Mid-Term Progress Report

Water Joint Programming Initiative
2018 Joint Call

Closing the water cycle gap - Sustainable management of water resources

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"Sustainable technology for the staged recovery of an agricultural water from high moisture fermentation products" – acronym RECOWATDIG

This document must be filled in by the project coordinator with the help of its project partners and must be sent to the WaterWorks2017 Follow-up Secretariat by **31/10/2020** (for Consortium consisting of Wroclaw University of Science and Technology, Poland (WUST); AGH University of Technology, Poland (AGH); ZGO Gac, Poland (ZGO), Kungliga Tekniska Högskolan, Sweden (KTH); University of Twente , the Netherlands (UT) and HOST, the Netherlands (HOST); financed by following national agencies: National Centre for Research and Development (Poland), Nederlandse Organisatie Voor Wetenschappelijk Onderzoek (Netherlands), and Swedish Research Council Formas (Sweden))**.**

The WaterWorks2017 Follow-Up Secretariat will ensure distribution to the concerned national funding agencies. The project coordinator is responsible for sending a copy of the report to its partners.

"SUSTAINABLE TECHNOLOGY FOR THE STAGED RECOVERY OF AN AGRICULTURAL WATER FROM HIGH MOISTURE FERMENTATION PRODUCTS" RECOWATDIG

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1. Publishable Summary

Irrigation of crops is one of the areas of agriculture in which significant improvement can be achieved through the introduction of new practices and strategies for the water recovery from different resources, neglected nowadays. The state-of-the-art biogas plant has a substantial land requirement for the storage of digestate, typically 8 ha/MW of installed power, which introduces significant costs. Since digestate is rich in nutrients, land spreading is used as a utilisation option. However, European Nitrates Directive (91/676/EEC) is a significant obstacle for wider implementation of this practice. Moreover, currently separated liquid fraction is stored in lagoons, thus leading to significant losses through evaporation. This project aims to find a synergy between novel thermal processing techniques of digestate, such as HTC (hydrothermal carbonisation) and membrane processes, in order to maximise recovery of water, that would've been otherwise wasted. The primary goal of the project is to develop a front-end engineering design of the modular and transportable installation for the staged recovery of agricultural water from dewatering and drying of high moisture fermentation products. Each of the modules will be designed to fit into standard containers along with all the auxiliary devices, thus making the whole installation work according to Plug and Produce (PnP) principle. The most important objective is the determination of the optimum configuration of the water reclamation module based on a few stage purification methods, including the pressure membrane processes. The use of the ultrafiltration process will allow the retention of residues of organics, nutrients, colloids, and microorganisms. The nanofiltration process will separate multivalent ions and high molecular weight organic compounds. Both polymer and ceramic membranes with various molecular weight cut-off have been considered. Separation and transport properties of the tested membranes will be determined. Moreover, low molecular weight organic compounds will be separated, using advanced carbon-based materials, such as magnetic hydrochar. The second objective is to determine the optimum set of parameters for the HTC process. Optimisation will be performed in a context of factors, such as suitability of the liquid for subsequent digestion; dewaterability of the obtained hydrochars; suitability of the produced hydrochars for the use as soil amendments; suitability of the produced hydrochars and magnetic hydrochars for the use as an adsorbent for water purification; suitability for the use of hydrochars as a solid fuel. The third objective is optimisation of the subsequent drying by using low quality heat. Here, the optimum parameters aiming for maximisation of the recovery of the evaporated water through condensing along with maintaining sensible efficiency and the size of the module feasible enough for the containerising process will be researched. All objectives will be related to modelling of all the main processes in the installation. Furthermore, efforts will focus on the determination of the maximum productivity of the installation that would still allow maintaining its modular and transportable nature, turning by-products into useful/marketable products (e.g. magnetic biochar) and the optimum size of the accumulation tank that would allow to maximise the use of cheap, off-peak electricity.

So far, in the first 18 months of the project, the cutting-edge research, conducted within the course of the project, has resulted in many scientific publications in internationally renowned, high-impact journal. The project team is pioneering the field of membrane purification of HTC effluent. Extensive research allowed to achieve a deep understanding of the influence of HTC parameters (temperature and residence time) on the structural changes of digestate, as well as on the composition of liquid fraction and, most of all, on the possibility to maximise water recovery, by energy-efficient mechanical dewatering. This gives a good basis for design activities that are planned in the next 18 months of the project.

2. Work Performed and the Results achieved during the reporting period

a. Scientific and technological progress

During the course of the first 18 months of the project, work has been performed within the scope of the following work packages:
WP1 "Project Management"
WP2 "Hybrid membrane purification of the recovered water for the agricultural use"
WP3 "Improvement of the dewatering properties of the digestate and its sanitization via HTC"
WP4 "Sustainable recovery of water from low temperature drying of hydrochars, using condensing heat exchanger."
WP5 "Determination of the physical, structural and chemical properties of hydrochars produced from digestate."
WP6 "Use of by-products from water recovery and purification stages."

WP1 is an ongoing task, throughout the whole project. Apart of standard management activities, additional effort was needed in order to develop the mitigation plan, when the 1st wave of COVID-19 pandemic was getting close to being over. However, currently 2nd wave of the pandemics started, which will require additional planning. This can be done, when the second wave will be close to being over. Milestones M1.1 and M1.2 have been achieved.
The aim of the WP2 task is to define a set of optimal parameters for conducting the process of water recovery from the liquid fraction of the digestate and post-condensation water using pressure membrane processes. The proposed technology guarantees the recovered water will be safe. Thanks to this, consumers will be sure that the products they consume are safe and businesses will get greater development opportunities. Within the scope of work of WP2 M.2.1 has been achieved. M2.2 is close to be achieved and only characterisation of the condensate after drying is required. This will be accomplished soon after finishing the tests within the scope of WP4.
As part of the task, a process diagram of the biogas plant located at ZGO Gać and a preliminary mass and energy balance were made.
The following laboratory setups have been prepared for this task:

- a laboratory setup for carrying out the process of chemical coagulation/precipitation using different reagents,
- a setup to carry out a membrane filtration process using flat polymeric membranes of different cut-off in a dead-end system,
- a cross-flow setup to carry out membrane pressure processes using flat ceramic membranes with various cut-off.

Process efficiency was determined by measuring the concentration of organic compounds, expressed as COD, BOD_5 and DOC contained in solution before and after treatment. The determination of COD and BOD_5 was carried out using standard methods: two chromate and dilution method respectively. The DOC concentration was measured on the Shimadzu TOC 5050 carbon analyser.
The research began with the determination of the physico-chemical properties of the liquid fraction of HTC digestate from a biogas plant processing the organic fraction of municipal waste and from an agricultural biogas plant. The properties of the research solutions are presented in the tables below.

