This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730285

Project Partners: 1. AQUALIA 2. DESAH 3. SLU 4. LEAF BV 5. LEITAT 6. NSVA 7. USC 8. WE&B 9. WU 10. ZFV 11. JETS 12. ISLE 13. CEIP 14. 4F 15. ASB	**RECOVERY AND UTILIZATION OF NUTRIENTS 4 LOW IMPACT FERTILIZER** H2020-CIRC-2016TwoStage Collaborative project Start date of the project: 01/06/2017 Duration 48 months **D5.1** **Risk and sustainability assessment**

WP	5	Risk and Life Cycle Assessment

Dissemination level[1]	PU
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V.1	16/04/2018	Prof. Moreira	USC	maite.moreira@usc.es	Creation
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[1] Dissemination level: **PU** = Public, **PP** = Restricted to other programme participants (including the JU), **RE** = Restricted to a group specified by the consortium (including the JU), **CO** = Confidential, only for members of the consortium (including the JU)

[2] Nature of the deliverable: **R** = Report, **P** = Prototype, **D** = Demonstrator, **O** = Other

[3] Creation, modification, final version for evaluation, revised version following evaluation, final

List of acronyms and abbreviations

1,4-DB:	1,4-dichlorobenzene
AMR	Antimicrobial resistance
AnMBR:	Anaerobic membrane bioreactor
DALY:	Disability-Adjusted Life Years
BES:	Bioelectrochemical system
BW:	Black water
CFC-11:	Trichlorofluoromethane
FU:	Functional unit
GHG:	Greenhouse gases
GW:	Grey water
HACCP	Hazard analysis critical control points
HHRA	Human health risk assessment
HTAD:	Hyper-termophilic anaerobic digestion
KW:	Kitchen waste
LCA:	Life Cycle Assessment
LCI:	Life Cycle Inventory
LCIA:	Life Cycle Impact Assessment
MBR:	Membrane bioreactor
NMVOC:	Non-methane volatile organic compounds
QMRA:	Quantitative microbial risk assessment
SLU:	Swedish University of Agricultural Sciences
UASB:	Up-flow anaerobic sludge blanket
USC:	University of Santiago de Compostela
UV-B:	Ultraviolet B
WE&B:	Water, Environment & Business for Development
WWTP:	Wastewater treatment plant
YLD:	Years lived with disease
YLL:	Years of lost life

Table of contents

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730285.

Figures

Tables

1. Introduction

1.1 The Run4Life project

Run4Life embraces the concept of circular economy by recovering nutrients and reclaimed water from decentralized wastewater treatment technologies. With the intention of radically changing the outdated "end of pipe" concept, Run4Life aims at developing smart and innovative technologies to improve the recovery of nutrients from domestic wastewater with a decentralized approach (Figure 1).

This will be achieved through the segregation of concentrated products as black water (BW), kitchen waste (KW) and grey water (GW). The technological innovations in Run4Life also include: i) low water flushing vacuum system for toilets, ii) separation of BW and KW, iii) hyper-thermophilic anaerobic digestion (HTAD) and iv) nutrient recovery strategies such as bio-electrochemical systems (BES). The integration of these technologies in decentralized domestic wastewater treatment plants (WWTP) will allow the potential recovery of 100% of nutrients (NPK) as hygienically safe fertilizers and, at the same time, achieve more than 90% of water reuse within an integral recycling concept aligned with the circular economy.

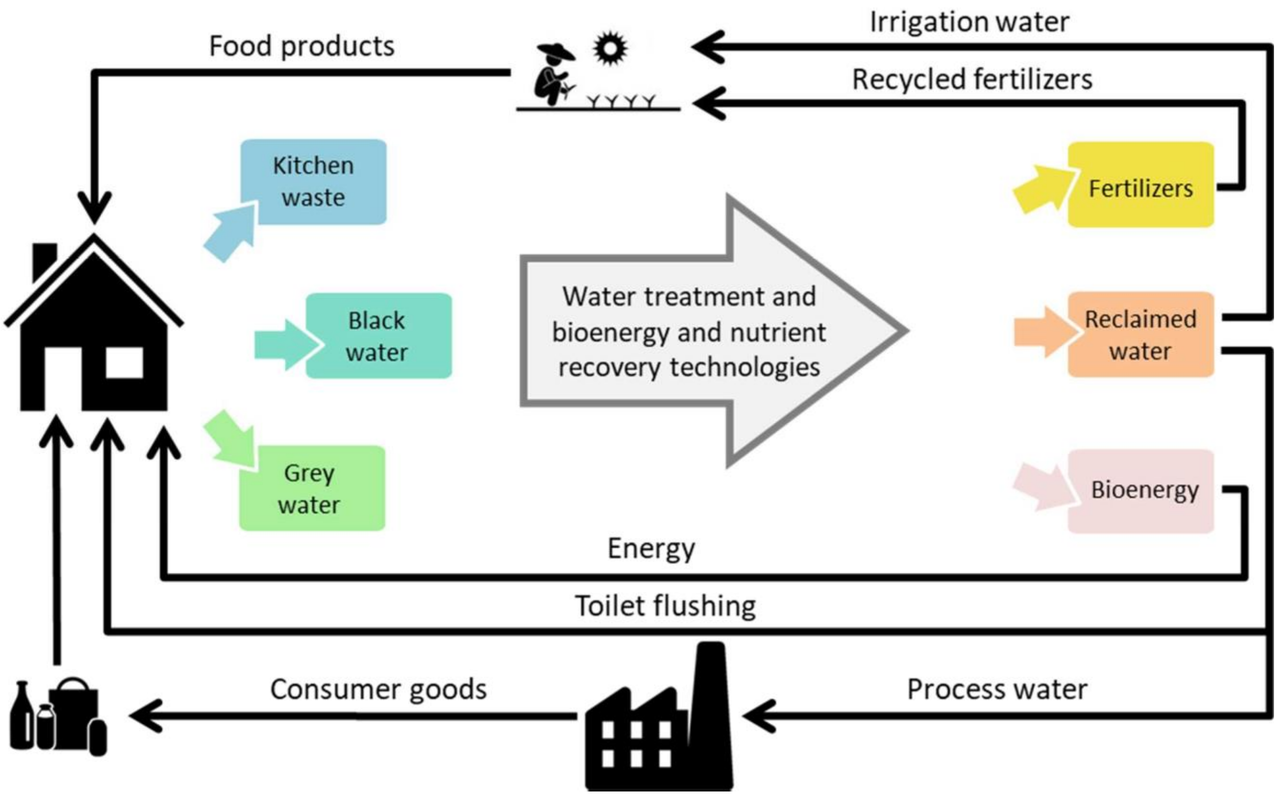

Figure 1. Basic flow scheme of the Run4Life concept

1.2 The demonstration sites

The technical feasibility of this innovative treatment process proposed in the project will be evaluated at four different demonstration sites. The selected demonstration sites are Sneek (The Netherlands), Vigo (Spain), Ghent (Belgium) and Helsingborg (Sweden), as shown in Figure 2.

- In **Sneek**, liquid and solid NPK fertilizers will be produced in 32 houses using HTAD as a single-stage process for the production of fertilizer from concentrated BW coming from ultra-low water flushing vacuum toilets.

- In **Vigo**, added value fertilizers such as struvite and ammonium nitrate will be obtained by integrating struvite precipitation and BES for the effluent of 3 office buildings. Anaerobic membrane reactor (AnMBR) technology is used for the treatment of black water in the office building equipped with black and grey water segregation. Greywater treatment and reuse is promoted for water save.

- In **Ghent**, struvite will be recovered from more than 400 houses. The treatment system will include anaerobic treatment of BW and KW in an Upflow Anaerobic Sludge Bed (UASB) reactor. After struvite precipitation the UASB-effluent is treated together with the separately collected GW in an aerobic membrane reactor (AnMBR) system.

- In **Helsingborg**, separate processing of BW and KW from 320 apartments will produce struvite and ammonium sulphate, which will be mixed in different proportions with hygienized sludge from KW digestion to obtain tailor-made fertilizers.

The proposed treatment scheme and therefore the fertilizers obtained will be different at each of the selected demonstration sites in order to meet the specific needs of the end-users in each country. Table 1 summarizes the key savings and recovery of resources, including water, fertilizer and bioenergy, expected at the Run4Life demonstration sites.

Table 1. Expected savings and resource recovery at each of the demonstration sites

Saving and recovering of resources	Ghent	Vigo	Helsingborg	Sneek
Water saving	35%	100%	35%	95%
Water reuse	>90%	75	0	0
NPK recovery	>3,5% - >78% - 0% (BW)	34-40-53 (BW)	78%-82%-0% (BW & KW)	90-63-90 (BW & KW)
Biogas production	10 - 13 Nm^3/ pe·year	10 Nm^3/pe·year	13 Nm^3 CH_4/pe·year	8 Nm^3/pe·year
Heat recovery	>600 kWh/ pe·year	-	300 kWh/pe·year	-

