centralized solution (for the Jajmau STP). Decentralized scenarios will also be proposed in section 5.2. in view of widening the circular economy proposal, as answers to specific problems that can find an on site-solution.

Participatory approach: Citizens' role in circular economy is fundamental. Their choices as consumers as well as users of products and services influence the success of new circular and sustainable solutions. Often, citizen clusters may even shape stakeholder opportunities in form of associated interests. One of the solutions is the sharing economy, where the collaborative consumption reduces the purchase costs, increases the utilization rate and strengthens the community cohesion. For water and wastewater to be treated in an integrated manner, stakeholders' participation mandated through comprehensive contracts outlining individual and mutual responsibilities is required. Community participation in the project generation phase should be encouraged not only to increase awareness and trust, but also for unlocking hidden financing opportunities.

Among the possible projects listed, several of them might generate unexpected implementation routes by use of a wider participation. For instance, the stand-alone scenario '*grey water reuse in rural, urban and peri-urban communities*' may depend on the capability of a citizenship community to associate and discern a future water shortage problem, activating solutions that single individuals could not approach. With more ample ambitions, special-purpose associations comprising representatives from relevant departments in India (urban development, pollution control, land revenue, industrial corporations etc.) could provide a single-window clearance for wastewater reuse projects. Similarly, a wide involvement is necessary to develop a market for extracted resources from wastewater treatment processes.

A mixture of rural areas and metropolis such as the Kanpur Nagar region implies a re-thinking of the project creation process, prior to project formulation. In other words, in a complex area where social diversities risk to endanger any project success, it is important to expand the project participatory level. The relationship between consumers and utilities will become more interdependent as consumers become *prosumers* (a consumer who becomes involved with designing or customising products for their own needs). A number of strategies has to be listed and further analysed to improve the capacity building of local actors. Amongst the many, we consider the following issues to be crucial:

- Organize seminars with the purpose to increase in environmental awareness. People should be aware that decisions and actions of consumers will have implications on service choice and business models.
- Unite and favour the constitution in groups of irrigation project users that have agricultural lands in proximity of the wastewater treatment plant effluent.
- Set the water at the centre of local communities, involving the representative of single rural communities.
- Evaluate industry's needs.

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Consistently, the present roadmap sets the analysis of the regional stakeholders as a crucial step of the social-economic analysis (Figure 1). In practise, the Pavitra Ganga project has deployed intense stakeholder participation. The project was introduced to the local stakeholders through a scoping workshop held in Kanpur with representatives from state and city level agencies, NGOs and academic institutions including experts from Uttar Pradesh Jal Nigam, Uttar Pradesh Pollution Control Board, National and State Mission for Clean Ganga, Solidaridad Asia, and Researchers from CSIR Indian Institute of Toxicology Research, Lucknow, Harcourt Butler Technical University Kanpur and IIT-Kanpur. The consultations' results are reported in section 3.3 of Pavitra Ganga Deliverable 2.1 (Cuadrado Quesada *et al*. ,2021).

Following the scoping workshop, co-creation workshops coupled with bilateral discussions are ongoing to map the challenges related to wastewater treatment, reuse and resource recovery in Jajmau area of Kanpur. Co-creation essentially means 'to create together' and is a merger of participant's experiences as well as external expertise for working towards a plausible set of solutions. It moves beyond working in silos and aims to bring together the priorities of the participants that encompasses overlapping technical, environmental, social, economic, and governance concerns. With the goal of working towards socio-technical fit, the co-creation process emphasizes on one hand on issues and challenges that the stakeholders have mentioned bilaterally in interviews and workshop settings, but also on developing solutions together. The co-creation process aims to address the systemic issues and not merely short term concerns by focusing on challenges and solutions related to wastewater issues over the long term.

The co-creation process in Pavitra Ganga project includes tailored problem structuring methods (PSM) and multi-criteria decision analysis (MCDA) approaches to facilitate a holistic situational analysis, search for promising solutions, and appraisal from diverse perspectives. Problem structuring is conducted with stakeholders identified via the scoping workshop, prior engagements and stakeholder analysis done with project partners. Data collection includes interviews and workshops, done as well as planned online and on location, next to process mapping of key events. The summary for the first workshop is reported in Saharan T. *and* Scholten L., (2021).

<u>Design pollution out</u>: For each of the proposed solutions, a systemic approach should be applied to minimize spent material, while achieving low pollution and low emissions.

The principle is to find alternative pathways or receivers to avoid any waste stream. Alternatively, the processes can be re-engineered to revitalize the value and the reusability of the waste streams. A critical example is the '*Clean Blocks'* case. The mineral wool that constitute the clean block adsorbent material, once spent, needs the identification of a proper disposal or reuse route. At the moment no value can be generated from this spent material.

In a centralized approach for STP, *the avoidance of the pollution* primarily means to identify a complete valorization of the dry solid mass exiting the WWTP. This aspect has been addressed in the section 3.4, and resulted in the energetic valorization of the primary sludge through anaerobic co-digestion, the mixing of the sludge with organic streams for boosting the caloric power of the digestible bulk, the phosphorous production from ashes after incineration of the secondary sludge, the co-pelletization of the whole sludge mass, the production of inert material for construction industry after digestion of the primary STP sludge.

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4.4 Initiative boosters

It was found that the following four critical factors could promote a circular economy in the wastewater sector in India:

Policies and regulations: The existence of supporting policies and regulations contributes towards better governance by acting as supporting structures for the reuse of wastewater. Policy changes can be adopted as leverage towards different spheres of influence. They can be categorized into two different main types (Figure 13): a regulatory framework for promoting the stakeholders participation; a regulatory framework for promoting resource valorisation. The enabling of resource valorisation through regulatory efforts points to some specific cases that have been found crucial during the roadmap elaboration:

1) Water-reuse in industries and productive services can be enforced as long as the access to groundwater is regulated. Controlling groundwater extraction in private land implies a control of the water cycle, an efficient control of its use, and the possibility to reverse the actual water consumption towards circularity and a better use of the existing resources. For instance, the state of Maharashtra billed an act to prevent misuse of groundwater resources. The authorities enforced the duty of geomapping new and existing bore-wells. The same act put in force a license requirement for the digging of new bore-wells, fixing a maximum depth of excavation. Authorities will monitor in real time the digging of borewell to prevent misuse of groundwater reserves.
2) The sewage sludge is usually categorized as non-hazardous substance and thus regulated by Municipal Solid Waste Management Rules. But nutrient recovery based end-products require to stand sufficient quality when having to enter a market. The specifications for organic compost quality, specified on Table 7 of deliverable D2.1, set clear limits to the content of different metals. In the specific case of chromium, the limit value for organic compost is 50 mg/kg. A clear consequence is that it would not be possible to do nutrient recovery or fertilizers production with any significant market penetration when sewage sludge is contaminated with chromium or other metals. As a result, the efforts in the direction of the fertilizers production should run in parallel with the efforts in tracing and impeding industrial sewage water discharge in the Kanpur Nagar region. In this sence the production of compost (from the sludge water of Jaymau STP) would not be allowed in a regulated market, and the fertilizer production process in Jaymau STP would be mandatorily oriented to those type of processes that are capable of selectively binding phosphorous and other nutrients with reducing the final product toxicity: the phosphorous recovery from ashes complies with this requirement better than the struvite production from wastewater. And the composting of food-waste complies with this requirement better than the sewage sludge composting (table in section 4.5).
3) Water quality is a key factor in rural areas in India. Therefore a regulation that ensures the quality standards promotes reuse and circularity.

