

Sustainable Energy Solutions for Rural Communities [†]

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Abstract: The Renewable Community Empowerment in Northern Territories (RECENT) project intended to enhance the utilization of unused assets in remote and sparsely populated areas and communities. The objectives were to enhance energy efficiency, implement renewable energy solutions and help communities to have more resilient and energy efficient public infrastructures capable of handling climate change related risks. The nexus approach was used to promote the efficient management of resources, i.e., water, waste and energy, while considering the interdependencies between them. The project developed 25 pilots related to energy, energy efficiency, waste, and water solutions across five Northern Periphery and Arctic Programme (NPA) partner regions (Finland, Sweden, Northern Ireland, Ireland, and Scotland). The project assessed energy generation and reduction potential; investment costs and payback times of the pilots. A sustainability assessment tool was also developed, to assess the environmental, social and long-term sustainability of the pilots. The combined benefit of the 25 pilots was 20 GWh/year renewable energy and saving 6070 t of CO₂/year. The sustainability assessment also highlighted the social benefits to the community. The project established opportunities for new ways of providing environmental goods and services and supporting innovative infrastructures based on the nexus approach of water-energy-waste-land resources. These innovative infrastructures would be based on decentralized systems which allow for synergies between different assets. These synergistic solutions can contribute significantly to the reduction of resource consumption and related emissions and to the sustainable development of European communities.

Keywords: renewable energy; energy efficiency; resource use and management; energy-waste-water-land-nexus; sustainability assessment

1. Introduction

Climate change and the depletion of natural resources are our major problems as we are living beyond the limits of Earth [1]. Due to increasing number of people with unsustainable consumption habits, we will need more food, energy and water in future than today. It will result in a scarcity of natural resources and also raise their prices. Therefore, smart sourcing of raw materials and the efficiency of their use will be a new competitive advantage [2]. The well-known definition of Brundtland Commission for “Sustainable development is “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”, so it is of extreme importance to look at the future when planning the sustainable energy solutions and/or resource utilization today. In addition, all the parts of the sustainability need to be taken into the account. Social, economic and environmental sustainability has been presented to be the three-pillars or three intersecting circles of the overall long-term sustainability [3].

The European Union (EU) has acknowledged the importance of bioeconomy and circular economy with resource efficiency, sustainable material use, and carbon neutral society e.g., [4–6]. Commission adopted proposals to turn Europe into a more circular economy and to boost recycling in the area of the EU [4]. The EU directive (1999/31/EY) aims to reduce the amounts of biodegradable waste going to landfill as they rather should be used as a valuable resource. When planning a sustainable material use for the rural areas, it should be noted that the environment of Northern Periphery and Arctic region is of a high quality but also is especially fragile. Local communities in the region are also affected by climate change impacts and rapid economic and environmental changes, e.g., large-scale industrial projects. As the scale of the challenges is often beyond the possibilities of the individual, mainly rather small communities are to manage on their own, and they may require a wide range of competences by many areas of expertise.

The Europe 2020 Strategy includes reduction of greenhouse gas emissions 20% from 1990 level; production 20% of energy from renewables and 20% increase in energy efficiency. Because of The Renewable Energy Directive (RED) (2009/28/EC), Finland needs to increase the amount of renewable energy from the gross final consumption of energy from 28% to 38% by 2020. In addition, Directive 2014/94/EU establishes standard rules on rolling out the EUs alternative fuels infrastructure (e.g., natural gas refueling points) and has minimum requirements for building up this infrastructure. Finland needs to designate networks for infrastructure, e.g., gas pumping stations also for the North of Finland every 150 km.

The nexus approach is used to promote the efficient management of resources while considering the interdependencies between them. There are numerous sectors between which nexus approach can be used but not many of them are related directly to energy–waste–water–land–nexus and/or climate change researched in this paper. Energy, water and food (EWF) resources have faced increased pressures globally due to fast population growth and increased urbanization. Therefore, there is a need for effective resource management which considers all components of sustainable development: societal, environmental and economic. Furthermore, the importance of the EWF nexus approach between sectors has been acknowledged [7]. Moreover, as resources belonging to EWF are deeply intertwined, there is a need for a nexus approach to realize and manage the complex cascading effects and tradeoffs [8]. The food, energy, water, and waste production (FEWWN) nexus provides a conceptual framework between those important sectors and lately it has become a key research area. Many of the biobased wastes of the FEWWN are unwanted byproducts, and bioenergy production based on them will minimize ecological damage and/or also maximize ecological restoration [9].