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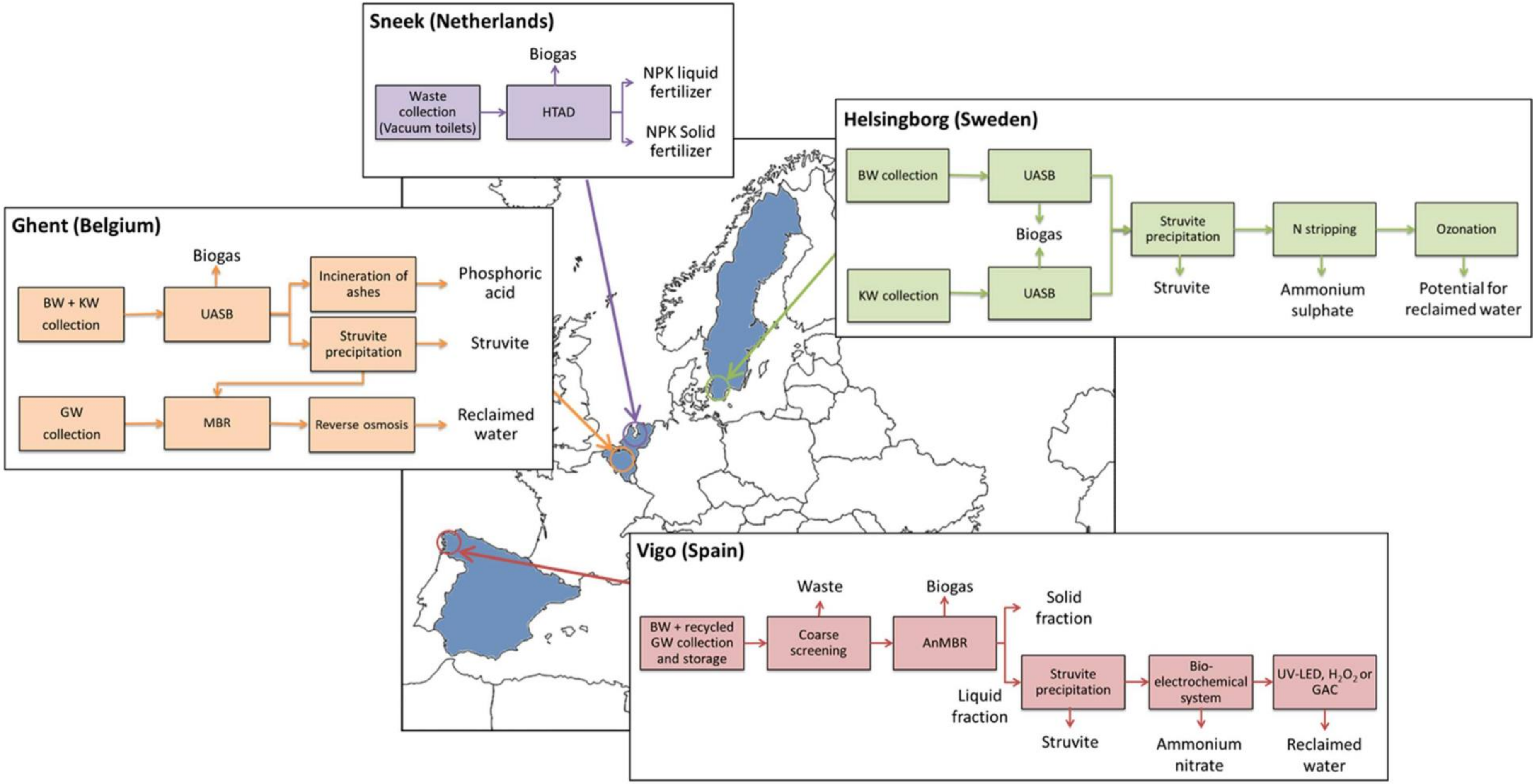

Figure 2. Location of the Run4Life demo-sites. Acronyms: AnMBR – Anaerobic Membrane; BES – Bioelectrochemical Systems; BW – Black water; GW – Grey Water; HTAD – Hyper-Termophilic Anaerobic Digestion; KW – kitchen waste; MBR – Membrane; UASB – Up-flow anaerobic sludge blanket

1.3 The expected results

These Run4LIFE goals will be useful to achieve the three fundamental principles of a circular economy (The Ellen MacArthur Foundation, 2012):

- **Principle 1:** "Preserve and enhance natural capital by controlling finite stocks and balancing the flows of renewable resources."
- **Principle 2:** "Optimize resource yields by circulating products, components and materials at the highest utility at all times in both technical and biological cycles."
- **Principle 3:** "Foster system effectiveness by revealing and designing out negative externalities."

The expected results from the Run4Life project are the following:

1. Decrease dependence on primary nutrient resources and increase European supply security.
2. Reduce the adverse effects of nutrient emissions on the environment.
3. Closing water and nutrient cycles throughout the production and consumption value chain.
4. Improve the quality of data on nutrient flows to support investments in the recycling of recovered nutrients.
5. Create new business opportunities in the EU, to generate new green jobs and export industries around the recovery and recycling of nutrients, contributing to the exploitation of innovative solutions in the global market.
6. Improve policy and market conditions in Europe for large-scale deployment of innovation, providing evidence-based knowledge on the framework conditions that facilitate a wider transition to a Circular Economy in the EU.

Within the objectives of the project, it is essential to ensure that the treatment systems developed by Run4Life, as well as the products obtained, are safe and reliable to use, environmentally friendly, socially accepted and techno-economically viable. Work Package 5 (WP5) "Risk and Life Cycle Assessment" aims to ensure that the treatment and recovery systems developed and the products obtained are safe and reliable for use, as well as environmentally, socially and economically sustainable.

The risk and sustainability assessment of the different technologies and approaches will be carried out in an integrated manner and taking into account the entire life cycle of Run4Life. Therefore, the aim of this Sustainability Management Roadmap and Guide is to map all the criteria needed to deliver a safe and reliable product to the market. It describes the different sustainability assessment criteria, environmental and socio-economic indicators, as well as environmental and health risks. The Sustainability Roadmap is an important implementation tool that defines the pathways that Run4Life will take to achieve its objectives. This Guide and Roadmap for Sustainability Management is part of Task T.5.1 "Definition of the integrated risk and sustainability plan for the Run4Life project", led by the University of Santiago de Compostela (USC) and integrated by the Swedish University of Agricultural Sciences (SLU) and Water, Environment & Business for Development (WE&B).

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2. Risk and Sustainability assessment

ENVIRONMENTAL	The project aims to improve wastewater management to ensure environment preservation and optimal consumption of natural resources, energy and water. For the analysis of the environmental consequences of the project, the Life Cycle Assessment will be the methodology selected. The burdens from all life-cycle stages will be assessed based on reliable information gathered from the operation of the different sites. The project expects to reduce nutrients emitted to water and soil (N and P), minimize water consumption, decrease chemicals used for wastewater treatment and produced bioenergy from biogas.
SOCIO-ECONOMIC	The socio-economic performance of the project is fundamental to ensure the sustainability of innovative wastewater technologies. Different assessment methodologies will be applied in this case, including: i) Assessment of Social Risk Perception in order to identify main facilitators, barriers and opportunities for the technology from the social side for each demonstration site, ii) Benefit Cost Analysis and iiI) Strengths, weaknesses, opportunities. The project will create new business opportunities in the EU, contributing to the exploitation of EU innovative solutions in the global market.
HUMAN HEALTH	To adequate market uptake of the new products recovered in the project it is essential to ensure their innocuousness for humans and environment and that they can be used in completely safety conditions. For assessment of human health risks, the project will evaluate risks related to the production as well as use of solid and liquid fertilizers and reclaimed water obtained for both chemical and microbiological hazards. The assessment will be based on the analytical data on the levels of residual contaminants and microorganisms using HHRA methodology as e.g. QMRA. The project will enable optimization of management of health hazards in waste streams and minimize environmental dissemination.

2.1 Selection of risk and sustainability indicators

Wastewater management is a complex phenomenon with several environmental, social and economic consequences. Assessing the sustainability of wastewater management systems is a very complex issue, as it must include environmental assessment, economic viability and social acceptability. Furthermore, it also depends on the selection of the most appropriate valorisation scheme for each particular case, taking into account all the specific areas in which a wastewater management system is to be implemented.

One possibility for evaluating the sustainability performance of these systems is through careful monitoring of different indicators that show the specific performance of the systems in terms of different dimensions of sustainability. According to Alex Farrell and Maureen Hart (2010), an indicator is "something that helps you understand where you are, where you are going and how far you are from where you want to be". More specifically, the construction of sustainability indicators for a wastewater management approach should consider demonstrating progress (or lack thereof) towards achieving the strategic objectives. In recent years, Responsible Research and Innovation (RRI) has become increasingly important as a practice that ensures that stakeholders work together throughout the research project to ensure that both the development of the project and its results are aligned with the values, needs and expectations of European society (European Commission, 2015). Indicators have been defined to promote and monitor Responsible Research and Innovation (RRI). Within this framework, a specific set of sustainability indicators is currently being developed to assess and monitor these innovative systems. These indicators will ensure that RRI requirements are met and that these systems contribute to inclusive and sustainable growth (European Commission, 2015). They should include several requirements, among them: (i) monitoring of stocks (renewable and non-renewable resources); (ii) monitoring of flows (consumption and regeneration of stocks); mapping and monitoring of interactions between flows and stocks; (iii) mapping of fund elements (labour and technology) and how influence interactions between flows and stocks; (iv) monitoring of ecosystem services and their effect on human well-being (European Commission, 2015).

To find the right set of sustainability indicators to help identify the actions needed to achieve the objectives on the road to a circular and sustainable economy, it is essential to understand the characteristics of the product or service under study. In this case, the environmental, socioeconomic and health risk indicators cannot be segregated into different segments, but analysed in an interconnected manner, since they are the cause and/or effect of their interactions. To this end, the data collected in WP3, which involves the monitoring of demonstration plants, as well as in WP4, which carries out the characterization of the products, is the basis for the evaluation of sustainability indicators. In addition, socio-economic indicators will be collected in close cooperation with technical partners, including comments and inputs from WP2, i.e., technology development. Human health indicators are also defined to monitor the safety of Run4life technologies and the resulting products. Sustainability indicators can be different and/or adapted according to the specification, needs and reality of each demonstration site. The identification of beneficial uses and values to be protected will be carried out through consultation with all relevant stakeholders and consideration of local and national strategies and policies for resource management and environmental protection. In addition, it will guide the report in the designation of indicators of risk to human health. Beneficial uses refer "to a reasonable quantity of water applied to a non-wasteful use", e.g. domestic, livestock watering, industrial, agricultural irrigation, etc. The main sustainability indicators are summarized in Table 2.