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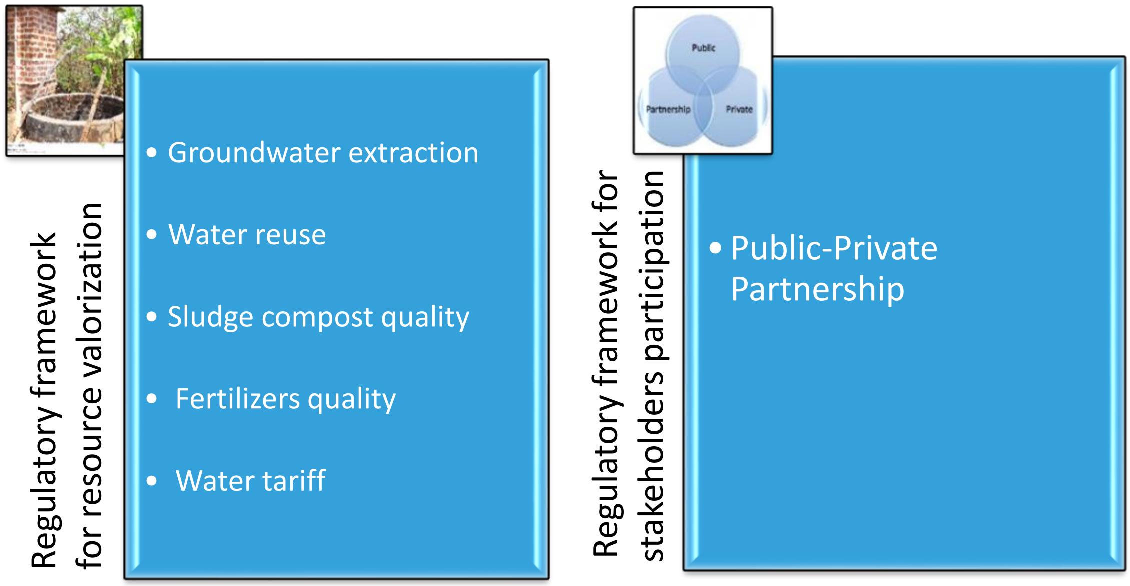

Figure 13: Categorization of regulatory efforts

Management strategy: It is recognized that public funding in the water sector would be best augmented by private capital. This could take the form of public-private partnerships (PPPs), making water a more attractive investment opportunity. Blended finance, which involves combining grants with loans, equity or other risk-sharing mechanisms, from other public and private financiers could be one of the vehicles to mobilize greater private-sector participation. PPP is operational across the globe, mostly under the Build, Own, Operate, and Transfer (BOOT) mechanism. However, cost recovery is not seen as the prime motive; key goals were, rather, pollution management and water augmentation. Government subsidies were directed towards these operations to meet private-sector requirements.

The private sector will have to support public utilities in financing, revamping, constructing new infrastructure, and sustainable operation and maintenance. Involvement of NGOs and CSOs would be crucial in advancing awareness about wastewater-related negative health impacts and the benefits of treating and reusing it. Industrial associations should be kept in loop during negotiations on establishing wastewater reuse systems, as they would be potential buyers. Consumer requirements would largely drive decisions on technology choices. Also, financial institutions would have to play an important role in such initiatives.

The existence of strong legal and regulatory frameworks for stakeholders participation, such as the Public-Private Partnership Act, is key to the success story of the waste plant of Nashik (Yadav *et al.*, 2014). Yet, the existence of such policies does not ensure adoption of sustainable practices as these will only be successful if implementation is strictly enforced.

Pricing strategy: Low prices for water and high infrastructure costs, and a combination of these factors, hamper to achieve a return on investment in projects related to circular water management. This is a significant barrier to circular economy around water treatment and reuse implementation. In fact companies and farmers pay very little for access to plentiful, high quality water, especially when compared to the cost of energy and raw materials.

Evaluating the true cost of water is a first, essential step in justifying water reduction, reuse and recycling. Factors that affect the real costs of water include: energy costs for transporting water; costs

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of labour to manage water systems; regulatory costs; the costs of chemicals for pre-treating water to be used in industrial processes; the costs of treating wastewater (capital equipment and operating costs) prior to discharge. *But a correct monetization of water should proceed with an inverse paradigm*. The value of water is not its production, even supposing that all costs components are accounted as above, but the costs of the risks associated with water shortage. Industries could not operate, and the crop yield from irrigated agriculture would be significantly reduced if insufficient water is available.
In terms of finance, any attempt of implementing circularity must be aware that wastewater recycling and resource extraction would only be profitable in the long-term (8-15 years), rather than offering immediate returns. In the Indian context, supporting the wastewater market might thus require an initial capital push from existing government funds dedicated towards river rejuvenation (for instance, Namami Gange), water-resources augmentation, and pollution abatement. In parallel, independent from the institutional or private subject raising the water tariffs, tariffs should be levied and collected generating a new source of revenue.

Water pricing can be powerful tool to control water demand, as demonstrated by Sao Paulo's hybrid water pricing structure (NITI Aayog, 2018). Sao Paulo's water and sewage management company introduced water pricing incentives which included subsidies as well as taxation provisions to influence consumer behaviour and tackle the city's water crisis. The programme involved rewarding customers that displayed a decrease in average consumption through discount on water price and sewage tariffs, while imposing a contingency fee on customers consuming higher quantities of water compared to previous levels, through taxes, fees, and higher per unit charges. This hybrid water pricing approach enabled a 25% reduction in the water consumption in the city (NITI Aayog, 2018). Some Indian cities such as Hyderabad and Indore have also taken initiatives for improving billing and collection. In Hyderabad, bills are raised on a bi-monthly basis for domestic users and payments can either be made online or at e-centres across the city that have designation cash collection counters, (NITI Aayog, 2018).

