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"NDCITYLINE^{IAKS}"-SYSTEM: A MODULE-LIKE DECENTRALIZED WASTEWATER TREATMENT CONCEPT FO R NAM ĐỊNH CITY

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***Abstract**: "NDcityline^{iaks}"-system is a complex wastewater treatment concept developed for Nam Định City. In this concept, sewage treatment is decentralized organized and the sludge treatment in a centralized manner, where the sludge from wastewater treatment (WWT) sites is transported via sludge pipelines to the sludge treatment location. Following the demands of sustainability "NDcityline^{iaks}"-system is based on results of material flow analysis (MFA). The MFA considers the theory of hierarchy of natural resources for the development of a suitable recycling concept, where sewage and sludge discussed as available natural resources. On this way, WWT-process and sludge treatment process offer a large series of so-called by-products (reusing of treated water for industrial purposes, methane gas, low and high temperature heat, cool, electricity, CO_2-conversion into biomass, activated carbon, heavy oil, coal, fertilizer).*

The approach of trickling filter technology for the WWT-process reduces remarkable the costs for the construction, the operating costs and the area consumption in comparison to common used activated sludge technology.

A linked municipal sewage and solid waste management and a specialized facility management increase the volume and efficiency of by-products. The mentioned orientation of management components supports new settlement of companies in direct neighborhood of treatment plants. In result of a successful strategy of industry settlement, the approaches of by-products create chances to refinance the investment and the operating costs in a certain time connected with lower costs for settled enterprises.

The "NDcityline^{iaks}"-system considers ecological aspects by reusing natural resources and a full recycling concept. It supports directly the future economic development of local industry and offers chances to link industrial and agricultural development in the region (e.g. via food processing industry). Finally, the lower costs and the presented option for refinancing offer better chances to construct WWT-plants without increase of any further fees for the population following the demand for safety of supply in the sense of sustainability.

I. INTRODUCTION

One of the main environmental problems in Việt Nam is recently the insufficient situation of wastewater treatment (WWT) in Việt Nam. The strong activities of authorities in Nam Định City in planning of wastewater treatment facilities in the last ten years are symptomatically for developing countries. The question of financing is one of the main problems, which is mostly responsible for long-term delays of construction of WWT-plants. In Europe WWT-plants are to refinance by fees of water consumer and wastewater “producer”. Because of the general low income of residents in developing countries, this system for financing of WWT-facilities is not transferable from Europe into these countries for the next years.

A sustainable concept for wastewater treatment has to consider economic, ecological and social criteria. These criteria have to be weighted for a sustainable decision between different action alternatives. A typical tool of sustainability, study on material flows, shall offer also new opportunities to develop concepts of WWT-facilities.

Material flow analysis as part of resource management can assist the identification of so-called by-products from wastewater and sludge treatment processes. Reusing treated water for industrial purposes, methane gas, low and high temperature heat, cool, electricity, CO_2converted into biomass, activated carbon, heavy oil, coal, fertilizer are the first selection of possible by-products. The approach of those by-products can reduce the operating costs and offer additional income sources for the WWT-plant.

Moreover, a synthesis of wastewater and solid waste management creates also further options to increase the amount of possible by-products.

This paper describes an innovative engineering-technical solution and its embedding in a future sustainable wastewater treatment concept for Nam Định City. The embedding of the engineering-technical development demands before an analysis of economic, ecological and socio-geographic situation following the conceptual rules of Integrated Water Resource Management (IWRM).

II. THE LOCATION – NAM ĐỊNH CITY

Nam Định City, located about 90 km SE of Hà Nội, is in the Red River (Hồng River) delta region the third largest city with a high developed degree of industry and services (98 % of GDP in 2004).

This city covers a total area of 4,622 ha where the inner city accounts for 1,864 ha (40 %) and the suburban areas to 2,758 ha (60 %). The city has currently 254,700 inhabitants where 203,800 people (80 %) live in inner districts, but only 50,900 people (20 %) live in the suburban areas [6].

Nam Định City is the political-economic-cultural-social centre of the province where all important administrative offices of the province concentrate. It is also an industrial and commercial centre of Red River Delta. The following industries are typically here: textile industry, food processing industry (including seafood, fruits, drinks and sweets), wood processing, woolen carpet and jute industry, production of plastic products, shipbuilding and car industry, production of electronic products, assembl age of electronic products, small craft industries producing fine handicrafts articles like textiles, sculptures, lacquer, rattan and bamboo knitting for export.

The GDP of the city reached more than 2,032 bill. VND in 2007. In the last 10 years, it rose two times and it represents now about one fourth of the GDP of the whole province. Industrial production and construction account for 48.6 % of the GDP. The average economic growth rate of the last five years was 10.5 %. The value of industrial production increased in the same time by about 20.5 %. Trade and services increased by about 8.5 %. As industry, trade and services grow the agricultural land is reduced from 2,400 ha to now 1,600 ha. In there about 1,200 ha are water rice culture. Nevertheless, the annual output could be increased by 3.3 % and reached 110 bill. VND in 2007. Currently industry and construction account for 56 %, services for 42 % and agriculture for 1.9 %. The city plays an important role for the industrial development of the province: two third of the provincial industrial production takes place in the city [8].

Nam Định has been becoming a level II city recently. According to Decree No 72/2001/NĐ-CP a city level II must ensure the following criteria: city is a centre of politics, economics, culture, science and technology, tourism, services, the traffic exchanges between the provinces, regions, province or country. The city has to roll over promoting economic development in social territories of the province. The rate of non-agricultural workers has to be developed from 80% up; the infrastructure is built to many of relatively complete. The scale of urban population has to increase from 25 thousand people and up and population density shall characterize in average by 10,000 capita/km².

Nam Định City lies at Red River right at the junction with Đào River. It is located in the Red River delta with low and quite flat terrain. The average elevation lies between 0.5 and 4.0 m above sea level. The inner area of the city shows elevations from 3 to 4 m, for constructions the foundation is set about 1 to 1.5 m higher. The agricultural areas and mainly the paddy rice fields often have elevations from 0.5 to 1.5 m above sea level. Areas with an elevation less than 2 m are often flooded when it is raining over long periods of time. The concrete dikes along the Đào River were constructed with an elevation of +6.50 m in order to prevent floods and to protect the city.