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Table 2. List of sustainability indicators for Run4life

Dimension	Indicators	
Environmental	1. Direct and indirect energy flows 2. Resources consumption 3. Solid waste production and management 4. Water use 5. Direct and indirect GHG 6. Nutrient discharge	7. Climate change 8. Potential eutrophication 9. Human toxicity 10. Ecotoxicity 11. Damage to human health 12. Damage to ecosystem diversity
Socio-economic	1. Food production in agricultural lands using Run4Life nutrients 2. Household water expenses 3. Decentralized treatment cost/energy cost 4. Revenue generation for SME nutrient fertilizer companies 5. Occupation and training on nutrient recovery technology and water reuse	6. Research and Development activities 7. Participation in the Run4Life community meetings 8. Noise 9. Odour 10. Aesthetics 11. Circular economy and/or nutrient recovery policies
Human Health	1. Chemical risks 2. Microbial risk 3. Fertilizer /Irrigation water quality	4. Food/crop quality from agriculture using Run4Life products 5. Recreational water quality 6. Drinking water quality

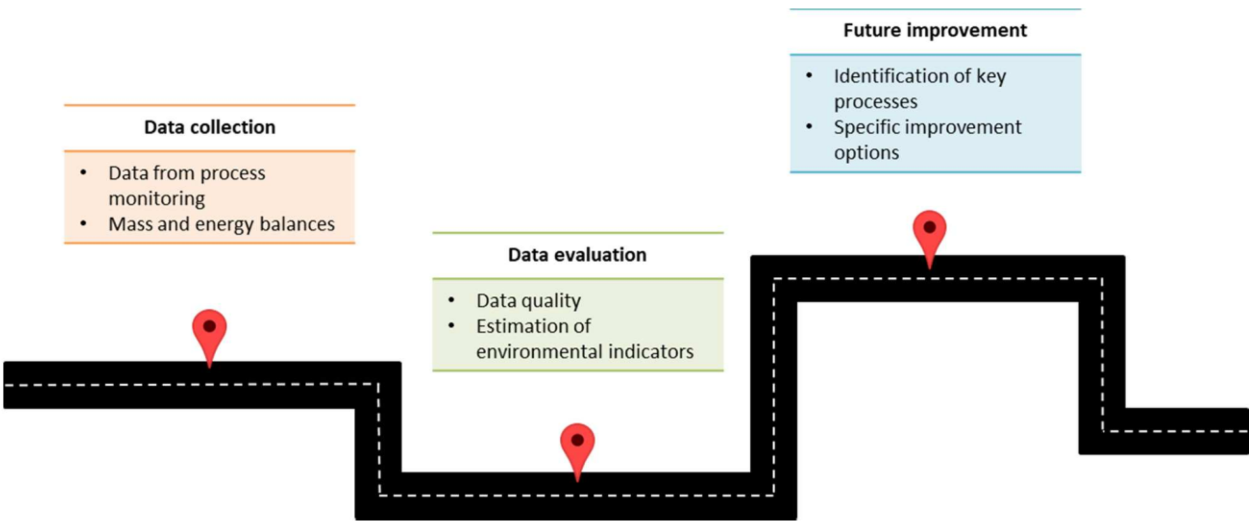
3. Environmental assessment

Environmental assessment planning includes three main steps:

i) **Data collection** – Detailed monitoring data will be collected from each demonstration site. This information will include the main inputs (such as consumption of electricity, heat, fuels, chemicals, water and building materials, as well as transport needs) and the main outputs (including outputs and co-products obtained, waste streams generated and their management, as well as emissions to water, air and soil). With this detailed information, modelling will be performed through the development of mass and energy balances for each treatment scheme evaluated within the project.

ii) **Data evaluation** – The quality of the data obtained at the previous stage will be evaluated to ensure the reliability of the results obtained for each of the environmental indicators under study. Where necessary, these inventory data will be transformed into environmental impacts in order to quantify the environmental indicators that are calculated as impact categories. For this purpose, characterization factors at mid-point and end-point level will be used. In this way, all the environmental indicators previously selected for each of the treatment schemes tested at the demonstration sites will be quantified.

iii) **Future improvement** – Once these environmental indicators have been quantified, it will be possible to identify the most environmentally relevant processes, including both beneficial processes and environmental hotspots, i.e. processes involving the greatest environmental impacts. With this information, it will be possible to provide specific improvement options that will help to further improve the environmental performance of the wastewater management options being evaluated.



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3.1 Environmental indicators

The environmental indicators used to monitor the sustainability of the treatment schemes proposed in the project can be divided into i) indicators that explain the environmental aspects that should be considered and ii) indicators such as impact categories of the LCA methodology that show the environmental performance of the project, including all stages of the life cycle. The quantitative value of these environmental indicators will be expressed by means of a functional unit (FU). This FU will be selected during the environmental assessment, but may be, for example, the volume of waste water managed (m^3 of wastewater managed) or the amount of nutrients recovered (kg of fertilizers recovered).

3.1.1 Environmental aspects to be considered

The environmental evaluation of the complex wastewater valorisation systems that are included in the Run4Life project should involve several environmental aspects and complex interrelations among elements. The most important environmental aspects to have into account in the Run4Life project to perform a reliable evaluation are:

- **Direct and indirect energy flows**

Energy flows should be identified since energy consumption is one of the major hotspots in the environmental assessment of conventional wastewater management. The Run4Life project will help to improve the energy performance of wastewater treatment by decreasing the demand of energy intensive processes. It is also expected that some of the treatment schemes will be able to recover bioenergy from the production of biogas generated from wastewater. In more detail, biogas will be produced in the HTAD that will be installed in Sneek, in the UASB that will be operating in Helsingborg and in the AnMBR that will be working in Ghent.

The production of mineral-based fertilizers is known to be highly energy-demand processes. More in detail, the production of these nitrogen fertilizers is responsible for 2% of the energy consumption in an industrialized society. In Europe, there is a considerable use of nitrogen-based fertilizers, such as ammonium nitrate (21%) and calcium nitrate (26%), which are produced with the Haber-Bosch process. This method entails the consumption of more than 10 kWh of energy for each tone of ammonia produced (Fertilizers Europe, 2012; Vaneeckhaute et al., 2013). Therefore, in addition to the reduced energy consumption for wastewater treatment, the Run4Life project will indirectly help to decrease the need of producing these energy-depending processes by recovering fertilizers from domestic wastewater.

In conclusion, this environmental indicator will include three main factors: i) the energy consumed in each treatment scheme, ii) the energy recovered from biogas production and iii) the energy saved due to the avoided production of mineral fertilizers. This indicator will be measured as net energy balance of these three factors, i.e. the difference between energy use and energy recovery and savings per FU.

Reduced net energy consumption

Run4Life will avoid inefficient energy consumption in conventional WWT.
HTAD of concentrated BW will allow safe NPK fertilizer recovering in a one-step net energy producing process.

Energy savings from the recovery of fertilizers

Energy savings will come from avoided mineral fertilizers production due to the recovery of NPK fertilizers from wastewater within the different treatment schemes of the project.

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- **Resources consumption**

In conventional wastewater treatment, nutrients are removed from wastewater to comply with legislation, which usually implies high energy consumption. In the Run4Life system, the waste streams (BW, KW and GW) separately collected and treated due to their different properties. This is done aiming to facilitate and systematically improve the management of resource recovery from them. Fertilizers production from the recovery of nutrients in the Run4Life project will lead to the reduction of resource consumption for mineral fertilizers production, which is an essential step for achieving a circular economy.

Resource recovery

Nutrients released in the wastewater in Europe: 4.5 kg N + 1.5 kg P + 1.4 kg K per person and year. Wastewater from 30 people could be used to fertilize about 7 t of wheat. Run4Life will recover nutrients from around 3000 people, corresponding to 13.5 t N and 4.5 t P per year.

Resource efficiency

NPK solid and liquid fertilizers will retain up to 100% of the micronutrients (e.g. Al, Ca, Cr, etc.) present in BW and KW after anaerobic digestion. In Vigo, for instance, an AnMBR will replace the current aerobic membrane.

- **Solid waste production and management**

This environmental indicator accounts for the production of solid waste generation through the treatment processes compared with the solid waste generated during conventional wastewater treatment. Therefore, it will be measured as mass of waste generated and managed per FU (kg waste/FU).

- **Water use**

Water use is an important feature when it comes to wastewater treatment, since the domestic sewage comprises approximately 99% water (Sperling, 2008). In most cases, water resources come from surface and/or groundwater sources. It is not only considered the amount of water used, but also the amount of water recovered in the Run4Life systems, including direct savings, indirect savings and reclaimed water. Reclaimed water will be obtained as a final product in Ghent and Vigo demonstration sites. Besides, potential reclaimed water can be produced from Helsingborg configuration. It is important to highlight that the relevance of impacts on water use and reuse will depend on the specification of each location, for example, if it suffers of water stress or scarcity.

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Direct savings

Ultra-low water flushing vacuum toilets:

(2 L/person·d)

Reduction water consumption by 95% compared to flushing toilets.

Indirect savings

Water use for chemicals production will be avoided:

Decrease the use of chemicals (80-100 %) used to remove nutrients.

Reclaimed water

Reclaimed water can be used for agriculture/ industry/ toilets, including recovery of 90% water from GW and 50% from BW.

- **Direct and indirect greenhouse gases**

Over the past 150 years, greenhouse gas (GHG) emissions into the atmosphere are mainly caused by human activities. Energy production processes are related to the emissions to the atmosphere of these kind of substances, mainly due to the use of non-renewable energy sources. Conventional wastewater treatment is well known for their low energy efficiency; moreover, they are also a source of direct GHG emissions such as nitrogen oxide (N_2O) from, for example, the biological reactor. On the other hand, the production of fertilizers from wastewater will avoid GHG emission related to the production and transport of mineral fertilizers, which require significant amounts of fossil energy. The production of reactive ammonium (NH_4) through atmospheric nitrogen gas corresponds to a non-renewable energy consumption of 10 to 15 kWh/kg. This accounts for 2% of the world's fossil fuel, which releases a high quantity of GHG because of the use of natural gas (Sutton et al., 2013).