Public perception: Government and NGOs could play an important role in making such initiatives a success. The wastewater and infrastructure utilities could allocate a certain portion of investment to building trust and awareness. Similarly, government can, itself or through a third-party, mandate the establishment of monitoring devices at the outlets of WW treatment plants to build trust, awareness, and consumer confidence. For example, in a Namibian project where treated wastewater is used for potable purposes (Veolia, 2018), extensive public education programs including advertisements and education in public schools were undertaken since the beginning of the project for reuse of wastewater. This contributed in a huge manner to the success of the reclamation project (Veolia, 2018). Similarly, in Amberpet STP (Sourav Mohanty, 2019) (Bachan Jeet Singh, 2018) a company called "Vinuthna Fertilizers" processes the sewage sludge in various stages to form compost. The farmers lacked a clear understanding of the usage of the city compost. In addition to the existing set of promotional measures, awareness programmes have been organised by government agencies to explain the benefits of compost.

4.5 Summary of rejections of the standalone scenarios

With the application of the roadmap to the Kanpur Nagar region, a number of standalone scenarios was first selected (pag. 25-28-30) and rejected through the different steps of the roadmap (pag. 34-37). The reasons for the rejection of the different scenarios is summarized in the Tables 4, 5 and 6 for the different pathways.

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Table 4: Water pathway. Summary of selected and rejected standalone scenarios.

Water pathway		Reason for rejection	Section
STP water reuse for paddy rice fields	✔		
STP water reuse for drip irrigation	✘	The crops grown in the region (rice and wheat) are not suitable drip irrigation. This could become a future scenario, only after eswitching to other crops in the region.	3.3, 4.1
Water re-use solutions in industries	✔		
Grey water reuse in rural or urban communities after source separation and "helophyte" treatment.	✘	No demand and no supply. Limited economic viability.	4.1 4.2
Wetlands restoration	✔		
Artificial recharge	✘	Economically unviable	3.3, 4.2

Table 5: Materials pathway. Summary of selected and rejected standalone scenarios.

Materials pathway		Reason for rejection	Section
Rehabilitation of the existing STP infrastructure	✔		
Fertilizers production	✔		
Bioplastics	✘	No demand and no supply. Limited circularity potential Limited role in the economy	4.1 4.2 4.2
Chromium recovery (precipitation/filtration/structured adsorbers)	✔		
Compost from wastewater sludge	✘	Health hazard. Social acceptance. Heavy metals and toxicity in the sludge. Low circularity potential	3.4, 4.4 3.4 4.1, 4.2 4.2
Compost from food-waste	✔		
Sludge as inert material for constructions	✔		

Table 6: Energy pathway. Summary of selected and rejected standalone scenarios.

Energy pathway		Reason for rejection	Section
Co-Digestion of primary wastewater treatment Sludge	✔		
Co-Digestion of secondary wastewater treatment Sludge	✘	It has very limited caloric value. Economic unviable Low circularity potential	3.5 4.2 4.2
Sludge for co-pelletization	✔		

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CHAPTER 5 THE CIRCULAR IMPACT OF THE PAVITRA GANGA TECHNOLOGICAL PROPOSALS

Within the Pavitra Ganga project a set of technologies are being demonstrated to provide robust and cost-effective solutions, both as addition to existing wastewater treatment installations or as standalone facilities. These technologies focus on improving overall treatment efficiency while also recovering energy and/or materials where possible. There is the necessity to explore their circularity potential in relation to the geographical area of impact. The scheme below positions the different technologies as part of a wider circular scenery, describing the potential applications and the barriers that need to be approached.

Table 7: Water Pathway – Pavitra Ganga technologies – Barriers and potential applications.

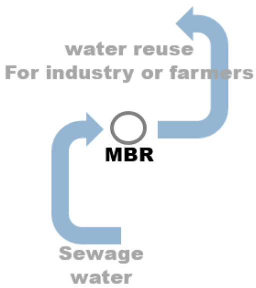
Water Pathway		
Place in the loops	**Barriers**	**Potential applications**
Membrane bioreactor (MBR)		
	The MBR requires a well-operated pre-treatment to avoid membrane damage. It needs operational knowledge to maintain the pre-treatment in good operational standard. It has significant operational and capital cost, and high energy demanding technology Availability of membrane modules spare parts might be at risk.	It could treat any type of wastewater (industrial, municipal) and can take high load concentrations, organic load shocks, and tolerates fluctuations in load and flow. It can be used as solution to polish effluent for N and P removal to high standards. Ideal for irrigation thanks to the very low e-coli effluent concentration. Applicable both as centralized or decentralize solution.
AquaTrack & Ozonation		
	The Aquatrack requires a post-treated effluent, best if by ozonation. It has high operational and investment cost. It is challenged by: dirty water; climate conditions; high temperature and moisture; electrical spikes; non-availability of filtered water .	The Aquatrack system increases the protection from pharmaceutical residues and pathogens in wastewater. It increase the chances for water reuse applications by raising the quality control level. Due to the operational and investment cost, it is rather suggested for a centralized solution.

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Table 8: Water Pathway – Pavitra Ganga technologies – Barriers and potential applications.

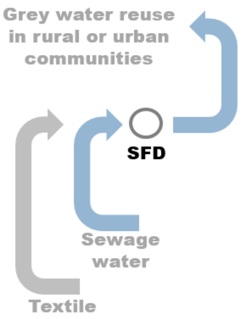
Water Pathway		
Place in the loops	**Barriers**	**Potential applications**
	SFD Membrane bioreactor (MBR)	
	The sewage water requires a well-operated pre-treatment to avoid membrane damage. It needs operational knwoledge to maintain the pre-treatment in good operational standard. It is not suggested for water reuse applications in large scale.	This is a cost-effective solution that can replace expensive and fragile polymeric membrane units in rural area. It can be used as solution to polish effluent for N and P removal to high standards, and lower e-coli effluent concentration. The limited capex costs suggest a wide approach in small decentralized scale units.
	Photo Activated Sludge (PAS)	
	It needs operational costs to maintain the process in good operational standard. The capex cost might be a limiting factor in small scale applications.	This is a cost-effective solution that can be placed in centralized locations of medium scale for water reuse projects. The water might be then useful for farming applications.
	Constructed Wetlands PLUS (CW+)	
	The capex cost of this technology is mainly governed by land prices due to simplicity of construction. The environmental performance of this technology is stable until metals and trace organics remobilization is avoided. It might therefore require a periodic assessment of the sorption capacity.	This is a cost-effective solution that can be placed in decentralized locations for water reuse projects. The water is reclaimed from toxic compounds and it might be then useful for farming applications. It can be used as solution to polish effluent for N and P removal to high standards.

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Table 9: Materials Pathway – Pavitra Ganga technologies. Barriers and potential applications.