Water, energy and waste nexus has strong possibilities but also challenges. The related water–wastewater systems, especially in urban systems, are resource intensive and lack circularity. Drinking water treating, heating and domestic wastewater treating are causing relatively high energy consumption. There are possibilities to reduce the environmental impacts of these systems by using energy and nutrients of the wastewater. With use of organic municipal waste, the energy efficiency of the whole system could be even further enhanced [10]. The energy–water–food–nexus application planning has become a central focus in the current research of developing systematic modeling but there is a huge gap on the decision-making tools binding water-energy-waste sectors with supply demand needs in spatial and temporal scales [11].

The Renewable Community Empowerment in Northern Territories (RECENT) project was a three-year international project (2015–2018) which aimed to increase the energy knowledge in the rural and/or Northern communities and help them to have energy efficient and more resilient public infrastructures which are capable of handling risks caused by climate change. The project researched 25 pilots including energy, energy efficiency, waste management, and water improvement methods in five Northern Periphery and Arctic Programme (NPA) partner regions (Finland, Sweden, Northern Ireland, Ireland, and Scotland) and the focus was on the innovative use of community-owned assets. Partners in the project were International Resources and Recycling Institute (IRRI) UK, Scotland; Action Renewables (AR) UK, Northern Ireland; Claremorris Irish Centre for Housing (CLAR ICH) Ireland; Mayo County Council, Ireland; Jokkmokk municipality, Sweden; and University of Oulu, Finland [12,13]. The NPA 2014–2020 has nine program partner countries and it is

part of the European Territorial Cooperation Objective which is supported by the European Regional Development Fund (ERDF) and ERDF equivalent funding from countries which are not EU partners [12].

RECENT also aimed to develop and support a change of attitude and behavior in relation to innovation processes, entrepreneurship and markets among communities in the sparsely populated areas possibly outside the regional centers. This may also enhance capacity of communities to handle the risks connected to climate change and exploitation of natural resources [13].

The objectives of the RECENT project for the remote and sparsely populated areas were:

- To increase the use of renewable energy and energy efficient solutions in housing and public infrastructures.
- To define the local or regional challenges and possible technical and economic solutions for them.
- To develop sustainable energy asset management and environmental management systems.
- To increase innovation and transfer of new technology.
- To exchange knowledge to increase the public awareness.
- To involve stakeholders throughout the project by joint monitoring and evaluation activities.

This article presents the results of the report of Work Package 4 (WP4) of the RECENT project on Monitoring, assessment and testing [14]. WP4 assessed the energy generation and/or reduction potential, investment costs and payback times of the pilots. The objective of WP 4 was also to monitor and assess the sustainability of the pilot projects and to demonstrate their long-term outcomes. A new sustainability assessment method was developed in RECENT to assess the environmental, social and long-term sustainability of the pilots [15]. The assessment tool demonstrates the sustainability of communities' energy, water and waste projects, also highlighting the social benefits to the community itself. The description of the pilots across the five regions will be shortly presented, including their energy generation and/or saving potential, CO₂ emission reduction, investment and payback times, and projections of their sustainability. Finally, the overall results of the pilots will be summarized. The expectation of the RECENT project was that the energy benefits and CO₂ emission savings of the pilots would be notable, and that the economic, environmental and social benefits achieved by the communities as a result of the participating the project would have a long-lasting impact.

2. Materials and Methods

The definitions of terms used in the RECENT project are specific to the project. Community meant a group of people in the NPA program area that were able to gain direct/indirect benefits from the pilot. Pilots were the actual technological solutions/implementations that contributed to the community's public infrastructure. The studied communities mainly were small, remote, and facing public infrastructure challenges (i.e., competing land and water use needs) also combined with climate change impacts. Some communities were not remote, e.g., University of Oulu (UOulu), but challenges were related to its Northern location and unused assets. RECENT supported studied communities to become more energy self-sufficient by developing small-scale solutions and building synergy between critical public infrastructures. All the communities had pilot or several pilots, 25 altogether in 5 regions, all of which had synergy between several assets (Table 1). Synergistic solutions included, e.g., energy recovery from wastewater, co-digestion of bio-waste, garden waste and/or wastewater sludge, land-use of generated digestate, generating transportation biofuel from wastes, harvesting of the solar and wind energy, in addition to a range of additional specific technologies appropriate to each region.