Nam Định City is directly affected by the hydrological systems of Đào River and Red River. The average water level in the rivers is +1.52 m, the highest water level measured up to now is 5.77 m.

Nam Định City is located in the tropical monsoon climate zone of the northern delta with the following characteristics [6]:

- ***Temperature***:

Annual average temperature +23.7 °C

Average temperature in the summer +27.8 °C

Average temperature in the winter +19.5 °C

- ***Humidity***:

Annual average relative humidity 84 %

Maximum relative humidity 94 %

Minimum relative humidity 65 %

- ***Rainfall***:

Annual average rainfall 1830 mm

Maximum daily rainfall 350 mm

- ***Wind velocity***:

Average wind velocity 2.4 m/s

- ***Wind direction***:

The main wind direction in summer: southeast

The main wind direction in winter: northeast

Nam Định City has a well-developed water supply and drainage system, but any wastewater treatment capacities are not available to clarify the domestic wastewater.

The authorities of Nam Định City have to consider few special problems in the further urban development. The water supply plant in Nam Định is using surface water of Đào River. But the inflow for the water supply plant is located only few hundred meters close to the northern pump station for the irrigation of Nam Định City. That means all surface water from Đào River, which is used for the production of potable water, is affected by wastewater. This situation demands an increased treatment process for the water supply of Nam ĐịnhCity.

Furthermore, Nam Định City is planning an intensive expansion until 2020 concerning area and population (estimated 1 mill. of inhabitants for 2020). This fast growing development of Nam Định City is raising the problem concerning the recent missing wastewater treatment facilities.

The extension areas include Nam Vân commune, Nam Trực district, Trực Ninh district in the north; the communes Lộc Hòa, Lộc Vượng, Lộc Hà ward in the north-west and Vu Ban district in the west and southwest. After the expansion of the administrative borders, the area of Nam Định City will be 21,406 ha in 2010, which is an increase of about 16,785 ha in comparison with 2008. For 2020 the area of the city is forecasted to be 45,217 ha. The population of Nam Định City is predicted to reach 955,000 people in 2020. The forecast also includes the population increase by expanding the city limits with about 300,000 people. The standard of the infrastructure of the city will be upgraded at least to the urban standard level II and should already fulfill the criteria of the urban standard level I in some areas. Scale and quality of infrastructure in the fields of education, training, science and technology, public health and sport of Nam Định City are intended to be upgraded to satisfy the criteria of urban standard level I.

The industrial development of the city will be enforced also in the future. Nam Định City will continue to be an industrial center of the Southern Red River delta with the main following industrial branches: mechanical production, agricultural machinery, shipbuilding, transportation, textile and clothing industries, technology of computer-electronics, etc. The city authorities plan to construct industrial zones and establish industrial groups, and to build up infrastructure to attract investment from within Việt Nam and from abroad. Also within residential areas, some space will be kept for industrial production. Regarding the water supply infrastructure Nam Định City aims to upgrade the system so that in 2020 at least 90 % of the population can use tap water [9].

III. THE WATER SITUATION IN NAM ĐỊNH CITY

The main source of water supply is the Đào River. The water supply system of Nam Định City was constructed in 1924, since that time it had to undergo many reconstructions and improvements. Today it has a total capacity of 30,000 m³/day. After the 1993 year a water supply program mainly funded by the French government was implemented in three phases. After the third phase will be finished, the water supply system of Nam Định City will have a capacity of 50,000 m³/day. The water supply network was extended to a total of 26,500 m of pipelines.

Based on investment of the French organization, the two further small-scale waterworks in Nam Phong and Nam Vân communes meets the water demand of inhabitants, offices and units in these areas. In 2008 the number of households that are connected to the central water supply system and can use tap water in the inner city area account for 98 %, in the suburban districts for 74 %. The communes of Lộc An, Mỹ Xá, Nam Vân, Nam Phong and Lộc Hòa show the main deficits of tap water access.

Up to now surface water is main source for daily uses. The water supply company organization is under supervision of Department of Construction and is acting on public interest.

According to subproject of improving urban in Nam Định city in 2007 and final report in 2008 of central water supply works, the drainage system of Nam Định City is not able to drain water only by gravitational force because the drainage network is constructed contrary to the slopes of the natural topography. The water is not drained directly to the Đào River but it flows to the paddy fields and into the drainage system. Nam Định City has for drainage purposes two large pump stations, one is managed by Nam Định province (Hữu Bi, Quán Chuột) while the other one is managed by the city itself (Kênh Giá). The two main pumping stations Kênh Giá with a capacity of 43,000 m^3/d and Quán Chuột with a capacity of 20,000 m^3/d control the water drainage of the city. Besides, there are 11 electric pump stations managed by irrigation co-operatives and 1,136 small water pumps. The city has in total 72 km of canals of level I and II. The system of drainage canals in Nam Định City is based on nine main canals of level II (main drainage in the city center). Its banks have been stone-walled at a length of about 6 km. Afterwards the water flows into a canal of level I (main channel and pumping station) and a system of agricultural drainage canals, which finally leads to the pump station to the main river.

In the storm season, the drainage of the city depends completely on the capacity and operation time of the two pump stations Kênh Giá and Quán Chuột [11].

The wastewater flows through the sewer network to sedimentation ponds and then is pumped into Đào River. The current network for the drainage of wastewater and rainwater is a mixed sewer network. This network only covers the inner city areas. In the suburban districts, only the system of ditches and canals which are used also for irrigation is available. There is only one system, which collects all types of water like household wastewater, industrial wastewater, wastewater from hospitals etc. and rainwater.

The only wastewater treatment facilities in the city are the septic tanks under the private houses and the sedimentation ponds before the water is pumped out to the Đào River. The industrial wastewater of Nam Định textile factory is not treated and flows directly to the sewer system. It is one reason of the heavy pollution of the water resources in the area.

Groundwater in Nam Định city and surrounding areas are more or less not available for exploitation. [2-4] characterized the groundwater for instant in the Pleistocene aquifer polluted by high salinity (1 … 3 g/l), high amount of iron (> 5 g/l) and ammonia (NH_4^+ > 3 g/l).