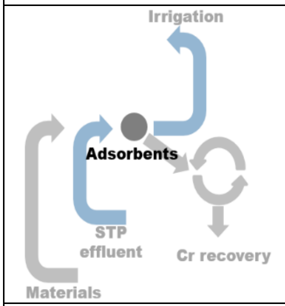
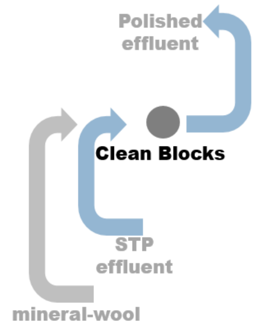
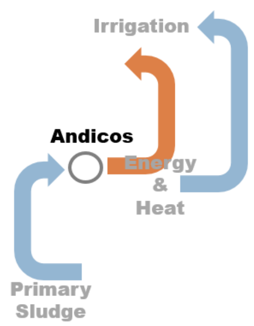
Materials pathway		
Place in the loops	**Barriers**	**Potential applications**
STRUCTURED ADSORBENTS		
	In a circular approach, ideally waste streams must be removed out in the design stage. The adsorbent regeneration is a relevant cost that might be only partially covered by the recovery of the products. With regards to the adsorbents supply, this must be guaranteed as a sufficient and reliable material flow.	The current STPs in Jajmau cannot adequately treat the mixed toxic discharges from industrial and domestic sources. The limitation in water quality reflects on the food-chain after irrigation. The proposed technology provides a compact solution for metal pollution, both in centralized and decentralized approaches.
CLEAN BLOCKS		
	The dumping of the spent adsorbent might transform in an hidden opex cost. As regeneration will not be possible, the mineral wool needs to be disposed. Similarly, adsorbent supply must be assured as a sufficient and reliable material flow. The process must be maintained in operation, guarding it from solid waste dumping, and ensuring the filterability through the filter.	The proposed technology provides a solution for suspended solids and carbonaceous removal in decentralized sites. It cannot be used for direct drain treatment, but only in water streams that can ensure enough filterability through the process, throughout the all course of the operations. It is suggested as pre-treatment of the wetlands feeds. It is suggested as well as pre-treatment of the constructed wetlands feeds.

Table 10: Energy Pathway – Pavitra Ganga technologies – Barriers and potential applications.

Energy Pathway		
Place in the loops	**Barriers**	**Potential applications**
ANDICOS		
	Primary settling tanks are in general expensive. The capex cost is a limiting factor in small scale applications. High capital cost required to building digestion processes. A decent pay-back time cannot be ensured by secondary sludge digestion.	Through this process, the energy recovery of the primary sludge from wastewater is maximized. Additional anaerobic digestion of source selected organic waste streams can increase biogas production. Both energy & heat can be reused internally in the same STP. The processed effluent water has passed an UF barrier and it is usable for irrigation purposes. It addresses, as a standalone solution, the energy recovery in sewage sludge, and the option of irrigation of paddy rice fields. It is suggested as centralized solution.

5.1 Definition of the base-line scenario and integration of the Pavitra Ganga technologies

The roadmap has been conducted with the purpose to identify the standalone scenarios that might contribute, in a circular perspective, to an efficient exploitation of the water resources in the Kanpur Nagar region. The results of the screening have been extracted with coloured boxes at the end of each

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section 3.3, 3.4, 3.5, 4.1, 4.2. A summary of all rejected scenarios with a description of the reasoning is provided in section 4.5. In section 4.5, the selected solutions are as well listed.

The remaining solutions point to the base scenario whereby water reuse is enforced for industrial sites and for paddy rice fields irrigation (Table 4). Another additional and independent point of value is the preservation of wetlands that would serve both a recreational and a restorative natural role.

The energy valorization has a crucial role in the wastewater treatment plant (Table 6). While the primary sludge would be treated through digestion, the disposal and the valorization of secondary sludge would depend mainly on the sludge co-pelletization. In the section 3.5, the authors have explained the high energy recovery potential of the co-pelletization.

The possibility of mixing wastewater sludde with organic material (at high caloric power) is enforced wherever possible (both co-pelletization with farming residues, and primary sludge digestion with other organic sources). It is important to realize that the energy valorization of the wastewater sludge ultimately depends on the incineration of the sludge. Sludge incineration turns to be the necessary step for a number of powerful circular solutions: P recovery from the ashes (fertilizers) as discussed in 3.4; energy recovery when mixed with farm residues (co-pelletisation); sludge inertization for construction; substitution of charcoal with a significant contribution to mitigation of global warming.

A high number of attractive solutions is ultimately proposed in the Materials pathway. Yet, for several of them, there has been a discussion on which technology to apply in order to realize sustainable processes. Being Utter Pradesh an area with a strong farming vocation, production of fertilizers is of crucial importance: the latter can be realized from the sludge ashes (as discussed in 3.4), rather than from the liquid-phase of a wastewater treatment plant. For the same purpose, the production of compost is an initiative with a secure circular success. Yet, as discussed in 3.4, wastewater sludge should not be used as fertilizer raw material. Instead, the compost should merely be derived from food-waste routes.

An element that was found to negatively impact the choice of the different applications is the impact of the toxicity (Complementary Risk Indicators in Table A3) and the efficiency of the circularity (in Table A3.1, A3.2, A3.3). The latter indicators drop the circularity potential of specific solutions and this results in a lower score in Figures 10, 11, and 12.

The roadmap has defined a number of solutions to upgrade the Jajmau STP in a centralized approach (Figure 14). The proposed centralized solution foresees a conventional activated sludge treatment plant to produce effluent water. The effluent water would still be further treated to remove metals and recover chromium solution. The water would be reused primarily for industrial applications, and only secondarily for agricultural applications. Energy and heat would be recovered and directly reused by co-digestion of primary sludge and other organic streams (primarily manure and septic sludge). The STP sludge would be co-pelletized with charcoal and agricultural residues and used in kitchens or in a power plant to substitute fossil fuels. The production of fertilizers would be partly extracted by the phosphorous recovery from ashes, and partly produced by the food-waste composting route.
The centralized solution proposed (Figure 14) would be accompanied with the implementation of a limited number of decentralized solutions (Figure 15). The soil fertilization with organic compost would be an essential application to boost the agricultural economy and it would be based on the compost production from food waste residues. The latter solution would help to reduce the cross-links between faecal matter and food-production pathways.