Table 1. Composition of the liquid digestate fraction from the municipal waste biogas plant

Index	Liquid digestate fraction from the municipal waste biogas plant	Liquid digestate fraction from the rural biogas plant after HTC
pH	6.2	7.2
Conductivity, mS/cm	8.13	14.95
Total suspended solids, mg/dm^3	254	3,950
Chemical oxygen demand (COD), mg O_2/dm^3	8980	38,595
Biochemical oxygen demand (BOD), mg O_2/dm^3	9520	12,320
Dissolved organic carbon (DOC), mg C/dm^3	2995	23,070

Na, mg/dm^3	293.6	521.3
K, mg/dm^3	688.9	1,966.5
Ca, mg/dm^3	28.2	104.7
Mg, mg/dm^3	449.7	101.9
Fe, mg/dm^3	2.2	15.9
Mn, mg/dm^3	3.9	1.5
Cu, mg/dm^3	0.096	0.545
Zn, mg/dm^3	0.630	3.977
Hg, mg/dm^3	0.0036	0.0029
Co, mg/dm^3	0.137	0.069
Ni, mg/dm^3	0.270	0.147

Preliminary studies were carried out to determine the effect of the filtration process of the liquid fraction of digestate coming from municipal waste biogas plants on the efficiency of removal of suspended solids and organic compounds using bag filters with different pore sizes (1, 10, 50, 100, 200 and 600 μm). It was observed that although the application of filtration process allowed to eliminate the suspended fraction, the liquid fraction still contained a large amount of dissolved substances and <1 μm particles.

Further research, aimed at determining the effectiveness of purification of the liquid fraction of the digestate in the process of coagulation/chemical precipitation, allowed to determine the usefulness of different reagents (PIX112 coagulant, $FeCl_3$ and CaO) and the influence of reaction time and dose on the effectiveness of organic and ammonium nitrogen reduction. It was found that all tested reagents can be effectively used for preliminary purification of the liquid fraction of the digestate. The effectiveness of organic compounds removal is determined by the dose of the reagent and the reaction time. An increase in the dose of each of the tested reagents allowed to improve the quality of the purified digestate. On the other hand, the increase in reaction time did not improve the efficiency of the process, even with the increase in reaction time there was an increase in the content of organic compounds due to their desorption. On the contrary, the concentration of ammonium nitrogen did not depend on the size of the reagent dose, but on the reaction time - in the first hours of the process the efficiency of desorption was low and a high degree of ammonium nitrogen reduction in the leachate required at least 24 hours of the process duration.

The next series of studies concerned the usefulness of the ultrafiltration process for the purification of the liquid fraction of the digestate. The research started from the preparation of polymeric membranes made of polyether sulfone with 10 kDa cut-off through the process of their conditioning. In order to determine the separation and transport properties of the tested membranes the permeate flux and the impurities retention factor were determined. It was noticed that an increase in transmembrane pressure did not cause an increase in permeate stream, which could be caused by the formation of a filter cake on the membrane surface. Also, no effect of transmembrane pressure on the effectiveness of contaminants removal was observed. The 10 kDa membrane allowed to remove only up to about 30% of impurities, with COD being lowered most effectively and BOD_5 least effectively. It was found that low separation efficiency suggests the necessity of using denser membrane.

Then the efficiency of purification of the analysed digestate was determined in the sedimentation-ultrafiltration process using flat ceramic membranes with cut-off 15 and 50 kDa. The results obtained show that the tested membranes can be used in the treatment of the digestate, although with an increase in the cut-off value a slight deterioration of permeate quality can be observed. The application of the sedimentation process before ultrafiltration allows not only to improve the final quality of the permeate but also to partially reduce membrane fouling.

At a further stage of the research, the effectiveness of the treatment of the liquid fraction of the digestate from the municipal waste biogas plant in an integrated process combining chemical coagulation/precipitation (using PIX112, $FeCl_3$ or CaO) with ultrafiltration (using polymeric membranes made of polyether sulfone (PES) or regenerated cellulose (C) with a cut-off of 10 and 30 kDa) was determined. The obtained results show that the improvement of the efficiency of the digestate purification is possible with this type of integrated process. The best results were observed in combination with 20 g/dm³ $FeCl_3$ coagulation with ultrafiltration on the 10 kDa PES membrane. In addition, it was observed that only the use of PIX112 coagulant before ultrafiltration partially reduced the fouling problem of the tested membranes.

Besides changes in the concentration of organic substances as well as particle size distribution and zeta (ζ) potential were analysed. 20 g/dm³ of $FeCl_3$, of out of the tested reagents, showed the highest effectiveness in removing organic pollutants. The use of a coagulation process for digestate purification caused significant changes in the properties of the particles remaining in the solution, including zeta potential and particle size distribution. The application of $FeCl_3 \cdot 6H_2O$ in the amount of 10 g/dm³ caused particle size distribution to shift towards finer particles, a median diameter decreased from 12 µm (in raw digestate) to about 8 µm. The ζ potential value was reduced by about 5-10 mV in the pH range 2.5-12. Increasing the amount of $FeCl_3 \cdot 6H_2O$ to 20 g/dm³ resulted in the disappearance of the finest and largest fraction and generated a positive high electrokinetic potential, Such significant changes in the properties of molecules in the purified solution were not observed for the other reagents.

Considering the insufficient efficiency of purification of the liquid digestate fraction in the membrane processes used on their own, sequential combinations of their properties were proposed. The aim of such a procedure was both to improve the final quality of the purified digestate and to reduce the intensity of membrane fouling. This research concerned the effectiveness of the purification of the liquid fraction of agricultural digestate after HTC. It was shown that the combination of screening mechanisms of the tested membranes significantly increased the effectiveness of removing organic compounds from the analysed digestate. It was found that the final quality of the purified solution was determined by the molecular weight cut-off value, while the value of applied transmembrane pressure and the material of the membrane used were of no significance. The best results were obtained by conducting sequential purification of the digestate in the variant: MF 0.2 µm → UF PES 10 kDa → NF NPO30P. It was also shown that the application of the nanofiltration membrane NPO30P improves the separation properties of the membranes, but it also deteriorates their transport properties.

Works, within the scope of WP3, started with a suite of experiments, focused on hydrothermal carbonisation. Milestones M3.1 and M3.2 have been achieved. As M3.2 has been received only recently, due to Covid19 difficulties, related to closure of labs followed by limitation of the personnel present in the labs, some time is till needed to achieve M3.3. The work on energy balances is ongoing and it is planned to be finished in November/December 2020.

The digestate from the anaerobic digester of Municipal solid waste of Z.G.O Gać company located in Poland was used as the feedstock. All the samples were taken to the laboratory and stored in a fridge at 4-5°C until for no longer than 6 months to prevent any enzymatic or chemical activity.