Table 1. Communities and pilots of the Renewable Community Empowerment in Northern Territories (RECENT) project with information about assets used and possible synergies between assets.

| Country | Community: Pilot | Main Asset | Nexus Approach: Synergies between: | | | | | |
|------------------|---|-------------------|------------------------------------|-------|--------|-----------------|-----------|-------|
| | | | Waste | Water | Energy | CC ¹ | Transport | Total |
| Finland | Sodankylä: co-digestion plant | Biodegr. waste | X | X | X | X | X | 5 |
| Finland | UOulu: Sust. bio-waste treatment | Biodegr. waste | X | | X | X | | 3 |
| Finland | Muhos: Easy ecological living | Eco-district | | | X | X | | 2 |
| Finland | Muhos: Maijanlenkki eco-district | Eco-district | X | | X | X | X | 4 |
| Finland | Oulu: Eerola farm co-digestion plant | Biodegr. waste | X | | X | X | | 3 |
| Finland | Oulu: Triangel hotel rooftop PV ² | Solar | | | X | X | | 2 |
| Finland | UOulu: univ. rooftop solar PV | Solar | | | X | X | | 2 |
| Finland | Enontekiö: building rooftop PV | Solar | | | X | X | | 2 |
| Sweden | Jokkmokk: co-digestion plant | Biodegr. waste | X | X | X | X | X | 5 |
| Sweden | Jokkmokk: waste heat recovery | Waste heat | X | X | X | X | | 4 |
| Sweden | Jokkmokk: energy efficiency in district heating | Energy efficiency | | | X | X | | 2 |
| Sweden | Vilhelmina: sustainable energy plan | Energy efficiency | X | | X | X | | 3 |
| Sweden | Vilhelmina: waste heat recovery | Waste heat | X | X | X | X | | 4 |
| Sweden | Haparanda: sustainable energy plan | Energy efficiency | | | X | X | | 2 |
| Northern Ireland | Armstrong farm: wind power | Wind | | | X | X | | 2 |
| Northern Ireland | Barnmeen: wind power | Wind | | | X | X | | 2 |
| Ireland | Aran Island Energy Coop: wind | Wind | | | X | X | X | 3 |
| Ireland | Mulranny Green Plan | Energy efficiency | | | X | X | | 2 |
| Ireland | Clare Island: Development co. | Energy efficiency | | | X | X | | 2 |
| Ireland | Tooreen/Aghamore: water conservation | Energy efficiency | | X | X | X | | 3 |
| Ireland | Tooreen/Aghamore: PV panels | Solar | | | X | X | | 2 |
| Ireland | Derryvohey GWS: solar power | Solar | | | X | X | | 2 |
| Ireland | Mayo community library: PV panels | Solar | | | X | X | | 2 |
| Scotland | Alt Duisdale: micro hydro | Water | | X | X | X | | 3 |
| Scotland | Drumnadrochit: waste heat recovery | Waste heat | | X | X | X | | 3 |

¹ CC = climate change; ² PV = photovoltaic solar panel.

The RECENT project provided a tool to assess the economic, environmental, and social sustainability of the pilot cases. There are many ways to measure sustainability with different methods but the general idea of sustainability indicator, e.g., for renewable energy sources is that they are based on well-known sources and they are developed to measure sustainability reliably [16,17]. Sustainability assessment tool of RECENT project with some selected indicators was helping to evaluate the progress of communities toward sustainability when they are participating the project with their pilot. These parts of the assessment tool are;

- Social sustainability assessment template;
- Economic sustainability assessment template; and
- Environmental sustainability assessment template.

To assess the long-term sustainability of communities, a wide overview of the sustainability of the pilots is needed. Sustainability assessment points out the successes and shortcomings of pilots and enables further sustainability plan for the communities. The sustainability assessment template gathers information from the social, economic and environmental sustainability assessment templates and forms a set of nine sustainability indicators (CO₂ reduction, synergy advantages, land-use implications, impact on the environment, payback time, impact on citizens’ health, teaching sustainable values, community building element and energy security), each of which has sub-indicators (Table 2). The result is presented in an easily interpretative form of a radar diagram.