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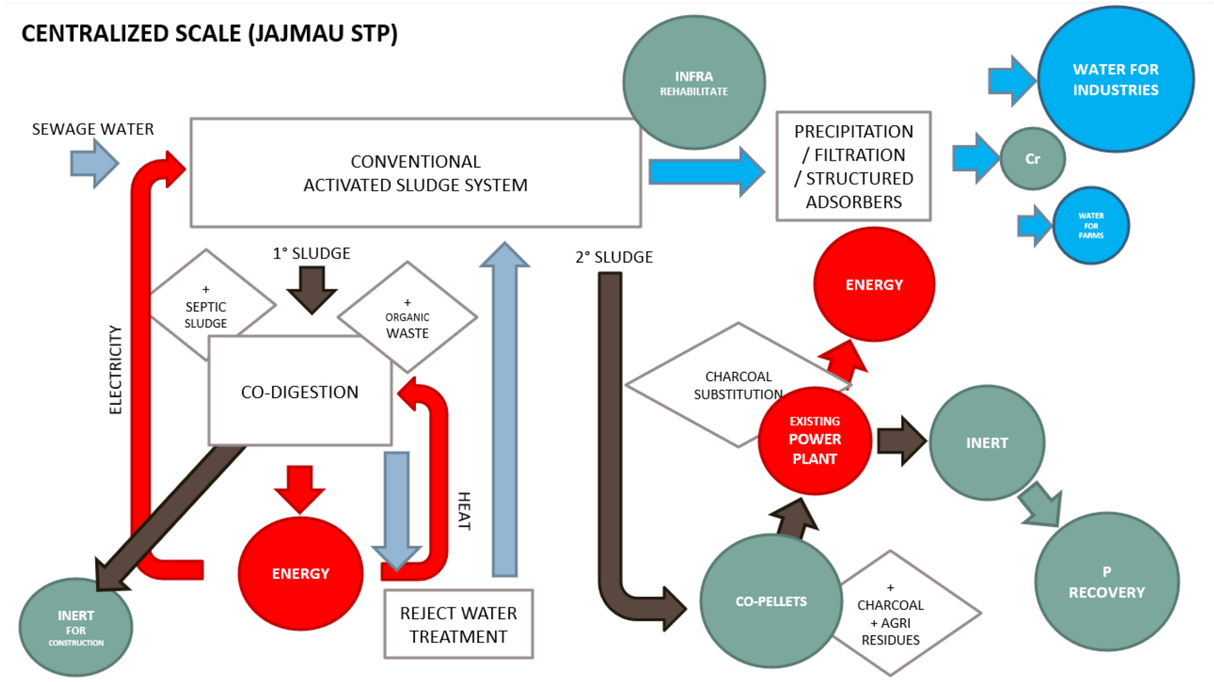

Figure 14: Suggested centralized solution.
Squares refer to operational processes, circles to products, rhombus to external products. The arrows represent the displacement of different materials: Dark Brown is sludge. Light brown is sludge water. Blue is water. Red/Green/Blue colors indicate energy/material/water pathway products.

The application of the Pavitra technology in the proposed scheme is quite extensive. The conventional activated sludge plant with primary sludge co-digestion can in fact be replaced by the application of the Andicos concept, providing an additional ultrafiltration protection to the effluent water. Alternatively, the existing aeration tanks of the conventional activated sludge plant can be retrofitted by use of the Taron SFD MBR. The latter technology would provide a easy possibility to retrofit aerated tanks of any size and dimension.

Effluent water treatment with higher standards will depend on the stakeholders engagement to further invest in water quality technology, but the Pavitra Ganga project offers a valid technological support to the monitoring by use of the AquaTrack application.

The chromium recovery would need to be applied wherever is possible giving priority to the locations where the effluent concentration is higher. The chromium recovery in the effluent water of any STP is a process where the structured adsorbents can be applied. Of course, the effective capacity of chromium recovery would depend on the process conditions, the chromium concentration and the technology efficiency.

In parallel, constructed wetlands should be encouraged and applied to improve the water quality of the influent streams reaching the natural wetlands. Constructed wetlands feed water would be pre-treated by means of the CleanBlocks application. Wetlands regeneration will be of extreme value with positive effect on flood protection, water quality improvement, biodiversity, recreation, and aesthetics.

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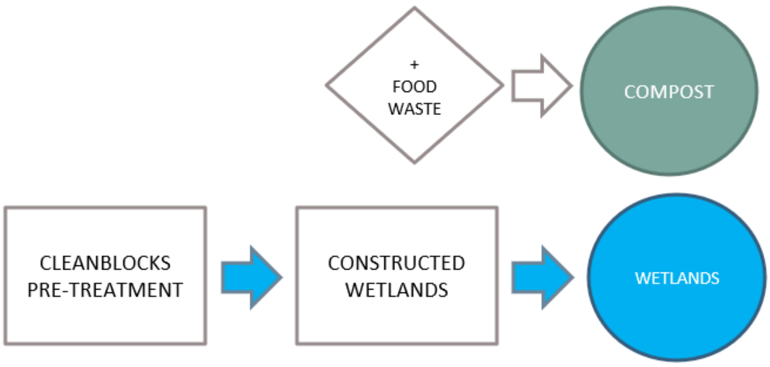

Figure 15: Suggested decentralized solution.
Squares refer to operational processes, circles to products, rhombus to external products added. The arrows represent the displacement of different materials: Blue is water. Red/Green/Blue colors indicate energy/material/water pathway products.

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CHAPTER 6 CONCLUSIONS

The present roadmap has been elaborated in order to process multidisciplinary information, prioritizing the data, and allowing to select promising circular scenarios for the Kanpur Nagar region. The roadmap starts with the processing of the socio-economic and infrastructural information related to the area, providing, where necessary, a reference to the existing project deliverables. The possible solutions have been firstly analyzed as standalone scenarios in the local context being split into three different pathways: water, energy, materials. A decision-making framework for circular solutions selection is then applied in Chapter 4, by evaluating the standalone scenarios against different parameters and framing them subsequently in a systemic approach. The decision-making framework concludes with the proposition of a scenario that integrates several processes or stand-alone solutions matching a scenario with a 50-year horizon.