The experimental work was carried out on a bench scale. The sample homogenization was carried out by grinding the wet biomass with a Retsch GM 200 knife mill. The prepared biomass was treated with HTC under different conditions. The thermally treated was dewatered with a filter press at different conditions as well. The resulting products were quantified and characterized.

Thermal experiments were conducted in a customized non-stirred 136 mL stainless steel batch reactor. In each batch experiment, 100mL of sludge sample was loaded in the reactor and sealed. Tests were carried out at 180 °C, 200 °C and 230 °C with a retention time of 15. 30, 60 and 120 min. The allowance for temperature fluctuation inside the reactor was in the range of +/- 5 °C. After treatment, the reactor was cooled down to 25°C. After every test, the solid fraction was removed mechanically by hand pressing and dried for 24 hours at 105 °C before grinding. HTC products (Solid and liquid) were collected in a separate container and retired for further characterization. All experiments were carried out in triplicate.

Special pressing assembly was designed and manufactured in order to perform mechanical dewatering of the digestate and hydrochar samples. This assembly was subsequently used, along with a hydraulic press (HBM Machines BV) equipped with a pressure gauge, to perform dewatering of hydrochars. The pressure tested was 30 bar and was selected in agreement with the values reported by the project partner company.

Table 3: Mass balance of the HTC-MSWD treatment

Sample	Initial stage: $Solid_{initial}$ (g)	Initial stage: $Liquid_{initial}$ (g)	HTC Treatment: $Solid_{HTC}$ (g)	HTC Treatment: $Liquid_{HTC}$ (g)	HTC Treatment: Gas_{HTC} (g)	Dewatering: $Solid_{Hydrochar}$ (g)	Dewatering: $Liquid_{Recovered}$ (g)	Hydrochar Yield (%)
MSW Digestate RAW	29.06± 2.42	70.94±0.70	-	-	-	28.34±4.57	18.39±2.78	97.52%± 3.33%
HTC MSW Digestate								
180 °C- 30min-10 bar	29.06± 2.42	70.94±0.70	27.08± 0.56	71.90± 0.65	1.01± 0.39	21.06±1.93	42.06±2.43	72.45%± 5.22%
180 °C- 60min-10 bar	29.06± 2.42	70.94±0.70	27.54± 0.07	71.81± 0.18	0.65± 0.24	21.33±0.69	43.58±3.40	73.40%± 5.31%
180 °C- 120min-10 bar	29.06± 2.42	70.94±0.70	27.77± 0.04	71.53± 0.11	0.70± 0.16	22.84±1.29	43.03±1.37	78.60%± 2.28%
200 °C- 30min-17 bar	29.06± 2.42	70.94±0.70	26.45± 1.48	72.49± 1.38	1.06± 0.20	20.56±1.54	43.47±3.78	70.74%± 5.73%
200 °C- 60min-17 bar	29.06± 2.42	70.94±0.70	26.00± 0.06	73.25± 0.18	0.75± 0.24	21.90±3.41	41.09±2.06	75.37%± 3.17%
200 °C- 120min-17 bar	29.06± 2.42	70.94±0.70	27.47± 0.03	71.59± 0.09	0.94± 0.12	20.75±1.27	46.74±0.48	71.41%± 0.79%
230 °C- 30min-27 bar	29.06± 2.42	70.94±0.70	26.40± 0.60	72.51± 0.97	1.08± 0.48	20.86±3.82	41.75±1.48	71.77%± 3.38%
230 °C- 60min-27 bar	29.06± 2.42	70.94±0.70	23.85± 0.04	74.79± 0.12	1.36± 0.16	19.51±1.24	48.13±3.71	67.11%± 1.55%
230 °C- 120min-27 bar	29.06± 2.42	70.94±0.70	21.40± 0.12	76.82± 0.43	1.78± 0.55	18.66±1.07	47.11±2.65	64.21%± 3.96%

Table 4: Ultimate analyses of the feedstock (MSWD) and hydrochar.

Sample	Ultimate analysis: C (%)	Ultimate analysis: H (%)	Ultimate analysis: N (%)	Ultimate analysis: O^a (%)	HHV (MJ kg^{-1})	Energy densification (MJ kg^{-1})	Energy Yield
MSW Digestate RAW	19.97 ± 0.85	2.37 ± 0.13	1.20 ± 0.15	13.13 ± 0.93	6.17 ± 0.23	-	-
HTC MSW Digestate							
180 °C- 30min-10 bar	20.46 ± 0.88	2.43 ± 0.16	1.40 ± 0.51	14.57 ± 1.19	8.24 ± 0.14	1.34 ± 0.02	96.82% ± 1.69%
180 °C- 60min-10 bar	20.67 ± 0.53	2.39 ± 0.06	1.48 ± 0.34	12.66 ± 0.78	7.43 ± 0.15	1.21 ± 0.02	88.45% ± 1.79%
180 °C- 120min-10 bar	22.21 ± 0.80	2.64 ± 0.21	1.45 ± 0.24	13.57 ± 1.07	7.03 ± 0.09	1.14 ± 0.01	89.61% ± 1.16%
200 °C- 30min-17 bar	21.90 ± 0.88	2.50 ± 0.12	1.51 ± 0.28	14.20 ± 0.87	8.20 ± 0.25	1.33 ± 0.04	94.05% ± 2.88%
200 °C- 60min-17 bar	25.67 ± 0.97	3.03 ± 0.05	1.67 ± 0.32	6.73 ± 1.22	8.36 ± 0.29	1.36 ± 0.05	100.48% ± 3.60%
200 °C- 120min-17 bar	20.67 ± 0.91	2.41 ± 0.12	1.24 ± 0.24	11.93 ± 1.05	9.24 ± 0.19	1.50 ± 0.03	106.00% ± 2.18%
230 °C- 30min-27 bar	24.31 ± 1.04	2.73 ± 0.20	1.79 ± 0.11	8.27 ± 0.74	7.94 ± 0.11	1.29 ± 0.02	92.47% ± 1.29%
230 °C- 60min-27 bar	22.51 ± 0.50	2.62 ± 0.06	1.75 ± 0.06	12.78 ± 0.60	8.94 ± 0.05	1.45 ± 0.01	97.32% ± 0.57%
230 °C- 120min-27 bar	23.01 ± 0.58	2.59 ± 0.09	1.68 ± 0.07	17.91 ± 0.65	9.22 ± 0.18	1.50 ± 0.03	96.04% ± 1.91%

The moisture content of the drained material was subsequently determined in duplicates, at 105 °C, using the moisture analyzer, with a scale resolution of 0.001 g and a maximum sample mass of 50 g. The mass of the sample was considered to be in equilibrium when the first derivative of the mass (dm/dt) was equal or smaller than 1 mg/min.