Avoided greenhouse gas emissions

Estimated to be around 90 kg CO_2 per person and year, preventing around 1-4% of CO_2 emissions per person equivalent.

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- **Nutrient discharge**

Conventional wastewater treatment is a source of emissions to air and water of nitrogen and phosphorus compounds. Levels of nutrient emissions released from WWTPs will depend on each plant, according to its design and operation characteristics. However, high nutrient removal efficiency may mean lower emissions of nutrients to water but higher to the atmosphere. Emissions of these nitrogen compounds can have diverse effects on air quality (for example, increased human morbidity and mortality by exposure to NO_x and NH_3 emissions); while nitrogen and phosphorus emissions discharged to water can have diverse effects on aquatic ecosystems, including marine and freshwater eutrophication.

In Run4Life, it is expected the recovery of 100% for nutrient and 90% of water, as presented in Table 1. Therefore, it will greatly reduce the nutrient load discharged directly into the environment. This will be performed though the implementation and testing of innovative technologies in the demonstration sites. The different waste streams, after anaerobic digestion, will be separated into solid and liquid compounds. The liquid part will pass through a nutrient recovery process, to obtain ammonium sulphate, ammonium nitrate, struvite, phosphoric and liquid NPK fertilizers for agriculture, whereas the solid part is used for solid NPK fertilizers for agriculture. For example, struvite and ammonium sulphate will be recovered through struvite precipitation and nitrogen stripping in Helsingborg. Moreover, struvite and ammonium nitrate will be also recovered from struvite precipitation and BES in Vigo.

Nutrient recovery technologies

Run4Life includes innovations such as HTAD and BES, which will avoid 100% of nitric oxide (NO) and nitrous oxide (N_2O) emissions into the atmosphere, compounds which are generated in traditional nitrification/de-nitrification processes.

Liquid and solid outputs

It is essential to analyze and monitor the quality of the liquid and solid outputs, e.g. BOD, COD, TSS, pH, nitrogen (N), phosphorus (P), heavy metals, etc. Moreover, the quality of the effluent discharged will be assessed considering local regulations/quality standards.

3.1.2 Environmental impact categories

There are many tools available for assessment of environmental impact, of which one of the most commonly used is Life Cycle Assessment (LCA). This methodology helps expanding the perspective beyond the waste management system by a systematic approach where the function and the boundaries of the system should be carefully defined. This fact is especially important in environmental assessment of waste management systems since their environmental performance often depends more on indirect impacts produced on surrounding systems than on direct emissions from foreground system (Ekvall et al., 2007). It allows the implementation of improvements options, considering upstream and downstream environmental consequences of these decisions, allowing the avoidance of shifting environmental burdens from one environmental concern to another, from one country to another or from one stage to another in a product's life cycle (Hauschild et al., 2011).

There are currently two international standards that regulates the implementation of the LCA methodology, the ISO 14040 and 14044. These standards facilitate the consolidation of procedures and methods of LCA, helping to contribute to the general acceptance of LCA by all stakeholders and the international community. In the first place, the ISO 14040 (2006) provides an overview of the methodology, including applications and limitations of LCA studies. Accordingly, LCA can contribute in identifying opportunities to improve the environmental performance of products and processes, informing decision-makers in industry and governments and marketing, including eco-labelling and environmental product declaration). Moreover, ISO 14044 (2006) provides guidelines for data collection and validation as well as for the impact assessment phase. ISO 14040 and 14044 established four general phases that are required for the completion of an LCA study. The stages of an LCA study are schematically represented in Figure 3, and include i) Goal and scope definition, ii) Life cycle inventory (LCI), iii) Life cycle impact assessment (LCIA) and iv) Interpretation.

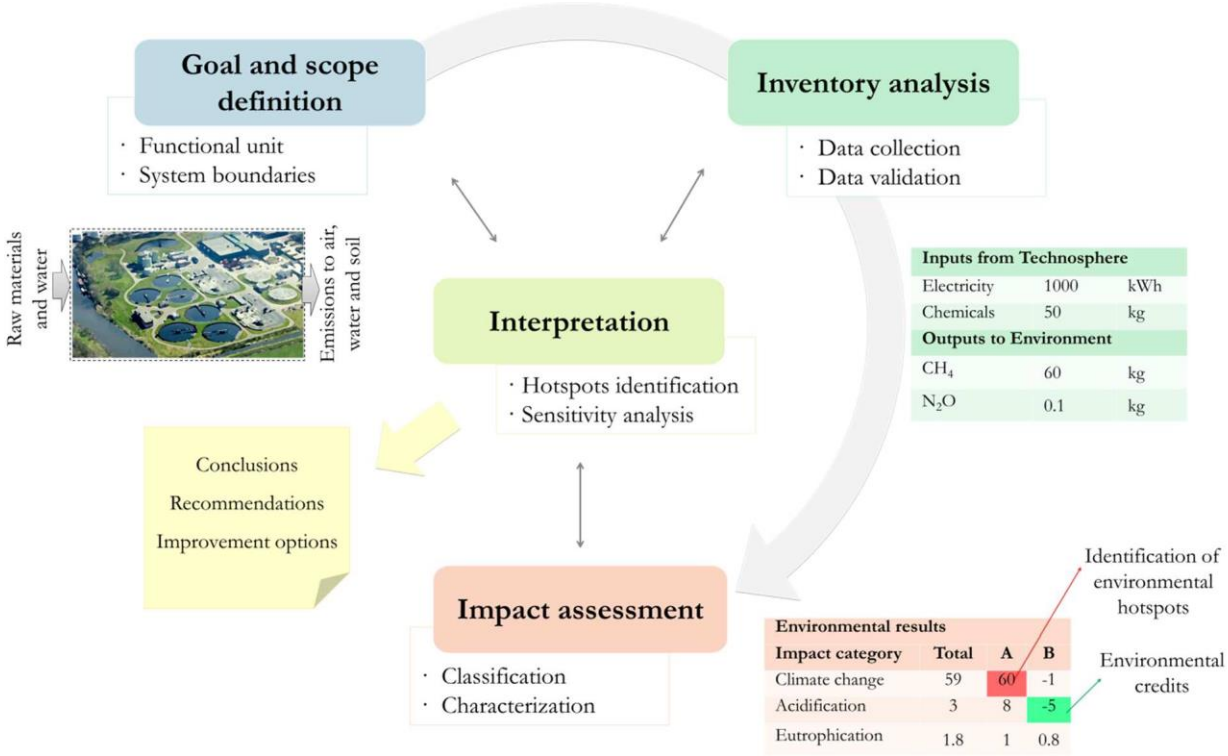

Figure 3. Methodological steps in LCA studies

- **Goal and scope definition –** It describes the goal and purpose of the study, as well as the scope concerning system boundaries, functional unit (FU) and flowchart, required data quality, technology and assessment parameters. The definition of the FU is the special importance in LCA since it expresses the principal function of the system in quantitative terms and provides the reference to which all the inputs and outputs of the system are calculated.
- **Life Cycle Inventory** (LCI) – This stage includes the collection of input data (resources and intermediate products) and output data (emissions, wastes) for all the processes identified within the system boundaries defined.
- **Life Cycle Impact Assessment** (LCIA) – In this LCA phase, inventory data concerning inputs and outputs are translated into impact categories, which can be seen as indicators referring the potential impacts that the system can produce on the environment, on human health, and on the availability of natural resources.
- **Interpretation** – It is the phase where the results of the LCIA are interpreted according to the goal and scope defined and where a sensitivity analysis is performed to verify the strength of the results obtained previously.

During the development of the LCA, important information showing the environmental performance of these systems is gathered during the LCI phase. Moreover, the impact calculated for each impact category calculated according to the different methodologies available can also be considered as environmental indicators. The environmental impacts produced can be measured at midpoint and endpoint level, which differ in the stages along the cause-effect chain where they calculate the impact. Midpoint categories reflect the environmental impacts produced at some point between the environmental stressors (origin of the impact) and the final of the cause-effect chain. Endpoint categories reflect the environmental impact produced at the end of the cause-effect chain. There are three main endpoint categories including damage to human health, damage to ecosystems and damage to resources (Huijbregts, 2016). Damage to human health is measured in Disability-Adjusted Life Years (DALY), which represent the years that are lost or that a person is disabled for due to a disease or accident. On the other hand, damage to ecosystems quality is local species loss over time (species year). Finally, resource scarcity is measured in dollar ($) which represents the extra costs involved for future mineral and fossil resource extraction. The proposed life-cycle environmental indicators enumerated in the section above will map the environmental performance of the four demo-sites.

- **Climate change**

Climate change is defined as the impact of human GHG emissions on the radiative forcing (i.e. heat radiation absorption) of the atmosphere (Guineé et al., 2002). GHG accumulate in the atmosphere and alter Earth's energy balance. Therefore, this environmental indicator takes into account the amount of direct and indirect GHG emissions associated with a system, considering the entire life cycle. Carbon dioxide has been set up as a reference gas to measure the emissions of different greenhouse gases based on their climate change potential. From a midpoint perspective, the aim of this environmental indicator is to measure the contribution to climate change potential from each demo-site. In more detail, wastewater management results in emissions of three main greenhouse gases: carbon dioxide, methane and nitrous oxide. Therefore, this indicator measures the amount of carbon dioxide equivalent emitted from wastewater management systems, which includes all the GHG directly or indirectly emitted from the system (measured in kg CO_2 equivalent/FU). Moreover, an emission of a GHG will lead to an increase of their atmospheric concentration, increasing the radioactive forcing capacity and, therefore, leading to an increase in the global mean temperature (Huijbregts, 2016). From an endpoint perspective, it can also quantify the damage to human health and to ecosystems quality produced by this increased temperature (Figure 4).