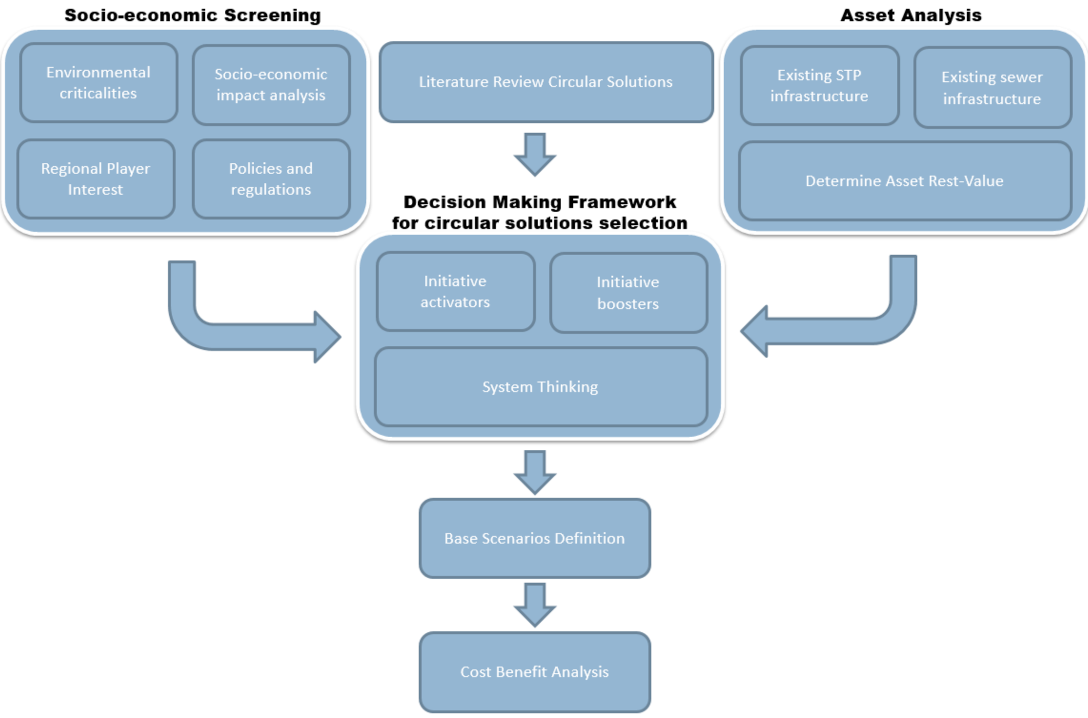

Figure 16: A roadmap scheme to exploit wastewater treatment, water reuse and resource recovery in the urban local body of Kanpur

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ANNEX 1 - ACTUAL SITUATION OF SEWERAGE INFRASTRUCTURE IN KANPUR

UPJN (Uttar Pradesh Jal Nigam) is the agency responsible for pollution prevention and planning capital projects for sewerage. UPJN also operates and maintains large pumping stations and the treatment plant. Kanpur Jal Sansthan is instead responsible for maintenance of trunk sewers, lateral sewers and collection of revenue from house connections. UP Jal Nigam is responsible for the planning, design and construction/development of the assets in the sewerage and drainage sector, while Kanpur Jal Kal (KJK) is responsible for the operation and maintenance of the assets. UP Jal Nigam is in the process of transferring the operation and maintenance of the assets in this sector to Kanpur Nagar Nigam (KNN). The sewage lines in Kanpur extend to an area of 260 Km2 (Figure 1). The operational hydraulic capacity of the sewage system is far below the required hydraulic capacity (Table 1). In Table 2, the capacity of the different items of the sewerage infrastructure is subdivided per pumping station. In Table 3, the sewerage infrastructure is presented as km development for each district.

Table A1.1: Sewerage Profile Kanpur - General Information.

Sewerage Profile Kanpur			
Number of wards			110
Area in Km^2 (Kanpur Nagar Nigam)			260 Km^2
Population	Year 2011		2774502
	Year 2019	Projected	3113263
Total capacity required (Currently) [MLD]			468
Total capacity operational [MLD]			372
Total capacity to be constructed [MLD]			85
Total capacity under Construction[MLD]			15

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Table A1.2: Sewer infrastructure at service of the STPs in Kanpur. "Sps" stands for "sewage pumping station". "Mps" stands for "main pumping station". "Cmps" stands for "common main pumping station".

STPs Infrastructure Details							
District	District -1 - Jajmau				District -2	District -4	District -3
STP	1	2	3	4	Bingawan	Sajari	Baniya purwa
Number of wards Covered [Nos.]	34				58	4	14
Capacity [MLD]	130	5	27	43	210	42	15
STP designed [Year]	2020	2020	2020	2040	2030	2050	2050
Current inflow [MLD]	95-100	4.5-05	24-27		145-155	12-15	
SPS/MPS details [MLD]	SPS Nawabganj: 15 SPS RSPH: 45 SPS Parmat: 40 SPS Muirmill: 6.5 SPS Guptar Ghat: 3.5 SPS Parmiya: 3.5 CSPS: 130 + 25				SPS Munshipur: 67 Rakhimandi: 100 Halwa Khanda: 20 MPS: 200	SPS Chakeri: 14 SPS Sanigawa: 14 MPS: 42	Lakhanpur: 05 MPS: 15

Table A1.3: Sewer line infrastructure presented as per kilometres development for each District

Sewerage Profile Kanpur – Sewer Line Infrastructure					
Districts	District-1	District -2	District -4	District -3	TOTAL
Total Sewer Laying Length required for full HH coverage of the STP project area (Main trunk line, and branch line) [km]	721	4000	174	450	5171
Total Sewer Line Infrastructure available (in Km) (A+B) [km]	618	1162	117	98	1995
A. Sewer line already available [km]	618	1162	117	98	1995
B. Sewer line laid under various STP projects [km]	0	0	0	0	0
Sewer line sanctioned in various STP projects (C+D) [km]	103	20	44	100	223
C. Sewer line laying work completed in various STP projects against sanctioned [km]	31	0	22	10	41
D. Sewer line laying work under construction in various STP projects against sanctioned [km]	72	20	22	90	171
Gap in Sewerage Line Infrastructure (Available – sanctioned) [km]	0	2818	13	252	2953