Sub-indicators are mainly in the form of the questions and the give positive or negative value depending their effect on given dimension (environmental, economic or social sustainability), e.g., in the form of the CO₂ reduction, effect on biodiversity and land use, payback time, social wellbeing, health and energy security (Table 2). If they improve the status the mentioned dimension, they will get positive value (the greater the improvement, the better the value) and if they weaken the status, they will get negative value (the greater the weakening, the worse the value). Some of the sub-indicators give easily comparable absolute values (e.g., amount of energy generated/saved, CO₂ emission reduction, investment value, payback time) but some of them are more subjective estimates (e.g., does the solution support social cohesion and interaction?) and may vary depending on the situation. Hence, not all the answers can be presented in the result section in a similar way although they all get the values for the radar diagram.

Table 2. Dimensions, indicators and sub-indicators of the sustainability analysis.

| Dimension | Number | Indicator | Sub-indicators |
|---------------|--------|----------------------------|--|
| Environmental | 1 | CO ₂ reduction | How does the pilot contribute to CO ₂ reduction? Does the chosen energy technology(ies) replace fossil fuel based energy production? |
| | 2 | Synergy advantages | Does the solution(s) utilize unused biomass, such as forest or agriculture biomass? How many of the following challenges does the pilot contributes to? Waste, water, energy, climate change, transportation. |
| | 3 | Land-use implications | Does the land area occupied by the pilot solution have significance, cultural value or other importance? Estimate the impact of the pilot solution on the land area occupied. |
| | 4 | Impact on the environment | Pilot’s effect on air quality? Does the solution decrease the quality of water and soil or does it have negative impact on biodiversity? |
| Economic | 5 | Payback time | How long is the payback time of the pilot investment? |
| Social | 6 | Impact on citizens’ health | Positive impacts on citizen health (solution is safe to inhabitants; ensures clean and healthy habitat; offers |

| | | |
|---|-----------------------------|--|
| | | sustainable water treatment or waste management possibilities; enable citizen with safe, clean, renewable and reliable energy) |
| | | Negative impacts on citizen health (noxious gases; or toxic compounds in harmful quantities; significant risk of injury; significant noise or aesthetic harm). |
| 7 | Teaching sustainable values | Does pilot include implementation of clean or renewable energy technologies? Does the pilot promote the energy efficiency? Does the pilot promote participation of stakeholders? Is the solution visible? |
| 8 | Community building element | Does the solution support social cohesion and interaction? Does the solution(s) improve the community's adaptation to climate change? Does the pilot improve local job creation and local business? To what degree does the solution contribute to energy needs of the community? |
| 9 | Energy security | How many months per year the solution functions due to seasonal variance? Is the solution prone to intermittency issues? Does the pilot offer energy storing capacity? |

The values of the sub-indicators give the total numeric values for each of the indicators (total can be from +2 to -2). The total points for each of the nine indicators can be entered to Excel to form radar diagram. The radar diagram itself and values of the indicators and sub-indicators can be used to assess the long-term sustainability and to describe the points of success of a pilot and the weaknesses to be improved on the long term (Table 3, Figure 1).

In addition of the outcome from the indicators and radars, the more detailed questions used for the long-term sustainability assessment were:

- Please describe the outcome of the sustainability assessment and consider sustainability long-term;
- Please specify points of success and strengths of the pilot;
- Please specify weaknesses and points of improvement.

Table 3. Total points used for the radars based on their impact on environmental, economic or social sustainability.

| Impact on Sustainability | Points |
|--------------------------|--------|
| Highly positive | 2 |
| Positive | 1 |
| Neutral | 0 |
| Negative | -1 |
| Highly negative | -2 |