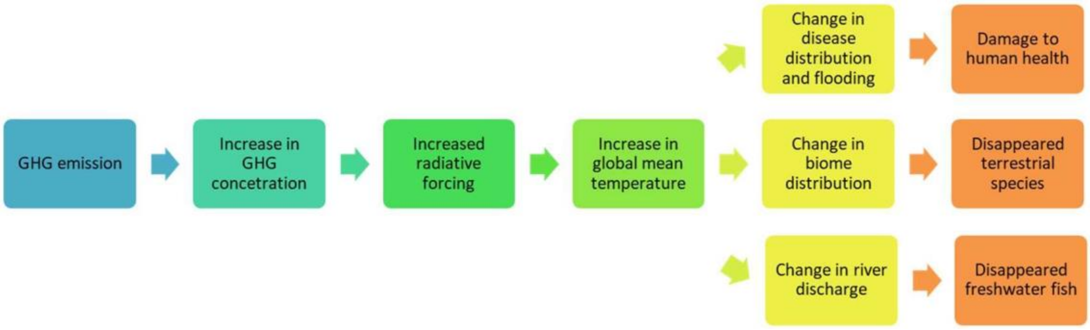

Figure 4. Cause/effect relation from GHGs to human health, terrestrial ecosystems and freshwater ecosystems

- **Potential Eutrophication**

Repeated soil over-applications of fertilizers, above crop requirements, have led to the accumulation of macro-nutrients, such as nitrogen, phosphorus and potassium. At saturation, nutrients are lost to either surface or ground waters. Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in aquatic ecosystems. In addition, high nutrient concentrations may also render surface waters unacceptable as a source of drinking water. In aquatic ecosystems, increased biomass production may lead to depressed oxygen levels.

Biomass growth in different aquatic ecosystems may be limited by different nutrients. Freshwaters are typical limited by phosphorus, whereas nitrogen usually is the limiting nutrient of biomass yield in marine waters. Therefore, marine and inland waters are treated as two different environmental indicators of aquatic eutrophication:

- **Freshwater eutrophication** measured in mass of phosphorus equivalent per FU (kg P eq/FU). The main emissions affecting this environmental indicator are phosphate, acid phosphoric and phosphorus.

- **Marine eutrophication** measured in mass of nitrogen equivalent per FU (kg N eq/FU). Regarding this environmental indicator, the most important related emissions are ammonia, nitrogen, nitrate, nitrite and nitrogen oxides.

Within wastewater treatment systems, these emissions arise when nutrients are not properly recovered from wastewater and are emitted in the effluent. Moreover, avoided emission may derive from the recovery of these nutrients from wastewater.

The release of nutrients into the soil or freshwater bodies is called freshwater eutrophication. The rise of nutrients levels can cause several environmental impacts. One of the largest impact is biodiversity loss. Eutrophication leads to relative species loss. However, at this point there is still a lack on characterization factors at the endpoint level for marine eutrophication; therefore, only damage to ecosystems quality due to phosphorus emissions can be measured (Figure 5).

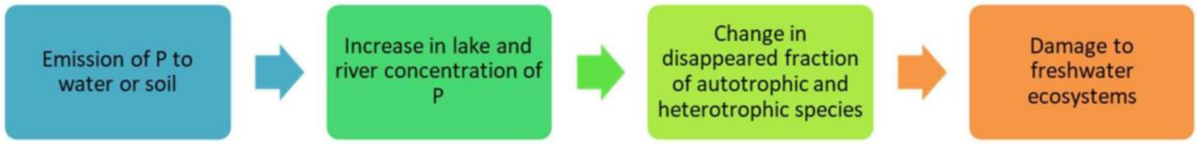

Figure 5. Cause/effect for phosphorus emissions causing loss of freshwater species richness

- **Toxicity**

Human toxicity, within the LCA methodology, refers to the emission of toxic substances on the human environment. Within wastewater management systems, these substances are emitted in background processes such as infrastructure, electricity, chemicals and fossil fuels production. Examples of these compounds are aluminium, iron, nickel, copper, zinc, arsenic and lead.

Ecotoxicity refers to emissions of toxic substances to air, water and soil related and it can be further subdivided in: i) freshwater ecotoxicity; ii) marine ecotoxicity and iii) terrestrial ecotoxicity. As in the previous indicator, they are emitted in background processes. Vanadium, copper, nickel, bromine and zinc are examples of these ecotoxic compounds.

These indicators are measured in terms of mass of 1,4-dichlorobenzene (1,4-DB) equivalent per FU (kg 1,4-DB eq/FU). A

According to Huijbregts et al., (2016), the characterization factor of human toxicity and ecotoxicity accounts for the environmental persistence, accumulation in the human food chain and toxicity of these substances. These indicators affect species and creates disease incidences, finally affecting human health and ecosystems (Figure 6). In this study, this environmental indicator is closely related to the emissions from chemical use in agriculture and from nutrients in wastewater, which may contain chemicals.

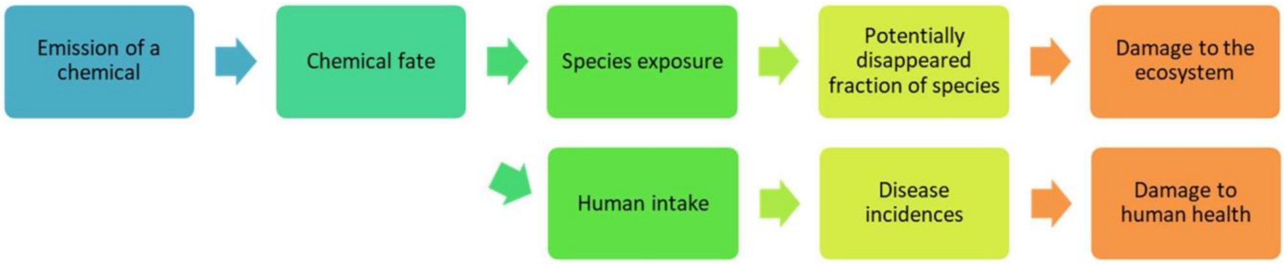

Figure 6. Cause/effect from toxic compounds to human health and ecosystems damage

- **Damage to human health**

This endpoint indicator aims to gather the damage to human health due to the emissions of: i) GHG due to direct effects (such as heat waves, air pollution and aeroallergens) and indirect (including infectious diseases, malnutrition, social and economic disruption); ii) ozone depletion substances (for instance, UV-B radiation causes non-melanoma skin cancer and plays a major role in the development of cataracts); iii) human toxic substances and iv) precursors of photochemical oxidants (for example, ozone concentrations can lead to an increased frequency and severity of events of respiratory distress). This indicator will be measured including all midpoint indicators that lead to damage to human health, as explained in each of the previous indicators selected.

- **Damage to ecosystem diversity**

The diversity of species shapes the quality of ecosystems. This endpoint indicator attempts to quantify the loss of species due to emissions of: i) GHG, since there is a connection between the rise of temperature and the loss of species on land; ii) acidifying substances, a deviation on the optimum acidity can harm severely the quality of species; iii) phosphorus emissions because freshwater eutrophication limits the dissolved oxygen, decreasing biological diversity and quantity; iv) toxic substances for ecosystems, including terrestrial, freshwater and marine ecotoxicity. As explained before, this indicator will be measured including all midpoint indicators leading to a damage to ecosystem diversity.

3.1.3 Relation between environmental indicators

Since environmental aspects of wastewater treatment are very complex and interconnected, there is a relation between many of the environmental aspects defined in section 3.1.1 and the impact categories selected in section 2.1.3. For example, GHG emissions have an obviously direct relation with climate change, but impacts in climate change are also related to energy flows, resource consumption and recovery, solid waste management and quality of the final products. Moreover, as explained before, impacts in climate change are cause of both damage to human health and damage to ecosystem. More detailed relations are presented in Figure 7.