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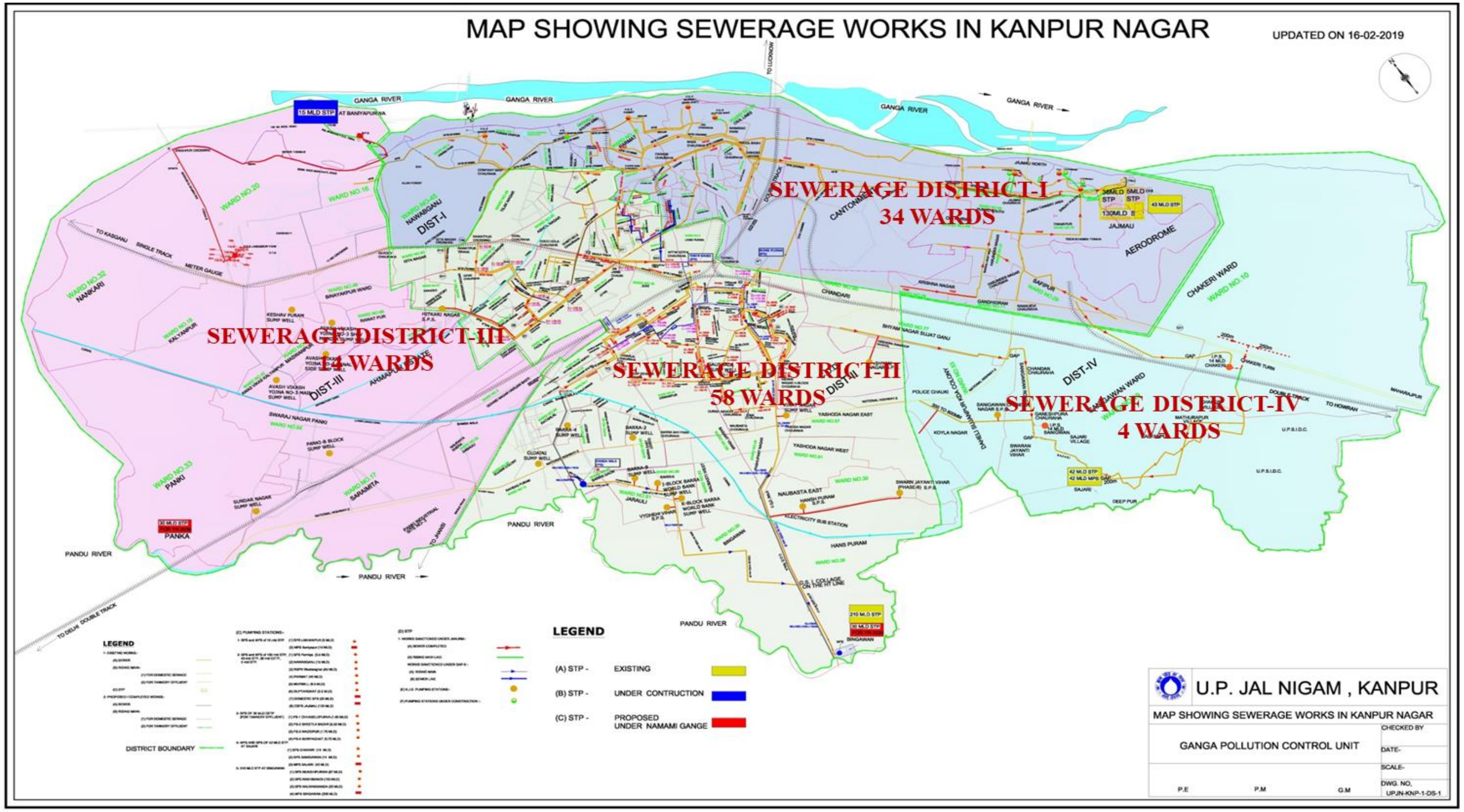
Figure A1.1: Map showing sewerage works in Kanpur Nagar.



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ANNEX 2 - ACTUAL SITUATION OF STPS IN KANPUR

The table below summarises the actual capacities and loads under operation for the different STPs located in Kanpur.

Table A2.1: Status of Sewage Treatment (Discharge in MLD)

STP Name	Status as on June - 2017		Status as on June - 2019		Remark
	Capacity	Treatment status as on June - 2017	Capacity	Treatment Status as on June - 2019	
Jajmau	130	86.3	130	92	Tannery Waste Water[TWW] Treated % in June 2017 = 39.85% Treated % in June 2019 = 68.11%
Jajmau	5	4.81	5	5	
Jajmau	--	--	43	40.7	
CETP Jajmau	27 + 9 (TWW)	21.74+5.63 (TWW)	27+9 (TWW)	24.98 + 12.7 (TWW)	
Sajari	42	7.92	42	14.48	
Bingawan	210	44.58	210	134.112	
Total	414+9 (TWW)	165.35+5.63 (TWW)	457+9 (TWW)	311.26 + 12.70 (TWW)	

The conditions of the Jajmau STPs have already been reported several years ago (Parivesh *and* East, 2015) (Parivesh *and* East, 2007), listing the operational failures and the poor state of the assets. In the absence of a renovation programme, the conditions have in the meanwhile further worsened with more effluent water quality deterioration.

Jajmau I - STP

The 130 MLD capacity STP with a conventional activated sludge process was constructed under GAP-I in the year 1996 for the treatment of domestic waste being pumped from common main pumping station (CMPS) at Jajmau. One out of two gas digesters is damaged and non-functional. The combined heat & power unit (625 KVA, 5 nos.) operated with biogas has not operated since 2003, being uneconomic due to excess consumption of diesel (about 40% more than the nominal consumption). The gas produced is stored in two gas holders and flared. The dome roof of one of the gas holders is heavily damaged. The gas meter installed to measure the gas production is defunct. The sludge

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dewatering centrifuges (4 nos.) are defunct for the last 4-5 years resulting in a shortfall in the capacity of sludge dewatering beds. As per testing done departmentally, treated effluent is not meeting the design standard for SS but meeting the BOD standard. Funds constraints impede a proper plant operation. No regular training is provided to the operators/staff.
(Grade: Very poor).

Jajmau II - UASB STP
A pilot plant of 5 MLD capacity using UASB technology was constructed under GAP-I in the year 1988 for the treatment of combined wastewater, *i.e.* domestic and tannery waste and later exclusively for domestic wastewater only. Based on the limited experience of the pilot plant studies, a UASB was the most preferred option under GAP-I. The pilot plant is being maintained by UPJN and the biogas produced is being flared. Treated effluent is not meeting the design standards for BOD & SS. Testing for coliform reduction is not done. Treated effluent is being discharged nearby into the river and sludge from the drying beds is being used as inert material for road constructions and levelling. (Grade: Poor).

Jajmau III - CETP
A combined effluent treatment plant (CETP) for treatment of municipal sewage and tannery effluent (in proportion of 3:1 respectively) with UASB technology was set up under GAP-I with 100% central funding in the year 1994. O&M of the plant and other ancillary works is being done by UPJN and annual expenditure on O&M is shared 50:50 between Municipal Corporation/State Government & Tanners. The common sump for pumping combined flow to the reactors is found filled with solids/floating matter and the pump well filled with sewage/sludge from leaking joints/glands of centrifugal pumping plants. A floating layer of scum/algae is found on the surface of reactors which needs to be regularly removed for improved efficiency. FRP gutters/V-notch weirs provided in the reactors are not in level so that flow is not uniform. Railings, platforms, metal plates are becoming rusted due to high emissions of sulphuric acid. The combined heat & power unit (225 KVA) installed for generation of power from biogas is out of order since 1998. As per testing done in departmental labs, treated effluent is generally not meeting the design standard for SS but meeting the BOD standard. It was informed by staff at site that proper O&M of the works is not possible due to financial constraints. Regular funds are not received by UPJN from State Government/ Municipal Corporation. Moreover, tanners are also not fully contributing towards their share of O&M costs. At some places tanners are discharging untreated tannery effluent into the conveyance system or have punctured the conveyance system to discharge their untreated waste containing lots of waste e.g. fibre material, chrome liquor etc. thus risking damage to the pumping machinery and other equipment which is adversely effecting treatment efficiency of the plant.