In [4] the authors offer also a short overview to the characterization of the surface water in Nam Định City. They have compared the results of 300 surface water sample analyses with the Vietnamese Standard for surface water as supply source for drinking water (TCVN 5942-1995 A). Mostly TDS, COD, BOD_5, and pathogens (coliforms) impair the surface water. Table 1 with measurement data by DoNRE (2007) visualizes this situation, too. Suspended solids, chemical oxygen demand and the biological oxygen demand exceed also here the Vietnamese standard TCVN 5942-2005 (A). Additionally, the values increase with the flow direction for suspended solids, hexavalent Cr, oil, phenol components and total coliforms. Furthermore, other measurements in 2008 show that also NH^{4+} and total phosphor exceed the limits of TCVN 5942-2005 (kind information by Mr. Ralph Emmerich, IWRM-group of Greifswald, Germany). They measured also extreme values for total coliforms with 2.4×10^4 to 1.5×10^8 MPN/100 ml.

Finally, authors in [7] confirmed for the Đào River in Nam Định City a water quality of categories II and II-III. This estimation based on investigation of diatom associations and chemical proofs. They noted also that the lakes and ponds in Nam Định City suffer on a high degree of eutrophication.

Table 1. **Surface water composition at selected sites of Đào River [8]**

No	*Parameters*	Unit	*Analytical results*			*TCVN 5942-2005(A)*
			I-4	I-5	I-6	
1	pH	-	7.2	7.3	7.1	6 – 8.5
2	DO	mg/l	7.2	6.24	6.72	≥ 6
3	SS	mg/l	112	263	280	20
4	COD	mg/l	35	25	24	< 10
5	BOD_5	mg/l	19	13	14	< 4
6	Cr (VI)	mg/l	0.002	0.018	0.016	0.05
7	Nitrite (N)	mg/l	0.01	0.008	0.007	0.01
8	DDT	mg/l	0.004	<0.0001	0.0034	0.01
9	Nitrate (N)	mg/l	7.6	4.7	3.9	10
10	As	mg/l	0.003	0.012	0.0087	0.05
11	Oil	mg/l	0.12	0.10	0.18	0.3
12	Detergent	mg/l	0.045	0.12	0.033	0.5
13	Phenol	mg/l	0.001	0.0013	0.005	0.001
14	Total Coliforms	MPN/ 100ml	186	120	1,214	5,000

***Legend**: I-4: Water of Đào River in river mouth Yên Phúc (617827X-2241757Y); I-5: Water of Đào River in Kênh Giá (621770X-2256109Y); I-24: Water of Đào River in Quán Chuột (626153X-2260490Y).*

Nam Định City not only lacks wastewater treatment facilities but also until now cannot solve the problem of solid waste disposal into the environment and the ditches, canals and rivers. The solid waste collection system only collects and treats 3 % of the waste produced in the city.

IV. THE ENGINEERING-TECHNICAL RECOMMENDATION FOR THE DOMESTIC WWT-SYSTEM IN NAM ĐỊNH CITY

The description of the fast growing development of Nam Định City in near future demands a solution, which can expand with the rising city. Authorities of Nam Định City prefer a low area demand for the mutual WWT-plant in order to reduce the further loss of agricultural land or to minimize the volume of any other resettlement programs. Additionally, the development of WWT-systems shall support the industrial development of the city.

Following these three main topics the engineers of iaks GmbH developed the so-called "NDcityline[iaks]"-concept. This concept recommends treating the wastewater in a decentralized manner. The stabilized sludge is to pump via sludge pipelines into a centralized sludge treatment plant (Fig. 1). For the wastewater treatment, they offer the use of trickling filters. Possible technologies for the sludge treatment are fouling into methane gas and low temperature conversion into oil, gas and coal. These technologies create different options for a full recycling of sludge (Fig. 2).

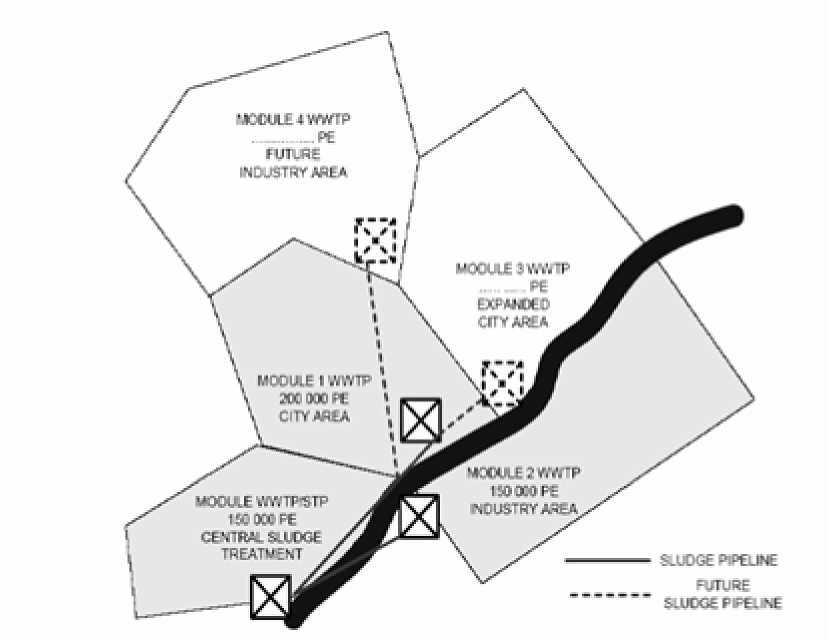

Figure 1. *General visualization of decentralized wastewater treatment and centralized sludge treatment*

1. Wastewater treatment

For the wastewater treatment process by "NDcityline[iaks]"-concept mechanical treatment with primary settlement, secondary biological treatment and the final clarification are integrated in a closed building avoiding any smell nuisance. Primary settlement and final clarification are carried out by sieves and microsieves (Fig. 2). Denitrification, nitrification and reduction of phosphor are processed by a biofilm technique – a set of trickling filters (Fig. 3).