The mass balance of HTC of MSWD are shown for the different process temperature and residence time in Table 3. The results showed that there was a solid reduction after the HTC treatment and the reduction increased as the reaction temperature of the treatment increased. HTC treatment led the MSWD to improve the dewatering water recover from 18% to up to 48%. The hydrochar yields ranged from 64 to 78% during all treatment.

The elemental composition and the energy properties of the feedstock and hydrochars are presented in table 3. The results showed that after thermal treatment, the carbon content increased from 19.97% (original feedstock) up to 25.67% (200 °C – 60 min -17 bar). The HHVs of hydrochars coming from MSWD were higher in comparison with the original feedstock ranging from 7.03 to 9.24 MJ kg-1.

The next step is to determine the energy balance of the different thermal conditions of the MSWD based on the information obtained from the experimental data.

HTC process had led to significant changes in physical and chemical properties of obtained hydrochars comparing to raw material, which was a focal point of WP5. The detailed analysis of obtained hydrochars were carried out by AGH group according to WP5 schedule. The following investigations were done:

- The proximate analysis of raw material and hydrochars was performed according to the standards EN15934:2012 (moisture, M), EN 15403:2011 (ash, A) and EN 15402:2011 (volatile matter, VM).
- Elemental analysis: determination of carbon (C), hydrogen (H) and nitrogen (N) contents in raw and hydrochars was performed using the Truspec CHN628 Leco analyser. The determination of elements is based on the Dumas method, where the studied sample is combusted in pure oxygen at 950 °C temperature.
- The structural investigation was carried using scanning electron microscopy (SEM) by the FEI Inspect S50 microscope. The imaging of the structure was carried out using a secondary electron detector, in a very high vacuum mode, at a voltage of 1 kV.
- The porosimetry was performed using ASAP 2010, produced by Micromeritics (USA). Firstly, the samples were degassed at 150 °C, for approx. 24 hours. Porosimetry was performed, using samples of approx. 1 g for each of the materials. Full adsorption/desorption isotherms of nitrogen were recorded for each experiment, for p/p0 ranging between 0.005 and 0.989 at the temperature of 77.35 K. Specific surface area and average pore diameter was determined for each sample, using BET method, based on adsorption isotherms for p/p0 ranging between 0.06 and 0.20. The total volume of pores was determined by applying the BJH method to the desorption curves. Furthermore, desorption curves were also used to determine pore size distribution for mesopores and lower size range of macropores, i.e. pores with the diameter ranging between 2 nm and 100 nm, by applying the BJH method.
- Thermogravimetric analysis was performed using Mettler Toledo apparatus. The analysis parameters were as follows: alumina crucible (Al_2O_3) was used, 10 mg of sample mass, air atmosphere, 40 ml/min volume flow rate, 10 K/min heating rate, temperature range from ambient to 700 °C. During the linear temperature increase, the weight change was recorded in the form of TG curves (thermogravimetry) and thermal effects in the form of the DSC curve. The DTG curve was created by calculation (it is the first derivative of TG results).

The most significant results:

- HTC chars resulted the slight increase of carbon content, in comparison to the raw digestate. It should be noticed that studied material was characterised by complexity and inhomogeneity. The most significant effect of carbon content increase (up to 25 %) was obtained in terms of carbonisation under 200 °C temperature with the residence time of 60 minutes. In this study the increase of process temperature did not influence on the carbon content increase confirming successful of HTC. Probably the part of carbon went to hydrothermal water under higher temperature. The impact of temperature and residence time (confirming successful of HTC) was observed based on increasing of ash and decreasing of volatile matter contents among hydrochar samples. There was not observed the increases of fixed carbon (FC) and fuel ratio (FC/VM) what is typical for sewage sludge samples.
- Based on structural and morphological investigations (under wide range of magnifications) it can be stated that the carbonization process caused evident fragmentation of samples. The raw sample was characterized by large elements of various shapes and morphology. The most significant destruction of material was observed for hydrochar obtained under 230 °C.
- In general, the use of HTC as a pre-treatment resulted in an increase of the specific surface area of the digestate. However, that change seems to be controlled mostly by the residence time, rather than by the temperature of the reaction. Moreover, for the longer residence time (120 min) obtained BET surface is significantly smaller, in comparison to the experiments performed with shorter residence times (60 min). This can be clearly observed for both temperatures of HTC. It seems plausible to hypothesise that the change of the specific surface area, observed in this study for HTC residence time of 60 and 120 min, was caused by repolymerisation of complex hydrocarbons in the liquid phase, which subsequently filled a part of new porous surface, initially created by HTC treatment. Moreover, it seems sensible to

suspect, that with longer residence time, more area of the porous surface would be gradually filled with particles of these compounds, which would subsequently lead to further decrease of the specific surface area, to the point that the surface area after HTC would be lower than the surface area of the feedstock. This hypothesis seems to be confirmed by the results of the total pore volume. In this case, total pore volume was also a subject of increase, for both HTC temperatures, and subsequently decreased for longer residence times. Overall, if the goal of HTC was to produce highly porous sorbent, then lower residence time would be advised. Alternatively, another activation step, e.g. plasma activation, would be required in order to open up the closed pores. Finally, it should not be overlooked that good agreement was obtained, regarding the determination of mean pore diameter, using BET and BJH methods.
The research on use of by-products from water recovery and purification stages (WP6) was focused on pyrolysis of hydrochars from HTC of various digestates as such pyrolysis is a prerequisite of the magnetization. The hydrochar derived from agricultural digestate, delivered by WUST, as well as the digestate, after anaerobic digestion of sewage sludge, has been a subject of characterization in order to initially determine their suitability for pyrolysis at KTH. This was followed by an extensive suite of pyrolysis experiments. The pyrolysis was performed at three peak temperature (450, 550, 650 °C) to produce the biochar. The magnetization of selected biochars will be performed and optimized in the coming 6 months. Moreover, the thermal behaviour of raw materials and hydrochar samples under combustion conditions was investigated by AGH, using thermogavimetric analysis. The results were obtained in the form of TG, DSC and DTG curves. Based on thermal analysis and obtained TG (thermogravimetric) and DTG (derivative thermogravimetric) data, the ignition (Di), combustion (S and Hf) and burnout (Df) indexes were calculated. Di indicates how fast the fuel gets ignited, while S gives the fuel overall characteristics.