Influent and effluent flows of the Jajmau I and Jajmau II STPs have been characterized with a sampling campaign in the period of 2017-2018 (Deliverable 3.1 – Pavitra Ganga). The influent characterization of the Jajmau I STP suggests an untypical set of concentrations: *e.g*. the nitrogen content of the water is far lower than its carbonaceous presence. Additionally, a contamination from heavy metals might have happened, *e.g.* chromium above 10 mg/l. The STPs Jajmau II and III, instead, report very high contamination with an extremely concentrated liquor in all its components that undoubtedly refer to an industrial discharge of wide proportions. Inhibiting components (such as sulphates, heavy metals like chromium) may affect municipal treatment performance when untreated sewage gets in contact with an activated sludge process.
(Grade: very poor).

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Jajmau III – CETP – Renovation (JTETA, 2018)

The existing CETP was not adequate for the treatment of effluent generated from tannery units to achieve standards given by MoEF&CC and the current treatment process and collection system of the effluent is not proper. Therefore, a new CETP of 20 MLD with closed and dedicated collection and conveyance system, with a zero liquid discharge pilot plant (200 KLD) has been initiated by Jajmau Tannery Effluent Treatment Association (JTETA). The process is based on low loaded extended aeration biological treatment up to ultrafiltration treatment in Phase-1.

Very ambitiously, the project includes a common chrome recovery unit (CCRU) with capacity of 900 KLD for 98-99% recovery and reuse. The spent chrome liquor, collected from each tannery unit, would be transported through tankers to CCRU & the recovered chrome will be sent through drums or sold. The recovered chrome in the form of a solution is stored in the storage tank and reused for chrome tanning along with required fresh basic chromium Sulphate. Depending on the site condition about 80% of fresh basic chromium sulphate and 20% of recovered chrome can be used for chrome tanning. This new plant is initiated by Jajmau Tannery Effluent Treatment Association (JTETA). The individual tanneries will segregate the spent chrome liquor to a collection tank from where the spent chrome liquor will be supplied by tanker for the treatment at the CCRU of 900 KLD capacity and further reuse of Chromium in the unit.

The ambitious 20 MLD CETP project includes a tertiary treatment with an ultrafiltration unit available already from the first project phase. The project will comprise two parallel modules (x 10 MLD) composed of: pre-treatment, sulfide removal, denitrification, two stage extended aeration and tertiary treatment consisting of clarification, quartz filtration and ultrafiltration. The CETP Jajmau is designed to meet the discharge standards (Table 4). The tertiary treatment is completed with a Treated Sewage Dilution Facility.

In a second phase, the project aims to achieve water recovery through incorporation of tertiary treatment with reverse osmosis systems to comply with the Hon'ble NGT Judgement, which restricts the effluent released to the river to only 25% of the total discharge. This means the CETP is to recycle and reuse a minimum of 75% of the treated effluent for industrial units at Jajmau, agriculture or horticulture activity in that area or nearby areas and for cooling purpose of the power plants located in close vicinity.

Table A2.2. Discharge limits of the CETP Jajmau. # FDS of 2100 mg/l will be achieved by dilution with available treated sewage.

Parameters	Discharge Standards	
pH	6 to 9	
Fixed Dissolved Solids	2100 #	mg/l
BOD3 27oC	30	mg/l
COD	250	mg/l
Chlorides	1000	mg Cl-/l
Sulphates	1000	mg SO42-/l
Total Suspended Solids (TSS)	100	mg/l
Ammoniacal nitrogen	50	mg/l
Sulphide (as S2-)	2.0	mg/l
Total Chromium	2.0	mg/l

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ANNEX 3 - EVALUATING THE CIRCULARITY POTENTIAL OF THE STANDALONE SCENARIOS

In the section 4.2, the circularity potential of the different standalone scenarios is analyzed in parallel with the capacity of the scenarios to generate a financial output (**Error! Reference source not found.**, Figure 11,
Figure 12). The circularity potential is an indicator that rates how effective a product is in realizing the transition from a linear to a circular mode of operation. In order to further outline its relevance, several authors [(1)] have articulated the circularity potential into a number of sub-parameters:

- *Input in the production process*: how much input is coming from recycled materials and reused components?
- *Utility during use phase*: how long and intensely is the product used compared to an industry average product of similar type? This takes into account increased durability of products, but also repair/maintenance and shared consumption business models.
- *Destination after use*: how much material goes into landfill (or energy recovery), how much is collected for recycling, which components are collected for reuse?
- *Efficiency of recycling*: how efficient are the recycling processes used to produce recycled input and to recycle material after use?
- *Complementary risk indicators*: material price variation, material supply chain risks, material scarcity and toxicity.

The circularity potential rating of the standalone solutions (Figures 11, 12, 13) is derived from the tables in Annex 3, (Table A3.1, A3.2, A3.3). The sub-indicators are rated from 1 to 5, being the "5" the mark that identifies the most circular condition, and the "1" the mark that identifies the least circular condition. A total mark is calculated as the sum of the 5 sub-indicators marks.

Table A3.1: circularity potential sub-indicators at the basis of the Figure 11

	STP water reuse for paddy rice	STP water reuse for drip irrigation	Water reuse solution in industries	Grey water reuse	Wetlands restoration	Artificial recharge
Input in production process	5	3	5	5	5	3
Utility during use phase	4	1	4	2	5	5
Destination after use	3	1	4	2	5	5
Efficiency of recycling	4	4	4	3	3	1
Complementary risk indicators	2	2	5	2	2	1
TOTAL	18	11	22	14	20	15

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Table A3.3: circularity potential sub-indicators at the basis of the Figure 12

	STP infrastructure rehabilitation	Fertilizers production	Sludge as inert material	Chromium recovery	Composting from sludge	Composting from food-waste	Bioplastics
Input in production process	5	5	4	4	4	5	3
Utility during use phase	5	4	4	4	3	5	3
Destination after use	3	5	4	4	4	5	2
Efficiency of recycling	5	2	3	2	3	5	2
Complementary risk indicators	5	3	4	4	1	5	1
TOTAL	23	19	19	18	15	25	11

Table A3.2: circularity potential sub-indicators at the basis of the Figure 13

	Co-digestion of 1° sludge	Co-digestion of 2° sludge	Sludge Co- pellettization
Input in the production process	5	5	5
Utility during use phase	3	3	3
Destination after use	2	2	4
Efficiency of recycling	5	2	4
Complementary risk indicators	3	3	4
TOTAL	18	15	20

(1) *inter alia* https://www.ellenmacarthurfoundation.org/assets/downloads/insight/Circularity-Indicators_Project-Overview_May2015.pdf

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