The wastewater flows by pumping via rotating biological contactors from top side downward into the trickling filters (Fig. 4). The recommended trickling filter consists of a fixed bed of a special plastic media over which sewage flows downward and causes a layer or film of microbial slime to grow, covering the bed of media. Aerobic conditions are maintained by splashing, diffusion, and either by forced air flowing through the bed or convection of air. The process mechanism, or how the removal of waste from the water happens, involves both absorption and adsorption of organic compounds within the sewage by the layer of microbial slime. Diffusion of the wastewater over the media furnishes dissolved air, the oxygen, which the slime layer requires for the biochemical oxidation of the organic compounds and releases carbon dioxide gas, water and other oxidized products. As the slime layer thickens, it becomes more difficult for air to penetrate the layer and an inner anaerobic layer is formed. This slime layer continues to build until it eventually sloughs off, breaking off longer growth into the treated effluent as sludge.

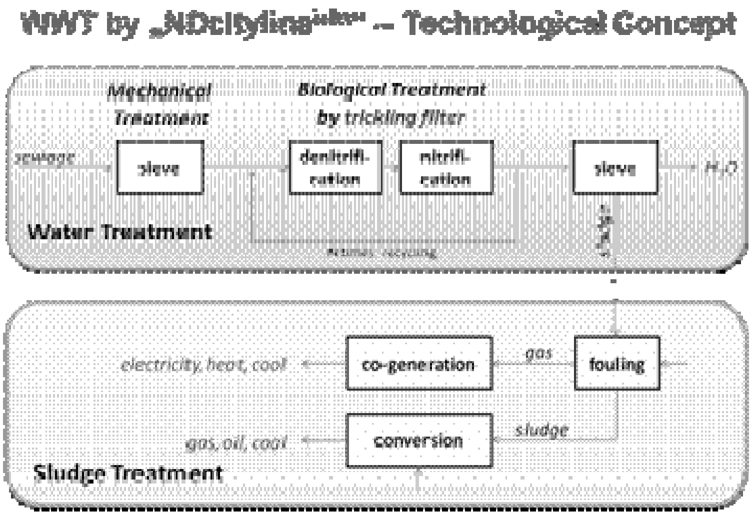

Figure 2. *Flow chart for the recommended wastewater treatment (incl. sludge treatment) in Nam Dinh City labeled as "NCcityline^{iaks}"-concept (part of water treatment is located in decentralized sites and part of sludge treatment is planned as centralized system)*

Wastewater treatment plants using the trickling filter technology have to following in its design and scaling the German regulation ATV-DVWK-A281 on "Dimensioning of Trickling Filters and Rotating Biological Contactors". The capacity of each facility is controlled by the height of the tower. That is why the real area consumption of "NDcityline^{iaks}" is only 1,800 m² for the wastewater treatment plus 1.500 m², if sludge treatment should be included. This area of 3,300 m² can serve as full equipped WWT-plant (water & sludge) without any problems for ten thousand to few hundred thousand of population equivalents (PE). In comparison to other WWT-systems like activated sludge (AS) treatment engineers have not to consider the high ground load of water column in the basins needed for these technologies. That means the constructional conditions for the foundation of the towers of trickling filters are much easier to handle than for

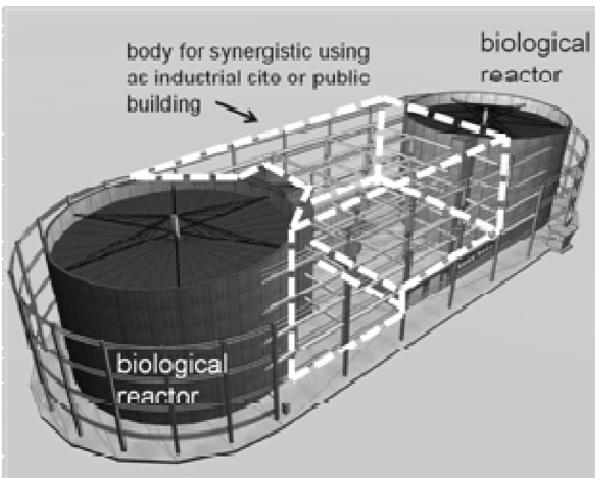

Figure 3. *The main building components of "NDcityline^{iaks}"-system for treatment of wastewater in Nam Dinh City (biological reactor – trickling filter incl. equipment for mechanical treatment and clarification by sieve technology; body for synergistic using – opportunity to develop new production sites with chances for recycling of cleaned water, for additional services by washing of polluted air etc. or to integrate this WWT-system also in central parts of city as public building as well as for commercial purposes)*

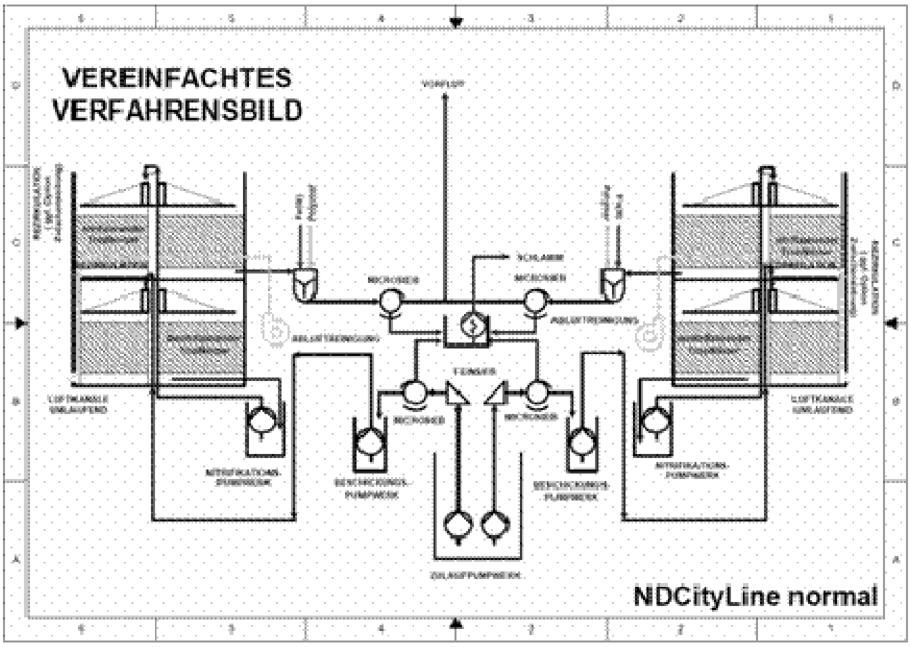

Figure 4. *Simplified flow chart of wastewater treatment (without sludge treatment) by trickling filter system "NDcityline^{iaks}" (towers include in the lower part the denitrification section (DN-reactor) and in the upper part the nitrification section (N-reactor); this system is mirrored in two towers by engineering-technological recommendations only; part of water treatment is located in decentralized sites)*