b. Collaboration, coordination and mobility

Collaboration between partners has been effective, leading to a couple of joint publications at international conferences and in internationally renowned journals. The contribution of each partner is clearly identifiable, as can be seen in the sub-section 2.a of this report. Coordination and organization of the project has been efficient, which allowed to minimize the delay time, caused by Covid19.
Collaboration was mostly realized by sending samples, exchanging knowledge and experiences, as well as support in interpretation of the obtained results.
Additionally, collaboration resulted in participation in the mobility programmes. I.e. one PhD student from Wrocław University of Science and Technology took part in Erasmus + programme and did an internship at the University of Twente. This internship started on the 1st of August 2019 and ended on 31st of May 2021. Moreover, one MSc student from Wrocław University of Science and Technology also took part in Erasmus + programme and did an internship at the University of Twente. This internship started on the 13th of January 2020 and ended on 31st of May 2021. During the lockdown time of the 1st wave of Covid19, the work was performed in the home-office mode, in regular contact with the staff of UT. The internship of the MSc student allowed doing experiments leading to successful defense of the MSc thesis, titled "Wet torrefaction of the digestate from anaerobic digestion process". Thus, the project can be considered to be of a transnational nature.

c. Impact and knowledge output

Main impacts of the project have been achieved. Since proposed solutions are highly innovative research work, obtained results were suitable for publication at the internationally renowned conferences and in the high impact scientific journals, as shown in section 7 of this report. Obtained results will be exploited in the second half of the project, as the results will become a basis for the front-end engineering design of the proposed installation for recovery of water from digestates.

3. Table of Deliverables

Please indicate whether the planned deliverables are completed, delayed or readjusted. Explain any changes/difficulties encountered and solutions adopted. Please add/delete rows, as necessary in the table below.

Deliverable name	**Lead partner (country)**	**Date of delivery (dd/mm/yyyy)**	**Changes, difficulties encountered and new solutions adopted**
WP1			
D1.1: "Project Quality Assurance, Risk Contingency and Data Management Plan, with templates (for financial and technical reporting, etc.)"	WUST (Poland)	15/08/2019	Final templates were adjusted to include information requested in the mid-term report template, based on the information supplied by the Project Manager of Water JPI by e-mail (29/07/2019).
D.1.2: *"Annual project report (1-st year)"*	WUST (Poland)	23/01/2020	Supplied ahead of schedule, to the funding agency in Poland (NCBiR). Such change of schedule was made, due to national regulations.
WP2			
D.2.1: "Physico-chemical properties of liquid fraction from HTC of the digestate."	WUST (Poland)	15/12/2020	Almost ready – the delay has been caused by COVID-19 pandemic. The mitigation plan has been introduced, when the 1st wave of pandemic was getting close to being over. However, currently 2nd wave of the pandemics started, therefore given deadline can be treated only as the approximation. The analysis of the agricultural digestate after HTC is ready. The analysis of the digestate from the municipal waste biogas plant after HTC is in progress because the samples for analysis have only just been received. Instead a full physico-chemical analysis of the digestate before HTC has been performed.

Deliverable name	Lead partner (country)	Date of delivery (dd/mm/yyyy)	Changes, difficulties encountered and new solutions adopted
D.2.2: "Multistage purification of liquid fraction from HTC of the digestate: optimal configuration and parameters of MF, UF, NF and FO membranes."	WUST (Poland)	29/01/2021	The work has been significantly delayed, due to COVID-19 pandemic. The mitigation plan has been introduced, when the 1st wave of pandemic was getting close to being over. However, currently 2nd wave of the pandemics started, therefore given deadline can be treated only as the approximation. Some of the configurations has been tested for agricultural digestate. However, the wet MSW digestate has only recently been HTC treated in the autoclave in WUST. Therefore, only recently sufficient amounts of HTC effluent from wet MSW have been produced. Optimum configuration of membrane cascades will require further testing.
WP3			
D.3.1: "Optimization of HTC process for maximum dewatering of the hydrochars produced from the digestate."	UT (Netherlands)	09/12/2020	There has been a delay on the completion of activities from April to July due the COVid-19 pandemic (the laboratory was closed, and no new experiments were possible to conduct). For that reason, a delay of about 3-4 months is expected.

4. Budget review

Please include a budget breakdown here, i.e. how the funding has been used so far.

WUST: Personnel Costs: 26 754.15 € Consumable: 36 973.51 € Travel: 1163.15 € Overheads: 16222.70 €

The single biggest expense was a purchase of different membranes (counted as consumables), amounting to 28 592,62 €. <u>AGH:</u> Personnel Costs: 10 495.72 € Travel: 217.08 € Consumables: 2 693.27 € Overheads: 3 351.51 € Total: 16 757.58 € <u>UT:</u> Personel cost 71004.00 € Travel 900.00 € Consumables 4260.00 € <u>KTH:</u> Personnel Costs: 57 825.00 € Consumable: 12 563.00 € Travel: 1 625.00 € Other: 133.00 € Overheads: 42 087.00 € Total: 114 233.00 € <u>ZGO:</u> Personnel Costs: 8000.00 € Overheads: 2000.00 € Total: 10 000.00 € <u>HOST:</u> HoSt did not request any funding from the project and joined the project with their own funding.

5. Consortium Meetings

N°	Date	Location	Attending partners	Purpose/ main issues/main decisions?
1	14/04/2019	Stockholm, Sweden	WUST, KTH	Kick-off meeting organised by Water JPI
2	23/09/2019	Wrocław, Poland	WUST, KTH, UT, AGH, ZGO	Progress meeting. Partners presented their progress so far.
3	09/04/2020	On-line	WUST, KTH, UT, AGH, ZGO	Progress meeting. Due to Covid-19 the meeting was organised on-line. Partners presented their progress so far. Delay due to Covid-19 related restrictions was assessed. It was agreed that project

				coordinator will ask Water JPI project management for possibility of extension of the project, due to delays, caused by difficulties in terms of the access to the laboratories.
4	01/10/2020	On-line	WUST, KTH, UT, AGH, ZGO	Progress meeting. Due to Covid-19 the meeting was organised on-line. Partners presented their progress so far. Delay due to Covid-19 related restrictions was assessed. An information, regarding possible extension of the project was communicated to the partners.

6. Stakeholder/Industry Engagement

Maximum 1 page

The involvement of the key user – ZGO Gać has been significant. Consortium obtained requested samples along with data regarding the yearly processing capabilities of the processing lines. Moreover, the insight from the staff of ZGO has been crucial in terms of understanding of the problems posed by wet MSW digestate. Samples were crucial for all the experimental work performed so far, which allowed to publish the results in high-impact, internationally renowned journals, due to high novelty of the performed research. This, along with the communication between ZGO and academic partners was also beneficial for ZGO, as it allowed gaining some insight regarding potential, novel utilization routes for the highly problematic digestate from anaerobic digestion of wet Municipal Solid Waste (MSW). All this experience, gained on environmentally friendly processing of wet MSW digestate, will be crucial during the 2nd half of the project. This knowledge will be especially valuable during the course of WP8, where front-end engineering design will be developed in close co-operation with technology developer and project partner HoSt.