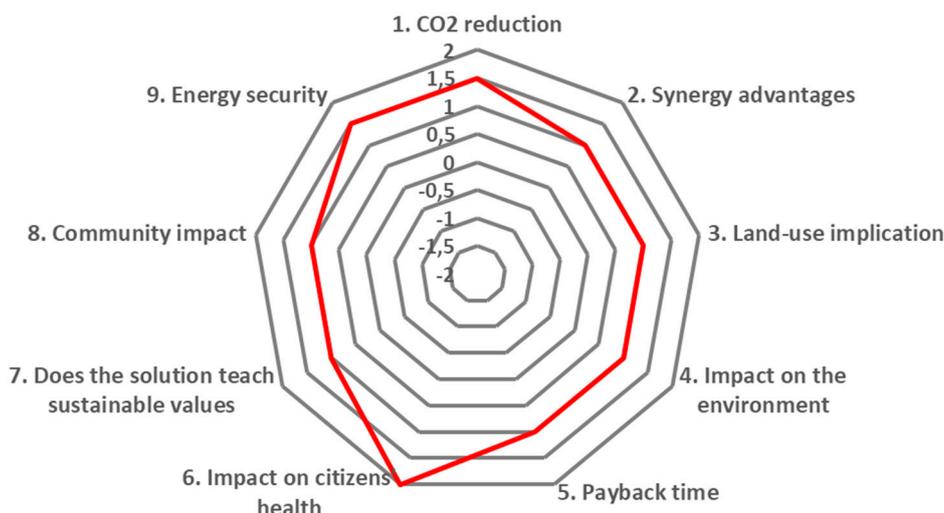


Figure 1. Example of sustainability radar pointing the values (from -2 to 2) for each of the nine indicators for the overall assessment.

Answers to these questions helped to assess the success of the pilots for the communities, and further on, to develop their performance in the future.

3. Results

The list of the pilot cases of the communities, results with absolute comparable values and gathered benefits of the pilots of the RECENT project are summarized in the Table 4. The combined benefit of the 25 pilots is 20 GWh/year renewable energy and saving 6070 tons of CO₂/year. The investment costs varied from the very small energy efficiency improvement pilot (780 €) to very large-scale energy solution (about 3.6 million €). Payback times varied similarly, from 1 years to 75 years, the most common time being about 8–13 years.

Table 4. Results from the pilot cases of RECENT project including the information about energy generation/savings, CO₂ emissions, investment costs and payback time [14].

| Country | Pilot Case | Energy Generation/Saving (MWh/Year) | tCO ₂ /Year | Investment Costs (€) | Average Payback Period (years) |
|---------|--|-------------------------------------|------------------------|----------------------|--------------------------------|
| Finland | Sodankylä: co-digestion plant | 1820 | 382 | 400,000 | 11 |
| Finland | UOulu: Sust. bio-waste treatment | 9 | 3 | 33,000 | 7 |
| Finland | Muhos: Easy ecological living | 166 | 23.6 | 230,000 | 13 |
| Finland | Muhos: Maijanlenkki eco-district | 226 | 47.4 | 22,000/household | 13 |
| Finland | Oulu: Eerola farm co-digestion plant | 356.5 | 87 | 388,000 | 8.5 |
| Finland | Oulu: Triangel hotel rooftop PV ¹ | 200 | 53 | 509,000 | 21 |
| Finland | UOulu: univ. rooftop solar PV | 2080 | 224 | 3.6M | 11 |
| Finland | Enontekiö: building rooftop PV | 50 | 13.5 | 84,000 | 14 |

| | | | | | |
|------------------|---|-------------------------|-------|---------|--------|
| Sweden | Jokkmokk: co-digestion plant | 400–600 | 50-70 | 550,000 | 75 |
| Sweden | Jokkmokk: waste heat recovery | 65 | 8 | 53,000 | 7 |
| Sweden | Jokkmokk: energy efficiency in district heating | 1000 | 125 | 10,200 | 1 |
| Sweden | Vilhelmina: sustainable energy plan | 1823 | 228 | 500,000 | 4 |
| Sweden | Vilhelmina: waste heat recovery | 45 | 5.5 | 47,250 | 7 |
| Sweden | Haparanda: sustainable energy plan | 506 | 63 | 100,000 | 2 |
| Northern Ireland | Armstrong farm: wind power | 606 | 329 | N/A | 20 |
| Northern Ireland | Barnmeen: wind power | 701 | 380 | N/A | N/A |
| Ireland | Aran Island Energy Coop: wind | 7480 | 2.1 | 3M | 7 |
| Ireland | Mulranny Green Plan | 186 | 39 | 70,860 | 14 |
| Ireland | Clare Island: Development co. | 4 | 0.002 | 780 | 2 |
| Ireland | Tooreen/Aghamore: water conservation | 400 m ³ /day | - | 25,000 | 3 |
| Ireland | Tooreen/Aghamore: PV panels | 43 | 20 | 66,000 | 8.8 |
| Ireland | Derryvohey GWS: solar power | 13.5 | 6.5 | 21,800 | 9.5–13 |
| Ireland | Mayo community library: PV panels | 9.7 | 5 | 18,500 | 13 |
| Scotland | Alt Duisdale: micro hydro | 120 | 45 | 143,000 | 12 |
| Scotland | Drumnadrochit: waste heat recovery | 1820 | 275 | 822,000 | 25 |

¹ PV = photovoltaic solar panel.