Legend: *Zulaufpumpwerk – inflow pump station, Feinsieb – fine sieve; Microsieb – microsieve; Beschickungspumpwerk – waste water pump station; denitrifizierender Tropfkörper – denitrification reactor by trickling filter (DN-reactor); Luftkanäle umlaufend – aeration channels, circulating; Nitrifikations-Pumpwerk – pump station to nitrification reactor (N-reactor); nitrifizierender Tropf-körper – nitrification reactor by trickling filter (N-reactor); Abluftreinigung – optional treatment of polluted air; Vorflut - waterstream*

AS-technologies. Furthermore, the aerators for AS-technologies are an important factor of investment and operating costs (like electricity and maintenance). The wastewater treatment by trickling filter needs only standard pump stations. In result of that, sites with a high water table, high bedrock, heavy clay, small land area, or which require minimal site destruction are ideally suited for trickling filters. All varieties of sewage trickling filters have low and sometimes intermittent power consumption.

2. Sludge treatment

The sludge treatment section (Fig. 5) contains also a full wastewater treatment unit by trickling filters to treat also the process water originated by sludge treatment. The sludge transport from the decentralized wastewater treatment sites to the centralized sludge treatment plant is planned via sludge pipelines. The fouling is a first step of sludge treatment. About 30 % of sludge is converted into methane gas. This gas can use by so-called CHP-cogeneration with an efficiency higher than 85 % for production of cool (C), low and high temperature heat (H) and electrical power (P). After the fouling process the rest of sludge has to pass a chamber filter press for dehydration. A part of the heat from the CHP-cogeneration is to use for this drying process. In a following step, the sludge is processed by low temperature conversion into new run products like heavy oil, gas and coal. The own energy consumption for this process needs the gas outcome. The new product "coal" shows also properties like activated carbon. That is, why this coal is usable as additional filter for wastewater (as sewage sludge is cleaning sewage) or as long-term storing for energy (e.g. for later firing approaches).

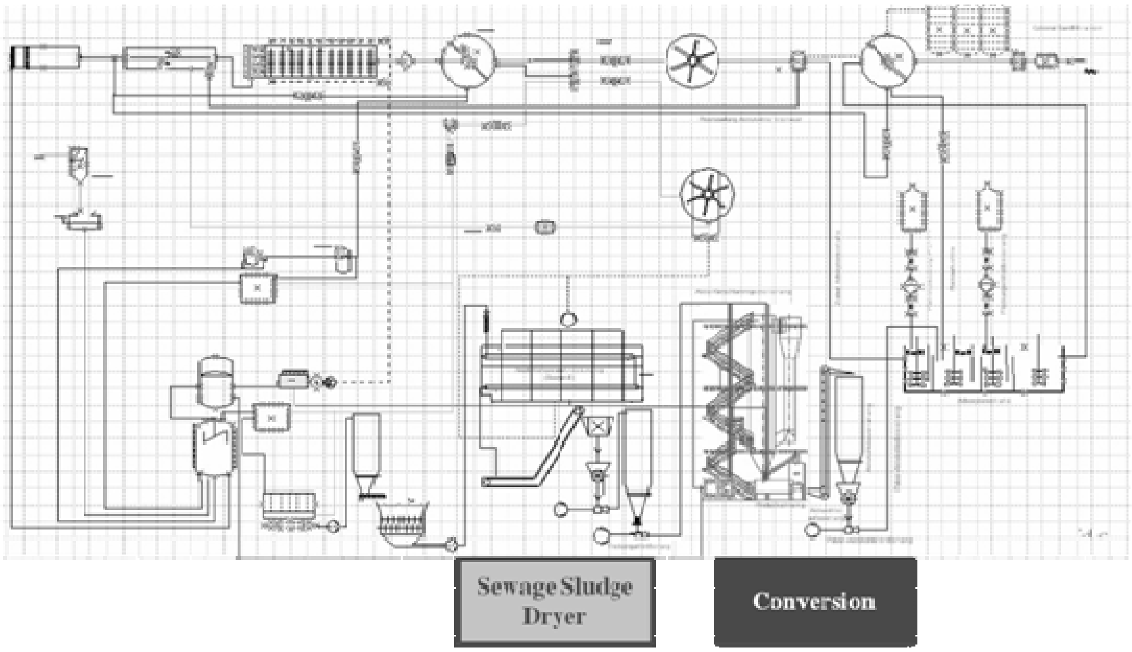

Figure 5. *Simplified flow chart for recommended sludge treatment by "NDcityline*[iaks] *"-system*

V. THE SUSTAINABLE EMBEDDING OF THE "NDCITYLINE[IAKS]"-CONCEPT

In Chapter 1, it was noted that a sustainable concept for wastewater treatment has to consider economic, ecological and social criteria. A typical tool of sustainability, study of material flows, shall offer also new opportunities to develop innovative concepts of WWT-facilities.

Few different tools of sustainability, which have published [10], can support this development. They translated the three basic topics of the intrageneration concept of sustainability (economy, ecology and social justice) into efficiency, minimizing of environmental impacts and safety of supply validated now also for non-renewable resources. These new terms implicate a further demand to recycle already used resources. For that, they transfer the model of cycle management for renewable resources "Resources - Consumption - Regrowth - Resources" into "Resources - Use - Recycling - Resource" for non-renewable resources. Furthermore, they have developed a so-called Hierarchy of Mineral Raw Materials (Fig. 6). They distinguish between use and consumption of resources. Water and metals are used, but not real consumed. After using of that these resources are again available. In opposite to the most applications of water the heating by fossil resources means a real consumption of resources. Approaching this system they have concluded, which resources are to characterize as precious raw material and which raw material shall be applied to substitute these precious resources. Waste and residues offer in this sense the highest potential as future raw material (Fig. 6). The conclusion for WWT-technologies means now, recycle your resources and use as far as possible waste and residues to create new resources in order to minimize environmental impacts and increase the efficiency of resource using. Waste and residues are available also in sufficient amount under poor and/or low budget conditions.