7. List of Publications produced by the Project - Open Access

Metadata on all project publications are required to be submitted as part of the final reporting. This will be done via the **Open Data & Open Access platform**, available at: http://opendata.waterjpi.eu/ (also accessible from the bar menu of the Water JPI website).

International	Peer-reviewed journals	1. A. Urbanowska, M. Kabsch-Korbutowicz, M. Wnukowski, P. Seruga, M. Baranowski, H. Pawlak-Kruczek, M. Tkaczuk-Serafin, K. Krochmalny, Ł. Niedźwiecki *"Treatment of liquid by-products of Hydrothermal Carbonization (HTC) of agricultural digestate using membrane separation"* **Energies 2020**, vol. 13, ISSN: 1996-1073, DOI:10.3390/en13010262 https://www.mdpi.com/1996-1073/13/1/262 Journal's Impact Factor: 2.702 (2019) Gold Open Access

2. H. Pawlak-Kruczek, A. Urbanowska, W. Yang, G. Brem, A. Magdziarz, P. Seruga, Ł. Niedźwiecki, A. Pozarlik, A. MlonkaMędrala, M. Kabsch-Korbutowicz, E. Bramer, M. Baranowski, M. Sieradzka, M. Tkaczuk-Serafin *"Industrial process description for the recovery of agricultural water from digestate"* **Journal of Energy Resources Technology 2020**, vol. 142, issue 7, ISSN: 0195-0738, DOI: 10.1115/1.4046141
https://asmedigitalcollection.asme.org/energyresources/article-abstract/142/7/070917/1073977/Industrial-Process-Description-for-the-Recovery-of
Journal's Impact Factor: 3.183 (2019)

3. H. Pawlak-Kruczek, Ł. Niedźwiecki, M. Sieradzka, A. Mlonka-Mędrala, M. Baranowski, M. Tkaczuk-Serafin, A. Magdziarz *"Hydrothermal carbonization of agricultural and municipal solid waste digestates - Structure and energetic properties of the solid products"* **Fuel 2020**, vol. 275, ISSN: 0016-2361, DOI:10.1016/j.fuel.2020.117837
https://www.sciencedirect.com/science/article/pii/S0016236120308334
Journal's Impact Factor: 5.578 (2019)
Gold Open Access

4. S. Wang, H. Persson, W. Yang, P. G. Jönsson *"Pyrolysis study of hydrothermal carbonization-treated digested sewage sludge using a Py-GC/MS and a bench-scale pyrolyzer"* **Fuel 2020**, vol. 262, DOI: 10.1016/j.fuel.2019.116335
https://www.sciencedirect.com/science/article/abs/pii/S0016236119316898
Journal's Impact Factor: 5.578 (2019)
Gold Open Access

5. A. Urbanowska, M. Kabsch-Korbutowicz *"Analysis of the pre-treatment efficiency of digestate liquid fraction from a municipal waste biogas plant"* **Environment Protection Engineering 2019**, vol. 45, issue 4, pp. 103-113, DOI: 10.5277/epe190408
https://dbc.wroc.pl/dlibra/publication/143545/edition/74977/content
Journal's Impact Factor: 0.812 (2019)

Manuscripts - submitted:

6. A. Urbanowska, I. Polowczyk, M. Kabsch-Korbutowicz "*Treatment of municipal waste biogas plant digestate using physico-chemical and membrane processes*" **Desalination and Water Treatment**, accepted for publication

7. A. Urbanowska, I. Polowczyk, M. Kabsch-Korbutowicz, P. Seruga "*Characteristics of changes in particle size and zeta potential of the digestate fraction from the municipal waste biogas plant treated with the use of chemical coagulation/precipitation processes*" **Energies**, under review

		Manuscripts - in preparation: 8. authors from KTH *"Kinetics study of HTC pretreatment influence on the pyrolysis of anaerobic agricultural waste digestate"* 9. authors from KTH *"Synergistic effect in co-pyrolysis of sewage sludge digestate and lignocellulosic biomass: Reaction mechanism, product characterization and char stability"* 10. authors from KTH *"Study of Pyrolytic Mechanism, Kinetics and Product of Hydrothermal Carbonization–Treated Pulp and Paper Mill Sludge"*
	Books or chapters in books	1.
	Communica-tions (presentations, posters)	1. International Conference on Advances in Energy Systems and Environmental Engineering (ASEE19), 9th – 12th of June **2019,** Wrocław, Poland *"Hydrothermal carbonization of the digestate as an innovation way for recovery of the water for agricultural purposes"* **Oral presentation**; A. Urbanowska, M. Kabsch-Korbutowicz, M. Wnukowski, M. Baranowski, H. Pawlak-Kruczek, M. Tkaczuk-Serafin, K. Krochmalny, Ł. Niedźwiecki 2. 44th International Technical Conference on Clean Energy (Clearwater2019), 16th – 21st of June **2019,** Clearwater, Florida, USA *"Hydrothermal carbonization of the digestate as an innovation way for recovery of the water for agricultural purposes"* **Oral presentation**; H. Pawlak-Kruczek, Ł. Niedźwiecki, A. Urbanowska, W. Yang, G. Brem, A. Magdziarz, A. Pożarlik, A. Mlonka-Mędrala, M. Kabsch-Korbutowicz, E. Bramer, M. Baranowski, M. Tkaczuk-Serafin, M. Sieradzka 3. 32nd International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems (ECOS2019), 23rd –28th of June **2019,** Wrocław, Poland *"Structural and energetic properties of hydrochars obtained from agricultural and municipal solid waste digestates"* **Oral presentation**; H. Pawlak-Kruczek, M. Sieradzka, A. Mlonka-Mędrala, M. Baranowski, M. Tkaczuk-Serafin, A. Magdziarz, Ł. Niedźwiecki 4. XXIV International Symposium on Combustion Processes (ISCP2019), 23rd – 25th of September **2019,** Wrocław, Poland *"Membrane separation as an innovative way of water separation from liquid by-products of wet torrefaction of agricultural digestate"* **Poster**; A. Urbanowska, Ł. Niedźwiecki, M. Kabsch-Korbutowicz, M. Wnukowski, M. Baranowski, P. Seruga, H. Pawlak-Kruczek, K. Krochmalny, M. Tkaczuk-Serafin 5. XXIV International Symposium on Combustion Processes (ISCP2019), 23rd – 25th of September **2019,** Wrocław, Poland *"Influence of the HTC treatment on fast pyrolysis of agricultural biomass"* **Poster**; E. Bramer, P.