The long-term sustainability assessment revealed that the proposed pilots of the RECENT are long-term viable and self-sustaining, and therefore, in an important role in the stability of the entire NPA region through the economic, social and environmental sustainability and stability of the communities. The diversity of the pilots and communities studied and assessed in the RECENT project will help in facilitating decision making about the development and use of renewable energy and energy-efficient solutions for housing and public infrastructures, especially suitable for dispersed settlements in harsh climates. The RECENT project dealt with many different unused assets (e.g., water, wind, solar, wastes and wastewater) and defined the challenges in the use of those assets and giving possible technical and economic solutions. This diversity of the communities and pilots will help to find the communities with such unused, available assets which can benefit from the results of the project.

4. Discussion

The aim of the RECENT project was to implement renewable energy solutions, enhance energy efficiency, improve utilization of unused assets mainly in the remote and sparsely populated communities and to increase public awareness and social well-being. According to the results, the realization of these pilots would provide competitive economic, environmental and social advantages and, in addition, contribute to the sustainability of communities.

Despite the northern location, solar photovoltaic energy generation seemed to be an increasingly attractive solution for the RECENT communities in the NPA region. With storage and smart control system, it can be seen as a viable solution even in the high north. However, as a negative note, lack of proper market incentives is hindering the profitability of solar systems in the NPA region. There is still huge unexplored wind potential in the NPA region, although investments in wind projects are large. As a key element in wind projects, this can be seen in the effective collaboration with local communities, in order to deliver benefits to the community these pilots work in. The uptake of heat pump technologies in Sweden and Finland is in active use, and there are more opportunities in the other areas and it could be explored in the NPA regions of UK and Ireland. Space heating technologies need more research, further technology development and support. Energy efficiency is rather easy solution; payback times of energy efficiency pilots can be as low as 1–2 years and they need only very reasonable investment costs.

Economics is only one of the dimensions to consider in sustainable energy projects; the community itself and its social and environmental benefits need to be recognized as well. This is one of the most important lessons learned from the RECENT and of the pilots; support systems are indispensable, especially for the rural and remote small communities. It is also of utmost importance that whilst most of the pilot solutions in RECENT are such that are replicable in the whole NPA region and also in other areas, there are also significant differences in legal and institutional framework of different nations and even regions and that needs to be taken into account when planning the sustainable solutions.

The project also aimed at pilots with synergies between environmental services. The result of RECENT project is similar to the recent results [10] which indicates that water, energy and waste nexus, in which organic municipal solid waste is in combination with wastewater, could be a promising and environmentally sustainable resource of energy and nutrient, and it could increase urban sustainability. This model should be modified to be used for the rural, sparsely populated areas as for the NPA program area. Synergies, achieved by nexus approach, can be estimated to be especially beneficial to small rural communities which have challenges to provide the services of the same quality for the reasonable or even same price as in more populated, southern parts of the countries. Infrastructures for energy and water supply, and waste and wastewater management are generally based on complex and centralized supply, collection and disposal systems which has become such an established standard that the reasoning behind its development and its sustainability and suitability for communities nowadays is still unquestioned. Although they have well-known advantages, they also have imminent disadvantages acting as barriers for effective integrated more sustainable resource management [10]. Moreover, this research should be done including even more wider resource base including, e.g., food [7–9].

The RECENT project presented the new and more sustainable way of providing environmental goods and services and to establish innovative infrastructures based on the integrated synergistic management of resources, e.g., water, waste and energy. An integrated sustainable resources management could be done in co-operation with land-use decisions and preservation of biodiversity. These integrated infrastructures could base on decentralized systems allowing synergies between different systems. Energy, water, and waste systems in nexus is needed when there is willingness towards more sustainable cities. Waste-to-energy pathways need to be emphasized, along with the water and energy sectors, when aiming to develop waste treatment and energy recovery with the lowest environmental and economic cost [11]. As the results of the RECENT project show, these synergistic solutions can significantly reduce resource consumption and related emissions, especially CO₂. In addition, they can aid to improve the sustainable development of European communities as

a whole. Hence, it is obvious, that the results of the RECENT projects are important, replicable and that there are need of such international information sharing projects in the future as well.

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