Following this guideline of recycling, it would be helpful to analyze the full process of wastewater "production" from the water consumer to the wastewater treatment and to evaluate the recent waste products of wastewater treatment, too (Fig. 7). The household and other water consumer in industrial, residential or agricultural areas are "producing" not only wastewater, but also solid waste. These waste "products" contain resources represented for instant by water, BOD, COD, nitrogen, phosphor, potassium and other nutrients as well as solid organic material. A non-use of such waste can cause problems of sanitations especially in rural areas. In urban areas, authorities describe also for Nam Định City a lack of acceptance of compost. In Nam Định City, a modern composting facility is operating with a processing capacity of 200 tons of domestic waste per day. A market for the produced compost material is more or less not available. An approach of this organic material before its composting would be also available now as additional material for co-fermentation. That means, the treatment of sewage, sludge and solid waste offers a series of so-called by-products (water, biogas, power, cool, heat with a temperature < 90 °C, heat with a temperature ~ 250°C, CO_2, activated coal, oil, etc.).

If industrial production sites or agricultural companies receive such by-products for its production, than this WWT-system can support the settlement of new companies creating new jobs in this region and generating new income sources for WWT-plants (Fig. 7).

Moreover, a synthesis of wastewater and solid waste management create also further options to increase the amount of possible by-products.

The presented design of water and sludge treatment (Chapter 4) is offering the mentioned series of by-products (Figs. 2, 4). The "NDcityline[iaks]"-system contains also a management concept to reduce the starting costs for investment of new sites for production, commercial or public activities in neighborhood of WWT-facility.

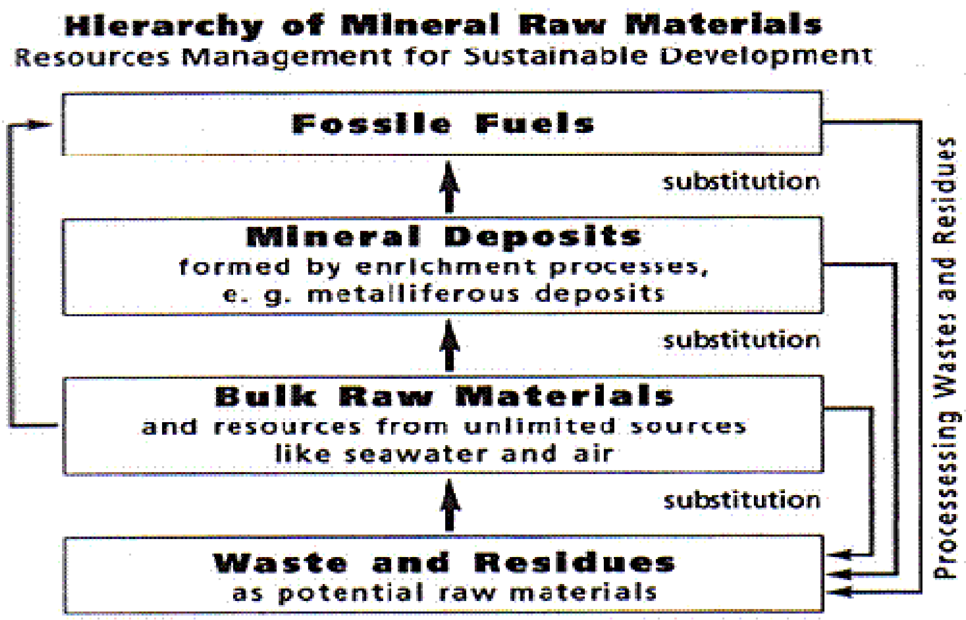

Figure 6. *Hierarchy of mineral raw material (Wellmer and Kosinowski, 2005) as approach for sustainable concepts of WWT-systems*

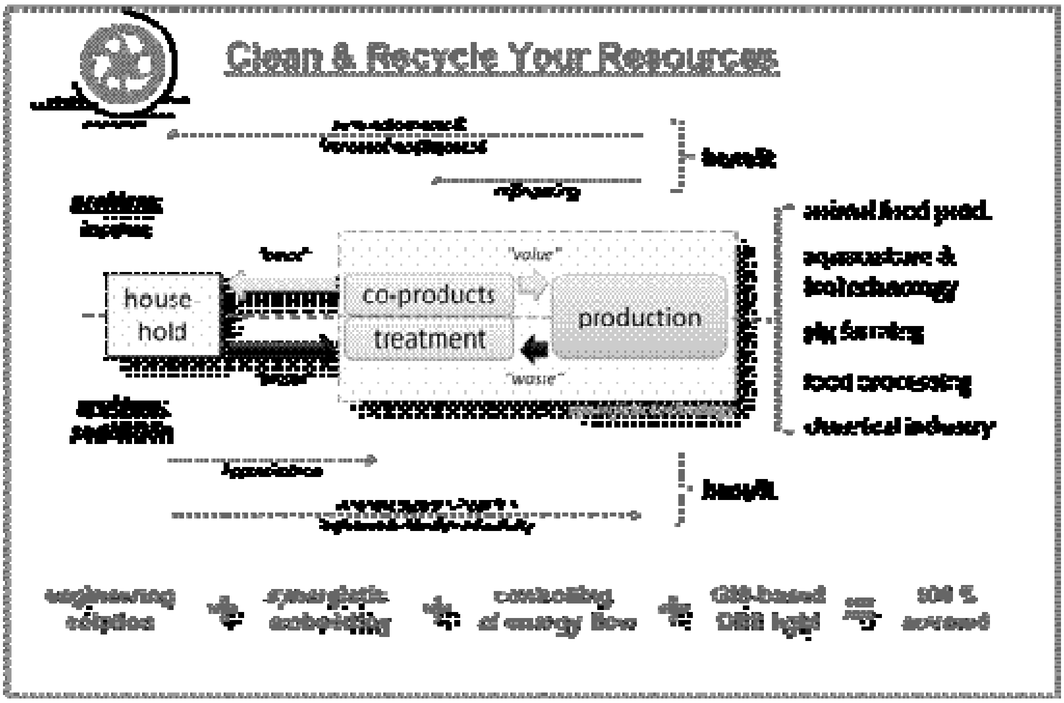

Figure 7. *Visualization of WWT-concept to generate by-products promoting settlement of new industrial production sites*

Figure 8 demonstrates the options to combine a WWT-plant with industrial productions, e.g. which are producing normally smell and dust. The ventilator system and the trickling filter as main parts of sewage treatment offer now a synergistic system to support a cleaner production for such companies by catching, cleaning an cooling of air. This solution combines the cleaning of air and a cooling of the treated air simultaneously in the trickling filter towers. On this way it is a suitable option to integrate the aeration system of trickling filter technology, which is demanded for the biological destruction of organic matter in the process of wastewater treatment, also in an air cycle management for buildings (including air condition) in neighborhood of the trickling filter towers.