		Owczarek, A. Bijl, Ł. Niedźwiecki, A. Pozarlik, K. Mościcki, M. Wnukowski, H. Pawlak-Kruczek, G. Brem 6. 6th International Conference on Contemporary Problems of Thermal Engineering (CPOTE 2020), 21st – 24th of September **2020**, Poland (on-line) *"Influence of the wet torrefaction treatment on the organic fraction of municipal solid waste digestate"* **Oral presentation**; C. Aragon-Briceño, A. Pożarlik, E. Bramer, G. Brem, S. Wang, W. Yang, H. Pawlak-Kruczek, Ł. Niedźwiecki, K. Mościcki, M. Płoszczyca Extended version of the conference paper will be submitted to one of the journals, which became media partners of the conference (high impact journals from Elsevier, MDPI, ASME, and Polish Academy of Science) – based on the recommendation from the Organising committee (expected in November/December 2020) 7. 6th International Conference on Contemporary Problems of Thermal Engineering (CPOTE 2020), 21st – 24th of September **2020**, Poland (on-line) *"Multiphase analysis of hydrochars from anaerobic digestion of municipal solid waste organic fraction"* **Oral presentation**; A. Magdziarz, A. Mlonka-Mędrala, M. Sieradzka, C. Aragon-Briceño, A. Pożarlik, E. Bramer, G. Brem, Ł. Niedzwiecki, H. Pawlak-Kruczek Extended version of the conference paper will be submitted to one of the journals, which became media partners of the conference (high impact journals from Elsevier, MDPI, ASME, and Polish Academy of Science) – based on the recommendation from the Organising committee (expected in November/December 2020) 8. 6th International Conference on Contemporary Problems of Thermal Engineering (CPOTE 2020), 21st – 24th of September **2020**, Poland (on-line) *"Separation of water from liquid by-products of the agricultural digestate HTC"* **Oral presentation**; A. Urbanowska, C. Aragon-Briceño, M. Wnukowski, M. Kabsch-Korbutowicz, A. Pożarlik, M. Baranowski, Ł. Niedźwiecki, P. Seruga, H. Pawlak-Kruczek, E. Bramer, G. Brem Extended version of the conference paper will be submitted to one of the journals, which became media partners of the conference (high impact journals from Elsevier, MDPI, ASME, and Polish Academy of Science) – based on the recommendation from the Organising committee (expected in November/December 2020)
National (separate lists for each nationality)	Peer-reviewed journals	1.
	Books or chapters in books	1.
	Communica-tions	1.

	(presentations, posters)	
Dissemination initiatives	Popular articles	1.
	Popular conferences	1.
	Others	1. H. Pawlak-Kruczek "RECOWATDIG – Waterworks 2017 RDI Funded Projects Booklet" 2019 http://www.waterjpi.eu/joint-calls/joint-call-2018-waterworks-2017/booklet/recowatdig/recowatdig-booklet.pdf

8. Knowledge output transfer

Short Title	Initial cleaning of wet MSW digestate effluent - basis for comparison
Knowledge Output Description	Knowledge, regarding feasibility of the initial cleaning of the effluent from wet MSW digestate, using coagulation and chemical precipitation. This is the basis for comparison with potential benefits, from incorporation of hydrothermal carbonisation as an integral part of the plant.
Knowledge Type	Exploitable scientific result
Link to Knowledge Output	Publication: A. Urbanowska, M. Kabsch-Korbutowicz "Analysis of the pre-treatment efficiency of digestate liquid fraction from a municipal waste biogas plant" Environment Protection Engineering 2019, vol. 45, issue 4, pp. 103-113, DOI: 10.5277/epe190408 https://dbc.wroc.pl/dlibra/publication/143545/edition/74977/content Submitted manuscripts: A. Urbanowska, I. Polowczyk, M. Kabsch-Korbutowicz "Treatment of municipal waste biogas plant digestate using physico-chemical and membrane processes" Desalination and Water Treatment, accepted for publication A. Urbanowska, I. Polowczyk, M. Kabsch-Korbutowicz, P. Seruga "Characteristics of changes in particle size and zeta potential of the digestate fraction from the municipal waste biogas plant treated with the use of chemical coagulation/precipitation processes" Energies, under review
Sectors & Subsectors	• Emissions and Water Reuse • Adaptation to Global Change

End User	o Environmental Managers & Monitoring – knowledge will be crucial in raising awareness, regarding digestate from anaerobic digestion of water, being a potential water resource, neglected so far. o Industry – knowledge will be crucial in raising awareness, regarding digestate from anaerobic digestion of water, being a potential water resource, neglected so far. o Scientific Community – published results will allow future comparison of different techniques of water recovery from wet MSW digestate.
IPR	n/a
Policy-Relevance	Knowledge is relevant in the context of the Sustainable Development Goals, especially Sustainable Development Goal 6 "Clean water and sanitation for all."
Status	One publication is published in Open Access and available at the Lower Silesian Digital Library. One of the manuscripts has been accepted for publication, whereas the other one is still under review. The knowledge can be applied by some end users, i.e. scientific community, as a basis for further research. Moreover, it will be a strong basis for future technology development efforts. Knowledge can be clearly deemed as a progress beyond the existing state-of-the-art, as one of the manuscripts has already been accepted for publication, after extensive peer-review in a high-impact, internationally renowned scientific journal.

Short Title	Membrane purification of the effluents after HTC
Knowledge Output Description	Knowledge on membrane purification of digestate gives information on the influence of the type of membrane and transmembrane pressure on the separation efficiency, i.e. reduction of COD, BOC, etc.
Knowledge Type	Scientific publications
Link to Knowledge Output	Publication: A. Urbanowska, M. Kabsch-Korbutowicz, M. Wnukowski, P. Seruga, M. Baranowski, H. Pawlak-Kruczek, M. Tkaczuk-Serafin, K. Krochmalny, Ł. Niedźwiecki "Treatment of liquid by-products of Hydrothermal Carbonization (HTC) of agricultural digestate using membrane separation" Energies 2020, vol. 13, ISSN: 1996-1073, DOI:10.3390/en13010262 https://www.mdpi.com/1996-1073/13/1/262 Conference proceedings: 6th International Conference on Contemporary Problems of Thermal Engineering (CPOTE 2020), 21st – 24th of September 2020, Poland (on-line) "Separation of water from liquid by-products of the agricultural digestate HTC" Oral presentation; A. Urbanowska, C. Aragon-Briceño, M. Wnukowski, M. Kabsch-Korbutowicz, A. Pożarlik, M. Baranowski, Ł. Niedźwiecki, P. Seruga, H. Pawlak-Kruczek, E. Bramer, G. Brem

	Proceedings are available only through the conference system. Extended version of the conference paper will be submitted to one of the journals, which became media partners of the conference (high impact journals from Elsevier, MDPI, ASME, and Polish Academy of Science) – based on the recommendation from the Organising committee (expected in November/December 2020)
Sectors & Subsectors	• Emissions and Water Reuse • Adaptation to Global Change
End User	o Industry – knowledge, which is a foundation for proper membrane selection. o Scientific Community expanding beyond state-of-the-art knowledge in the area of membrane purification of HTC effluents.
IPR	n/a
Policy-Relevance	Knowledge is relevant in the context of the Sustainable Development Goals, especially Sustainable Development Goal 6 "Clean water and sanitation for all."
Status	This output has been published in Gold Open Access in high-impact, internationally renowned scientific journal. Knowledge can be clearly deemed as a progress beyond the existing state-of-the-art, as it has been published, after extensive peer-review process.