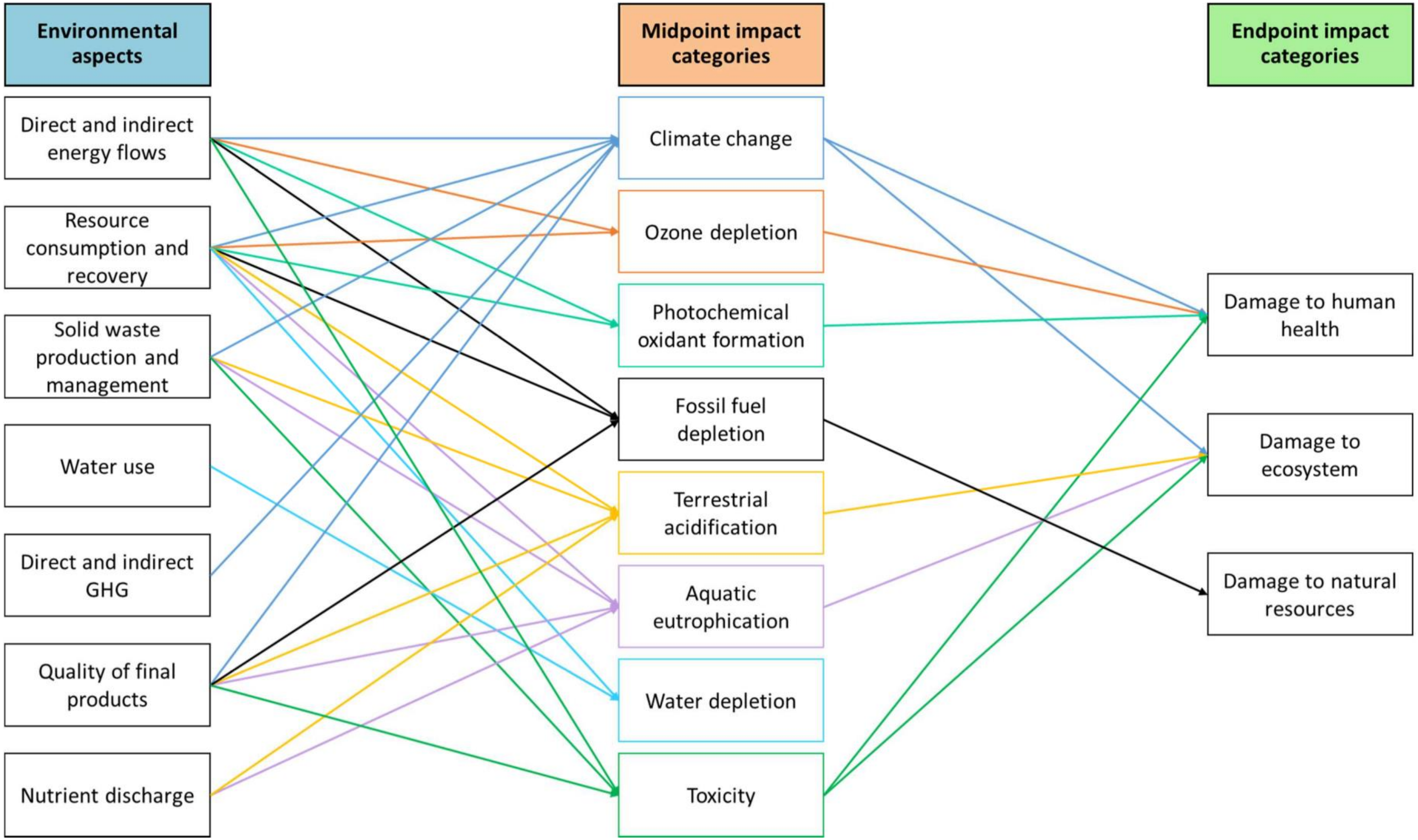

Figure 7. Relations between environmental aspects considered and midpoint and endpoint impact categories

4. Socio-economic indicators

The impacts associated with wastewater reuse should be assessed with an integrated approach taking into account not only the monetary costs and benefits in terms of ecological, social and economic factors, but to also consider a systemic perspective of the sustainability impacts.

4.1 Details of the indicators

4.1.1 Economic Conditions

Economic sustainability implies paying for itself, with costs not exceeding benefits. Mainly focusing on increasing human well-being, through optimal allocation and distribution of scarce resources, to meet and satisfy human needs. Economic indicators give an indication of how a society is growing and developing in economic terms. An increase in food production at a cheaper cost or a decrease in household bills related in this case to water and energy give an indication that economically a society is progressing well. Therefore, the indicators included below cover these two main points through the 3 main indicators detailed below.

- **Food production in agricultural lands using Run4Life nutrients**

The commodities covered in the computation of indices of agricultural production are all crop products originating in each of the pilot areas. These indices are gathered through the agricultural production index by the Food and Agriculture Organization of the United Nations (FAO) (World Bank, 2018)[4]. The FAO indices of agricultural production show the relative level of the aggregate volume of agricultural production for each year in comparison with the base period 2004-2006. They are based on the sum of price-weighted quantities of different agricultural commodities produced after deductions of quantities used as seed and feed weighted in a similar manner.

- **Household Water Expenses**

The United Nations, has explicitly recognized the human right to water and sanitation and recommends that expenditure on household water bills should not exceed 3% of household income. Ensuring the availability and sustainable management of water and sanitation for all features as one of the United Nations Sustainable Development Goals for 2030. It is expected that the Run4Life project objectives will aid in reducing the treatment costs and therefore reduce water bills in the homes. However, it needs to be borne in mind that changing household water bills is related to many aspects that are not only related to reducing the treatment costs, but there are also political influences in raising or reducing household water bills.

- **Decentralized treatment cost/energy cost**

Centralised wastewater treatment costs are high and are demanding to recover nutrients from wastewater. However, on a household level, reducing the movement of wastes away from the source and ensuring that wastes and reused in close proximity to their generation will be more sustainable. Therefore, the generation of 0.1 % of N, 0.2% of P of the total EU's demand of organic-based fertilizers in the next ten years can be achieved through reducing the energy costs of producing and reusing these nutrients close to their source.

4.1.2 Business

The circular economy concept is relatively new and growing in popularly, this has created the space for innovation and thus the prospect of new jobs created in this sector. According to Koellner et al. (2007), it is

[4] https://data.worldbank.org/indicator/AG.PRD.FOOD.XD

vital to promote the circular economy concept as it boosts recycling and prevents the loss of valuable materials; creates jobs and economic growth; shows how new business models can emerge; moves towards a zero waste concept through eco-design and industrial symbiosis; and reduces the greenhouse emissions and environmental impacts. Therefore, to gain an idea of how business activities improve around the circular economy concept the following indicators have been considered: a) Jobs created in circular economy in the region; a) Revenue generation for SME nutrient fertilizer companies; c) Infrastructures related to Run4Life technologies; and b) Mineral-based fertilizer imports and exports

- **Revenue generation for SME nutrient fertilizer companies**

Related to the indicator above is the revenue generation for SME nutrient fertilizer companies. As the quantity and quality of N and P increases and involves more innovative ways of treating and obtaining these nutrients (such as using the Run4Life technology), the SME companies are best placed to take advantage of these new opportunities. This indicator will give us an idea of how these companies are increased their revenue through taking advantage of the new opportunities.

4.1.3 Social conditions

This factor builds upon the idea of human relations, the need for people to interact, to learn, to develop capacity, and to organize their society. In this regard the Run4Life indicators focus on 3 main aspects: a) Water use at household level; a) Occupation and training on nutrient recovery technology and water reuse; b) Research and Development activities; c) Participation in the Run4Life community meetings.

- **Occupation and training on nutrient recovery technology and water reuse**

An informed and educated society on circular economy is one that promotes future sustainability. Therefore, the Run4Life project will not only engage with the four local areas to educate on the circular economy principles related to the Run4Life project but will also measure how many local workers in the environmental sector are trained on nutrient recovery technology and water reuse practices.

- **Research and Development activities**

Along with creating new and innovative products and adding features to old ones, Research and Development activities connects various parts of a company's strategy and business plan, such as marketing and cost reduction. Research and development consists of the investigative activities that a person, university, research center or business chooses to do with the desired result of a discovery that will either create an entirely new product, product line or service, or strengthen an existing product or service with additional features. Therefore, to deliver on customer expectations, it is essential that employees have the requisite skills to perform the research required and therefore training helps people to improve their competencies. In the context of the Run4Life project, research and development activities surrounding the circular economy sector in companies and universities will show that the society is moving towards sustainability. Therefore, the project will look at the percentage change in these research and development activities.

- **Participation in the Run4Life community meetings**

It is critical for every person, community, city, region and country to be well informed. According to the Global Agenda Council on Informed Societies[5], evidence is strong that in a knowledge economy and in an age of networked intelligence, those societies that are best informed are more successful. Increasingly, economies create value through "brain rather than brawn" and the societies with the best-informed brains are the ones that advance further. It is clear that our current linear models of production and consumption are outdated and that circular economy models are the keys to successful societies. Consequently, through the RUN4LIFE activities we will monitor the participation in the community meetings to gain an understanding of the demographics of the people that will be better informed on nutrient recovery and water reuse in relation to their current understanding.

4.1.4 Environmental

The Environmental indicators mentioned in section 3.1.2 differ to the indicators mentioned here as the indicators mentioned below are related to social perception of certain environmental impacts. Within this socio-economic factor the following indicators are highlighted noise, odour, aesthetics and GHG emissions. According to the EU barometer on "Attitudes of European citizens towards the environment"[6] The most acute concerns of the EU public relate to pollution of both air and water, the amount of waste that is generated in the EU, and the depletion of natural resources. Hence, the indicators chosen go hand in hand with the concerns of the EU public.

- **Noise**

Although Noise pollution is not a top 5 priority for most EU citizens, according to the EU barometer, the installation of vacuum toilets in the household could be a potential source of noise pollution. Therefore, the perception of noise at the household level will be an indicator that will be measured to see if the perception increases or decreases.

- **Odour**

If residents' perceptions, concerns and attitudes towards water and waste management are either not well understood or underestimated, people can produce strong opposition that may include protest demonstrations. The common standard measure of odour strength: 'European odour unit' (ouE) includes the quantity of a malodorous substance, which, when vaporized in one cubic meter of neutral gas, at standard conditions, induces a physiological reaction in the olfactory organs for at least half of the members of the odour evaluation panel. In the Run4Life project we will use the hedonic tone of 'acceptability', is it pleasant or unpleasant? (Landfill vs baking bread). The Run4Life project could result in reduced odour from wastewater treatment plants due to the onsite treatment of household wastes.

- **Aesthetics**

Centralized wastewater treatment plants do not generally create a vision of an aesthetically pleasing landscape especially to those residents that live within eyesight of the plants. In the RUN4LIFE project, the perception of the aesthetics of a centralized wastewater treatment plant vs an onsite vacuum toilet will be measured to gain insight into the perceptions of the demo site public.

4.1.5 Governance

A circular economy demands a holistic approach, involving economic growth, jobs, environment, innovation, social and cultural affairs etc. Therefore, the governmental ministries that look after these areas need to find ways to make collaboration work throughout all the ministries and would need to work outside of their silos. Most European countries lack a common agenda and of governance to ensure that all these ministries can work together in a more organized way. Thus, in the Run4Life project we will look at the following indicators to sustainability in terms of: a) Circular economy and/or nutrient recovery policies and focused on this topic governance structures for circular economy and b) Governance structures at local level for circular economy.

[5] https://www.weforum.org/reports/global-agenda-council-informed-societies-2012-2014
[6] http://ec.europa.eu/commfrontoffice/publicopinion/archives/ebs/ebs_416_en.pdf

- **Circular economy and/or nutrient recovery policies**

As a project, Run4Life cannot change policies, however the project can give recommendations on policy changes through the research and demonstration activities of the project. Consequently, as a project to ensure the sustainability of the circular economy activities and nutrient recovery we will provide policy recommendations on water and nutrient reuse and deliver it to the decision makers. They will be based on the recommendations or actions defined in the new legislation on circular economy. Therefore, the indicator will be quantified as the number of specific proposals or recommendations that will be obtained according to the project results. The project will also initiate discussions over incorporating circular economy in current governance structures.