The technology of trickling filter is traditionally well suitable to treat sewage mixed by domestic and industrial wastewater. This design of WWT-plant and this situation concerning the option for mixed sewage treatment offer also chances to combine the sewage treatment from domestic and industrial areas.

Another version of WWT-facility design for central urban areas is visualized in Figure 9. It is no problem to combine the WWT-facility with functions of commercial or public buildings.

Safety of supply was mentioned above as one of three topics for the intrageneration concept of sustainability for non-renewable resources. In the case, the investment costs are to reduce in comparison to other typical technologies of WWT it would be better chances available to establish new WWT-facilities and an improved water quality in rivers and lakes.

Engineers and planners for wastewater treatment facilities are using models of costs per population equivalents (PE) to estimate the expecting budget. The iaks GmbH has offered its estimation tool based on own objects in Germany between 500 … 500,000 PE. This tool includes not only the estimation for wastewater treatment, but also the costs for the channel system and for the sludge treatment. This tool represents the estimated costs for standard treatment technologies like activated sludge treatment (AS-T).

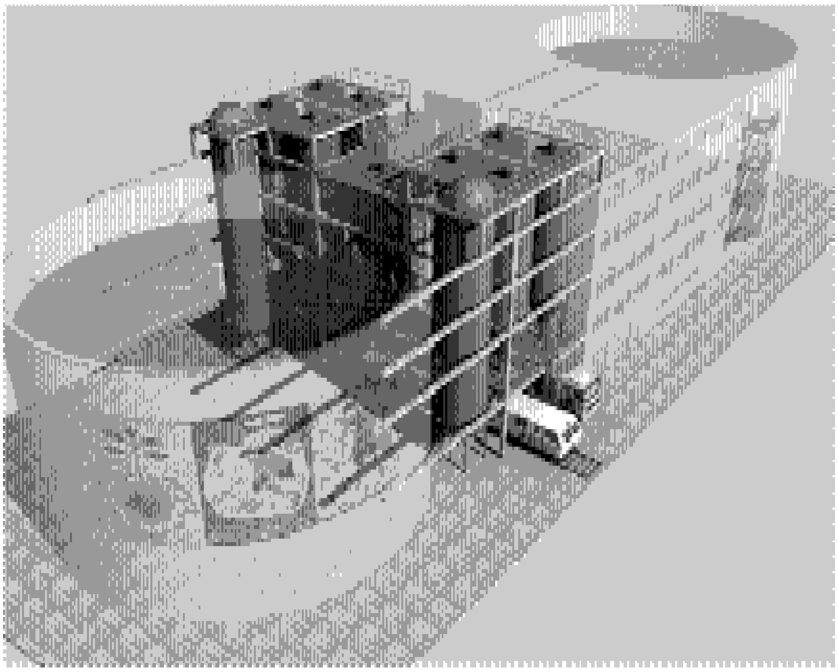

Figure 8. *Visualization for a synergistic connection between WWT-plant and industrial production site (a typical synergistic approach for industrial sites is to catch and wash polluted air caused by chemical industry, production of construction material, etc.; the already available WWT-components ventilator and trickling filter offer a perfect solutions to treat also polluted air)*

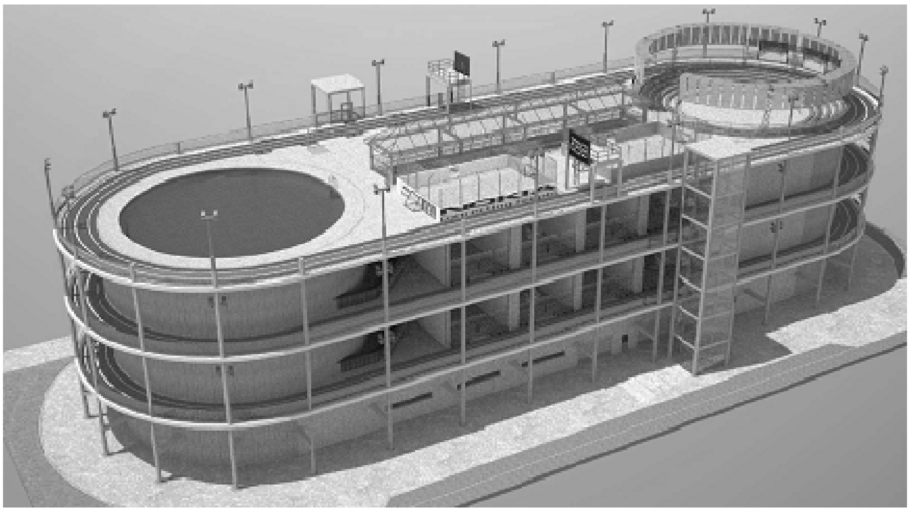

Figure 9. *Visualization for embedding of a city sport area (e.g. with public pool and open air cinema) in a wastewater treatment facility as synergistic approach also in central parts of urban areas*

Following equations are representing the iaks-database:

- ***Activated sludge technology***:

Estimated costs (€) for sewage treatment: $y = 3{,}756\ x^{0.753}$

Estimated costs (€) for sludge treatment: $y = 434.18\ x^{0.763}$ (y = costs in €; x = PE)

Estimated area for WWT-facilities: $y = 12{,}353\ \ln(x) - 92{,}105$ (y: m²; x: PE)

As example two possible planned 75,000 PE units (based on 30,000 m³/day of water supply and 0.2 m³/day and capita) have following estimated costs in European frame:

- *Activated sludge technology*:

Estimated costs for decentralized sewage treatment: ~ 40.7 million €

Estimated costs for centralized standard sludge treatment: ~ 4.1 million €

Estimated area consumption: ~ 10 ha

Estimated energy consumption: ~ 4,700 MWh per year.

For the selected example it is to explain, that 37,000 m³ of basins constructed by non-water permeable concrete are demanded to fulfill the DWA-rules for the treatment effects [1]: four PE per m³ incl. stabilization of sludge; 430 € per m³ of this special concrete mean 15.9 million €). This sum for basin construction would be already 40 % of estimated total investment.

The data basis for the modeling of trickling filter (TF) is much smaller. Using few tenders of iaks GmbH and GeoENcon Ltd. and the known costs for the running system in WWT-plant of Kempten / Bavaria (supervised by iaks GmbH) following equation is used for the estimation of costs for trickling filter technology:

- *Trickling filter technology*:

Estimated costs for sewage treatment: $y = 7{,}931\ x^{0.604}$ (y: costs in €; x: PE)

Following this equation the mentioned planned two WWT-facilities with 75,000 PE for each would be characterized for sewage treatment in trickling filter technology by 14.5 million € (that means 1/3 only in comparison to activated sludge technology).

- *Trickling filter technology*:

Estimated costs for decentralized sewage treatment: ~ 14.5 million €

Estimated costs for centralized standard sludge treatment: ~ 4.1 million €

Estimated area consumption: < 2 ha

Estimated energy consumption: ~ 3,750 MWh per year.

The costs for channel system (38 million €) and standard sludge treatment (4.1 million €) are more or less the same like for activated sludge treatment.

The area demand for trickling filter is depending from the sizes of towers and the machine hall. A rising PE-value is increasing the diameter and the heights of towers, but not the area consumption.

That is why it is allowed generally to estimate less than 1 ha for the full facility for each size.

The offered system to estimate the expected costs for WWT-facilities shows a remarkable advantage for the trickling filter technology concerning investment, operating costs and area consumption in comparison to common applied activated sludge technology.

As next step, it is to introduce in the basic strategy to refinance wastewater and sludge treatment facilities. One option to refinance the wastewater process is a so-called module "WWT & Industrial Park". Sludge treatment is discussed below separately. Like visualized in Figures 3 and 8, the "NDcityline^{iaks}"-system offers additional space for development of new production sites in direct neighborhood of trickling filter towers. The concept of by-products includes a partial re-using of treated water as process water for industrial purposes and a synergistic support for building facility management. The synergistic component "facility management" in the module "WWT & Industrial Park" contains the mentioned item "air cycling system" and a so-called item "rental offer for basic infrastructure". Figure 3 demonstrates the main idea of this item. The investment of WWT includes already first construction of parts of building and few components of infrastructure (tap water- & process water network, air cycling management network etc.). This solution reduces the starting costs for investment of new production sites. The saving for investment for an enterprise is compensated by a rental charge for production activities in this building in a volume requested for a time of 5-7 years.

First model-like calculations show that the new settled industry can cover the refinancing. The re-used water contributes with 35 % in this refinancing budget. The wastewater treatment charge for additional demanded tap water brings 30 % and the support of facility management offers 40 %.

Input data for these model-like calculations are:

- Component "Process Water":

+ 1/3 of WWT-plant capacity is re-used and treated again
+ 1/3 of WWT-plant capacity is treated because of additional demand for tap water by companies
+ Branches with a high water demand are preferred only
+ Income by "process water" is assumed with 0.07 USD/m³ for treated water (e.g. tap water costs mainly > 0.20 USD/m³) and with 0.25 USD/m³ as retreatment charge
+ Income by treatment charge because of the mentioned additional demand of tap water with 0.25 USD/m³

- Component "Facility Management":

+ Income by item "air cycling system" with 1 USD/m³ per year for cleaning building volume
+ Income by item "rental offer for basic infrastructure" with annual 40 USD/m² of production site

The refinancing concepts of sludge treatment facilities base mainly on energetic using of sludge by fouling and further conversion of residual sludge after the fouling process (Fig. 2). The mentioned by-products originated by sludge treatment can cover the own energy demand of treatment facility and support e.g. food processing industry by offering heat and cool. The special focus to food industry creates also options to improve the income situation in agriculture of Nam Định province. The problem is that the sludge amount from sewage treatment is not sufficient to cover the investment costs for the sludge treatment. The principle "co-fermentation" as part of fouling technology offers the tool to solve this situation. A strictly linked wastewater and solid waste management guarantees the additional amount of biomass from solid domestic waste. The model-like calculations of available energetic capacity of sludge and solid domestic waste used the GIS-planning tool "WWT in industrial zones" [5] and the simulation tool "biogas" developed by Fraunhofer Institute. The simulation tool "biogas" considers also the production of cool (C), heat (H) and electrical power (P) by CHP-co-generation. The typical efficiency of CHP-co-generation is commonly 85 %. In addition, this tool integrates costs for investment of CHP-aggregates, its typical operating time and different ratios for production of co-generated electricity and heat. Typical input data for sludge are 1 kg of sludge (related to dried mass) bring about 430 l of biogas and 1 kg of domestic waste (without ash, related to dried mass) have equivalents of 280 l of biogas (see also: [1]). The sludge from trickling filter is to estimate with 25 g per (PE * d) with 70 % of organic matter [1]. That means the above-introduced example for WWT-plant with total capacity of 150,000 PE causes sludge of 3.75 t per day [25 g * 150,000 PE = 3.75 t] or 1,100 m³ of biogas per day [25 g * 70 % * 150,000 PE * 430 l / 1,000,000 =

1,100 m³]. Involving the domestic waste of Nam Định City (100 t/d), with recently not used organic matter of waste, additional biogas result is here about 12,000 m^3 per day. Fouling and the further conversion process of sludge and solid domestic waste offer together an energy capacity of 40,000 MWh per year. Using Diesel fuel as equivalents, this energy capacity of about 40,000 MWh per year represents 2.9 million USD. This sum may cover an investment of about 20 million USD for sludge treatment.

Those model-like calculations offer only a generalized view to few key values supporting a further planning process and cannot substitute any later detailed engineering processing.

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