4.2 Expected Run4Life socio-economic impacts

Water reuse systems provide certain socio-economic effects that can contribute to the overall impact of the treatment systems. These socio-economic effects can happen directly, indirectly, or through induced effects over the long term. These different levels of socio-economic effects, and the indicators that identify them are important to take into consideration to be able to implement the Run4Life technologies as efficiently as possible and to create the desired socio-economic impact. The different impacts will vary with location and type of plant and available information; however, these socio-economic effects will help provide an overview of the benefits and impacts towards implementing a water reuse system.

Run4Life goes beyond technical implementation to promote market and social uptake by: i) minimizing the risks through proactive mitigation, ii) implementing new Business Models; iii) boosting social and organizational innovation and iv) including the end-user perspective (fertilizer companies and farmers) to achieve real use of the obtained products. The table below specifies the expected socioeconomic impacts and their related indicators that can be used to measure the progress of the impacts over the project lifetime.

In every project, the progress and performance has to be measured to get a good overview of the progress being made. The Table 3 below provides information regarding the set of targets for the Run4Life project, how they can be achieved. and the expected output of these targets. The first column of the table divides the indicators into the socio-economic factors that can impact on the project. The second column of the table defines the indicators within each one of the socio-economic factors. The third column details the expected impacts taken from the Run4Life description of the action (DoA), the objective of this column is that the indicators should help define the expected impacts of the project. Columns 4 (Proposed TARGETS for the Run4Life project) and 5 (Targets (DoA)) are the targets that the indicators should aim to achieve. The difference between these two columns is that the DoA has a set of targets that in some instances are very specific and are unlikely to be achieved in each demonstration site (for example: the Run4Life project will result in 400+ new jobs). Without baseline data and given the idiosyncrasies of each site, it would be more correct to have a target related to a positive percentage change. Therefore, column 4 are the targets that have been proposed to be achieved throughout the life of the project. The last two columns of the table indicate the methods to which the project partners will use to gather the information for the targets and the final column indicates which workpackage or project task is related to the showcased indicator.

Table 3. Run4Life Indicators

Socioeconomic factor	Indicators	Proposed TARGETS for the RUN4LIFE project	Method	Source and Project related Activity
Economic conditions	Food production in agricultural lands using Run4Life nutrients	% increase in agricultural productivity through the use of high nutrient low impact fertilizers	Questionnaires	Public (Consumers and users at regional level)
	Household water expenses	% change in household water bills		
	Decentralized treatment cost/energy cost	Generation of 0.1 % of N, 0.2% of P of the total EU's demand of organic- based fertilizers in the next ten years produced close to source reducing treatment and energy costs		
Business	Revenue generation for SME nutrient fertilizer companies	% increase in revenue generation for SME nutrient fertilizer companies	SME Stakeholder meetings	Workshops and seminars at local level (WP7)

Socioeconomic factor	Indicators	Proposed TARGETS for the RUN4LIFE project	Method	Source and Project related Activity
Social conditions	Occupation and training on nutrient recovery technology and water reuse	Percentage of local workers trained on nutrient recovery technology and Water reuse practices	Workshops, interviews and focus groups, and seminars at various locations. Survey – Using Questionnaires	Actions within WP 6
	Research and Development activities	% change in research and development activities in local companies and universities		
	Participation in the Run4Life community meetings	Better informed public on nutrient recovery and water reuse in relation to current understanding		
Environmental	Noise	Perceived Improvement in the noise at the demo area.	Interviews Official data from local municipalities	People living around Demosite regions (WP6). Actions related to WP7
	Odour	Perceived Improvement in odour at the demo area.		
	Aesthetics	Perceived Improvement in the aesthetics with regards to wastewater treatment in the demo area.		
Governance	Circular economy and/or nutrient recovery policies	Policy recommendations on water and nutrient reuse delivered to decision makers. Discussions initiated over incorporating circular economy in current governance structures	Interviews	Direct contact with regional and municipal governments (WP6)

5. Human health risk assessment

Formulation of benefits in relation to human health risks are crucial for the acceptance and uptake of Run4Life concept utilizing nutrients, energy and water from waste streams. Risk assessment is one part of risk analysis and provides information on whether and how to manage risks within the society to protect human health and the environment (Haas et al 1999). Human health risk assessment consider risks to human health from different agents, with metals being the first hazards studied during the development of the methodology, which often includes a dose-response component. Direct and indirect effects on health from chemical risks e.g. micropollutants, heavy metals and other risk elements will be assessed in Run4Life as part of substance flow analysis and life cycle assessment. Microbial risk assessment estimates the microbial risk, i.e. risks from infectious agents, to human health, an assessment that uses other methodology to assess risk compared e.g. chemical hazards since its assessing the effect from living organism which interact with the environment and the animal or human host. The health risk assessment of the complex wastewater valorisation systems that are included in the Run4Life project will involve several routes of transmissions and population subgroups at potential risk. Aspects of the Run4Life concepts for which the microbial risks should be assessed includes the end consumers of produce which are fertilized or irrigated with Run4Life products but should also asses the whole process and handling chain so occupational hazards can be assessed/minimized and so that as a risk management control points for the process can be established (Figure 8).

5.1 Quantitative microbial risk assessment (QMRA)

Quantitative microbial risk assessment is a method to quantify microbial risks, in a way that the knowledge about microorganisms behaviour are used to estimate the risk they pose to human health, often including uncertainty and heterogeneity (CAMRA, 2018). QMRA in general has four stages which may be named differently depending on field or by defining organizations (CAMRA; WHO, US National Academy of Sciences; Codex Alimentarius Commission) but in essence they fill the same role in the microbial risk assessment (Figure 8). The Codex Alimentarius Commission (CAC), an international standard-setting organization for foods in international trade, and the EU Scientific Committee for Food, has adopted a four-step framework for risk assessment using the terminology (1) Hazard Identification; (2) Exposure Assessment; (3) Hazard Characterization and (4) Risk Characterization.

- The **hazard identification** identifies and describes the microorganisms that may pose risk to human health for an investigated scenario and includes information that enables the identification of important agents as e.g. symptoms, severity of disease and death rates. The hazard identification may also include identification of subgroups of the population that may be more prone to infection than the general population or for which the disease outcome is different. Since it is not feasible to quantify the potential impact of all pathogens in a risk assessment, a few are chosen as reference pathogens for the investigated scenario (WHO, 2004), preferably representing pathogens with different associated risks, e.g. different survival, virulence and morbidity. The microbiological hazards can be identified from relevant data sources as clinical and epidemiological studies and surveillance data, scientific literature and be based on the interaction between microorganisms and their environment (CAC).

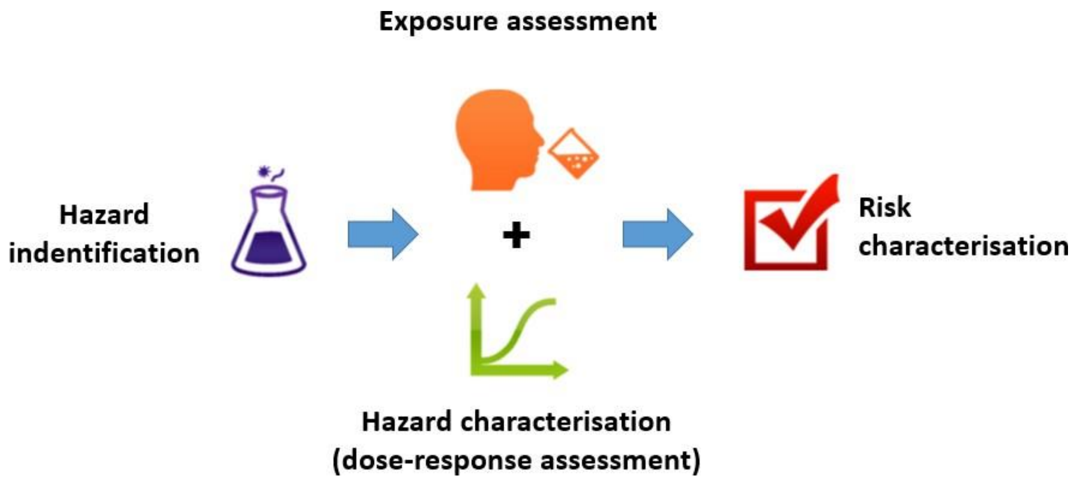

Figure 8. The four components of quantitative microbial risk assessment (QMRA). Graphical elements are used with the courtesy of Camra

- The **exposure assessment** describes the frequency, duration and magnitude of pathogen exposure by one or more pathways of the investigated scenario. Depending of the identified pathways and data available, the exposure model can be more or less complex. The exposure assessment aims to determine what dose of microorganism that a person is exposed to. For assessment of risks from food or water, patterns of consumption need to be defined as well as the pathway from production to consumption considering effects of processing etc.

- The **hazard characterization** describes the health effect of the dose of microorganism a person is exposed to. The number of microorganisms needed to be infected, the infectious dose, varies for different microorganisms as well as for hosts populations. The dose-response relationship is characterized under the hazard characterization and this step is by some methodology defined as the dose-response assessment. Data from animal and human trials as well as outbreak investigations allow the construction of mathematical models to predict dose-response and preferably, difference in sensitivity for different population subgroups should be encountered for. When an individual is exposed to a certain number of microorganism there are three possible outcomes: that the exposure does not lead to infection, leads to infection but without symptoms or leads to an infection with symptoms ranging from mild to severe cases and death. In general infection are more sever in elderly, children and immunocompromised persons.

- The **risk characterization** is computation of the outcome of the integrated information from the exposure assessment in combination with the dose-response relationship and calculates the risk in the form of the probability of an outcome as e.g. infection. For the simplest case, point estimates can be used but more often, since one of the key features of QMRA, the input data as dose, exposure etc. is described with variation and uncertainty and the risk characterization will be stochastic giving the outcome in the form of a probability function. The risk characterization is often derived from simulations, rather than analytically solved.

Depending on the focus for the risk assessment, the outcome of a QMRA can be e.g. the probability of infection. However, an infection can be asymptomatic and do not necessarily cause any adverse health effect in one person but may be lethal to another person. The same variability may apply in between different agents for infectious disease where one pathogen may result in mild but prolonged symptoms, e.g. parasitic infection, whereas others may result in death. In 1992 the Global Burden of Disease (GBD) Study was describing world's disease burden status and health trends was initiated by the World Bank. To allow comparisons to be made between different health outcomes and allowing quantification of non-fatal outcomes a new unit was introduced: Disability Adjusted Life Years (DALY). DALYs are the sum of life years lost to premature mortality and years lived with disability adjusted for severity (Murray and Lopez, 1997). The basic principle of the DALY is to weight each health effect for its severity from 0 (normal good health) to 1 (death). By multiplying this weight with the duration of the effect and by the number of people affected by a particular outcome, it is then possible to sum the effects of all different outcomes due to a particular agent. In consequence, the DALY is the sum of years of life lost by premature mortality (YLL) and years of healthy life lost in states of less than full health, i.e. years lived with a disability (YLD), which are standardized by means of severity weights. The key advantages of this metric lie in its "aggregation" of different effects (disregarding the cause) and the combining of quality and quantity of life. WHO promote the use of 1 µ DALY per person per year as the upper tolerable health burden related to drinking water and for food products produced with excreta and greywater (WHO, 2006).

5.2 Hazard analysis and critical control points (HACCP)

The goal of risk management is to reduce or eliminate risks and the negative consequences associated with risks. Within food and drinking water production the risk management system Hazard Analysis and Critical Control Points (HACCP) has been applied and is now common within the production and distribution of food. The system facilitates managing and is compatible with other quality management systems, such as the ISO 9000-series (FAO, 1997). Current EU legislation decrees the incorporation of HACCP within drinking water production and the WHO also incorporates HACCP as part of their Water Safety Plans (WHO, 2004).

HACCP offers a preventative management and quality assurance approach rather than random monitoring of the end product and has also been applied for wastewater treatment processes with the objective of reuse (Westrell et al., 2004; Salgot et al., 2008, Godwin et al. 2015). The HACCP system involves identification of critical points to control hazards and maintain best management practices throughout production and distribution. Criteria are established for each control point, which are monitored, and corrective actions are established that should be carried out when critical limits are not met (FAO, 1997).

The working process in the HACCP system consists of several consecutive steps where the first step, similar to for QMRA methodology, is **hazard analysis**. The second step is to determine the **Critical Control Points** (CCPs). A critical control point is a location in the process where a certain hazard can be controlled, through either prevention, elimination or reduction. If a QMRA have been conducted for a system, the risk characterization may indicate the need to manage the risk by HACCP and the exposure assessment can enable the detection of the critical control points. The consecutive steps are the establishment of **critical limits** (a criterion that separates acceptability from unacceptability, e.g. a certain temperature, time, moisture level, pH etc.); establishment of a monitoring system to control the CCPs and establishment of the corrective action to be taken when monitoring indicates that a particular CCP is not under control. Procedures for verification to confirm that the HACCP system is working effectively shall be established and finally establishment of documentation concerning all procedures and records appropriate to these principles and their application.

5.3 QMRA for Run4Life

5.3.1 Hazard identification

The hazard identification of the QMRA for the Run4Life concept will identify microbiological hazards and will include microorganisms that are excreted trough human excreta and thus present in black water (BW) and grey water (GW) as well as microorganisms that can present in food waste and in greywater (only ABP category 3 waste considered). Routes for infection that will be considered include ingestion, inhalation, skin and eye contact. The hazard identification will thus include microorganism bacteria, virus and protozoan and helminth parasites and, if identified a hazard for the Run4Life scenario, fungal parasites as well as risk from toxins produced by microorganisms. The hazard identification will consider pathogens prevalence in all member states but will specifically focus on the Run4Life countries. The identified organisms will be characterized in terms of prevalence, virulence, symptoms, morbidity and mortality rates. Identification of extra sensitive subpopulation dependent on critical timing (children; elders; pregnant women) as well as health status e.g. as for immune compromised persons, will be undertaken.

As part of the hazard identification, a selection of representative reference pathogens will be determined to represent different risks within the Run4Life concept. The hazard identification and choice of reference organisms in Run4Life will be based on incidence data from European disease surveillance as well as research and health studies as well as on from the actual measures of the waste streams with in the project.

The actual legislation regarding hygienization of wastewater and fertilizers produced from waste for agricultural reuse will be also taken into account.

Origin	Organisms	Exposure	Background	Population	OUTCOME
Kitchen waste Black water Grey water	Bacteria Virus Propozoa Helmiths Fungi	Oral Inhalation Dermal Conjunctival	Surveillance Analyses	General public Sensitive subgroups	**Establishment of relevant microbiological hazards and choice of reference pathogens for Run4Life scenario**

5.3.2 Exposure assessment

The exposure model will be based on the Run4Life scenario with the system borders of processing in the different sites including occupational exposure as well as accidental exposure to the general public if the systems are failing. The end-point risk that will be assessed is the risk for consumers getting infected from products that have been cultivated with reclaimed fertilizers or reclaimed water. The exposure model will also include occupational risks to plant workers and farmers and recreational risks by the general public when using reclaimed flush water, when bathing in nearby waters and spending time on land. The exposure to microorganisms (and toxins) will include exposure to raw waste streams, fertilizer product/reclaimed water, fertilized/irrigated soil, aerosols, and contaminated recreational water.

The exposure model for Run4Life will include exposure to the materials: raw waste streams, partly processed waste streams, processed fertilizer and irrigation water, irrigated/fertilized soil, irrigated/fertilized food feed and drinking water. The fate of the organisms in the transmission pathway as reduction during processing, possible regrowth and dilution by land application will be included in the exposure model. The model will include exposure by the routes of: ingestion (intentional and accidental (incl hand-to-mouth), inhalation, skin contact or conjunctival. The exposure model will describe the frequency, the duration and the magnitude of the exposure so that the dose of ingested microorganisms in the Run4Life scenario can be established.

Data gathered in WP3, which entails the monitoring of demonstration plants, will establish incoming concentrations in waste flows and achieved reduction by treatments whereas WP4 will characterize the output products (fertilizers and reclaimed water) as well as investigate the fate of microbial and other contaminants during crop production at experimental and field trials and final investigation of crop uptake. Estimations of ingested /inhaled amounts of materials (waste, reclaimed fertilizers and water, irrigated/fertilized soil) will be based on literature data, preferably with a European focus.

Materials	Environmental fate	Exposed	Infection route	OUTCOME
Raw waste streams partly processed waste stream Fertilizer/reclaimed water Fertilized/ Irrigated soil Fertilized/ Irrigated crop Recreational water Drinking water	Treatment reduction Regrowth Soil dilution Environmental decrease Environmental transport	Plant workers farmers consumers general public trough recreational activities	Intended ingestion Accidental ingestion Aerosol inhalation Dermal contact Conjunctival contact	**Dose of microorganism that a person is subjected to for each of the exposure pathways and subgroups**

5.3.3 Dose-response assessment

The infectious dose for the microorganism identified under the hazard identification will be established with the aim to differentiate for subgroups of the general population as highly susceptible or highly exposed and consider different live stages as children and elderly or pregnant/nursing women, both for the id. This step determines the probability of infection due to a certain dose.

Pathogen characteristics	Host characteristics	Infection route	OUTCOME
Organisms group Infectivity Virulence	Live stage Health status Nutritional status Immunity development	Intended ingestion Accidental ingestion Aerosol inhalation Dermal contact Conjunctival contact	**Mathematical description of the health outcome for a certain dose of ingested microorganism**

5.3.4 Risk characterization

The Run4Life microbiological risk characterization will quantify any health outcome for different subgroups trough occupational exposure ant to the general public by consumption of irrigated/fertilized products or from recreational activities and spending time in environment including bathing. The probability of infection will be assessed and well as the heath outcome of infection in terms of severity and duration. The use of the metric disability adjusted life years will allow comparing the microbiological risks to other health risks (assessed in the LCA) and also allows the weight the health out come from different types of diseases. To calculate years lived with disability (YLD) disability weights from the global burden of disease study 2015 (IHME 2016) as well as disability weights from survey in Hungary, the Netherlands, Sweden and Italy which may be more representative to socio-demographic groups of the EU/EEA population (ECDC, the Institute for Health Metrics and Evaluation). The hazard indication will show which hazards that are most sever and to which subgroups. This will indicate if measures to decrease risks shall be undertaken or if the risk associated with the Run4Life system are acceptable. The QMRA can relate the risks for Run4Life (where the waste streams are treated separately and redirected to agricultural land) to risks related to a reference scenario where partly treated effluent are discharged to watercourses. The aim with the QMRA can also be to see what reduction in the treatment processes that are necessary to achieve a certain health output benchmark.

Probability of infection	Infection outcome	Diability weights	OUTCOME
Organism groups Infectivity Virulence	Severity Duration Future effects	Acute Chronical Debilitating Primary and secondary disease	**Disability adjusted life years as an outcome to different subgroups during different exposure pathways in Run4Life**

5.4 HACCP for Run4Life

To manage the risks identified in the QMRA, the principles of Hazard Analysis Critical Control Points (HACCP) can be applied on the Run4Life scenario to facilitate a systematic quality assurance. The exposure model for the exposure assessment in the QMRA will account for pathogen reduction by the Run4Life technologies and the resulting products and the HACCP will determine which Critical Control Points where pathogen reduction can be controlled, and for these processes, define critical limits for relevant treatment parameters. Such treatment parameters can be directly linked to the pathogen inactivation but can also be linked to the continuous function of the system. The Run4Life products shall also be traceable and the pathway from production to the use as fertilizer/irrigation water will be evaluated. The establishment of a monitoring system for Run4Life would, as a consequence, include both process monitoring but also a component of product monitoring.

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