Short Title	Influence of HTC on fouling of membranes, by the purified effluents
Knowledge Output Description	This is a grey knowledge, that emerged after observation of the fouling of membranes for effluents from both untreated and HTC treated digestates. This output is unexpected as to our knowledge no other team world-wide has been working on membrane purification of effluent after hydrothermal carbonisation. This will be investigated further and seems to be publishable in high-impact, internationally renowned journals.
Knowledge Type	Exploitable scientific result
Link to Knowledge Output	n/a
Sectors & Subsectors	• Emissions and Water Reuse
End User	o Scientific Community – expanding beyond state-of-the-art knowledge in the area of membrane fouling
IPR	n/a
Policy-Relevance	Knowledge is relevant in the context of the Sustainable Development Goals, especially Sustainable Development Goal 6 "Clean water and sanitation for all."
Status	The knowledge cannot be applied directly by end users but will be a strong basis for future technology development efforts. Knowledge can be clearly deemed as a progress beyond the existing state-of-the-art.

Short Title	Structural characterisation of hydrochars
Knowledge Output Description	Chemical, physical and structural characteristics of hydrochars from hydrothermal carbonisation of digestates.
Knowledge Type	Scientific publications
Link to Knowledge Output	Publication: H. Pawlak-Kruczek, Ł. Niedźwiecki, M. Sieradzka, A. Mlonka-Mędrala, M. Baranowski, M. Tkaczuk-Serafin, A. Magdziarz "Hydrothermal carbonization of agricultural and municipal solid waste digestates - Structure and energetic properties of the solid products" Fuel 2020, vol. 275, ISSN: 0016-2361, DOI:10.1016/j.fuel.2020.117837 https://www.sciencedirect.com/science/article/pii/S0016236120308334 Conference proceedings: 6th International Conference on Contemporary Problems of Thermal Engineering (CPOTE 2020), 21st – 24th of September 2020, Poland (on-line) "Multiphase analysis of hydrochars from anaerobic digestion of municipal solid waste organic fraction" Oral presentation; A. Magdziarz, A. Mlonka-Mędrala, M. Sieradzka, C. Aragon-Briceño, A. Pożarlik, E. Bramer, G. Brem, Ł. Niedzwiecki, H. Pawlak-Kruczek Extended version of the conference paper will be submitted to one of the journals, which became media partners of the conference (high impact journals from Elsevier, MDPI, ASME, and Polish Academy of Science) – based on the recommendation from the Organising committee (expected in November/December 2020).
Sectors & Subsectors	• Adaptation to Global Change
End User	o Scientific Community – expanding beyond state-of-the-art knowledge in the area of influence of HTC process conditions on the structure of hydrochars.
IPR	n/a
Policy-Relevance	Knowledge is relevant in the context of the Sustainable Development Goals, especially Sustainable Development Goal 13 "Take urgent action to combat climate change and its impacts."
Status	This output has been published in Gold Open Access in high-impact, internationally renowned scientific journal. Knowledge can be clearly deemed as a progress beyond the existing state-of-the-art, as it has been published, after extensive peer-review process.

Short Title	The use of hyrochars from HTC of digestate, after anaerobic digestion of sewage sludge, as a feedstock for pyrolysis

Knowledge Output Description	Influence of hydrothermal carbonisation on pyrolysis of hydrochars. Pyrolysis in different pyrolysis conditions (temperature of the process) is taken into the account and pyrolysis products were a subject of detailed characterisation.
Knowledge Type	Scientific publications
Link to Knowledge Output	Publication: S. Wang, H. Persson, W. Yang, P. G. Jönsson "Pyrolysis study of hydrothermal carbonization-treated digested sewage sludge using a Py-GC/MS and a bench-scale pyrolyzer" Fuel 2020, vol. 262, DOI: 10.1016/j.fuel.2019.116335 https://www.sciencedirect.com/science/article/abs/pii/S0016236119316898
Sectors & Subsectors	• Adaptation to Global Change
End User	o Scientific Community – expanding beyond state-of-the-art knowledge in the area of pyrolysis of hydrochars.
IPR	n/a
Policy-Relevance	Knowledge is relevant in the context of the Sustainable Development Goals, especially Sustainable Development Goal 13 "Take urgent action to combat climate change and its impacts."
Status	This output has been published in a high-impact, internationally renowned scientific journal. Knowledge can be clearly deemed as a progress beyond the existing state-of-the-art, as it has been published, after extensive peer-review process.

9. Open Data

9.1. A. Urbanowska, M. Kabsch-Korbutowicz, M. Wnukowski, P. Seruga, M. Baranowski, H. Pawlak-Kruczek, M. Tkaczuk-Serafin, K. Krochmalny, Ł. Niedźwiecki *"Treatment of liquid by-products of Hydrothermal Carbonization (HTC) of agricultural digestate using membrane separation"* **Energies 2020**, vol. 13, ISSN: 1996-1073,
DOI:10.3390/en13010262
https://www.mdpi.com/1996-1073/13/1/262

9.2. H. Pawlak-Kruczek, A. Urbanowska, W. Yang, G. Brem, A. Magdziarz, P. Seruga, Ł. Niedźwiecki, A. Pozarlik, A. MlonkaMędrala, M. Kabsch-Korbutowicz, E. Bramer, M. Baranowski, M. Sieradzka, M. Tkaczuk-Serafin *"Industrial process description for the recovery of agricultural water from digestate"* **Journal of Energy Resources Technology 2020**, vol. 142, issue 7, ISSN: 0195-0738,
DOI: 10.1115/1.4046141
https://asmedigitalcollection.asme.org/energyresources/article-abstract/142/7/070917/1073977/Industrial-Process-Description-for-the-Recovery-of

9.3. H. Pawlak-Kruczek, Ł. Niedźwiecki, M. Sieradzka, A. Mlonka-Mędrala, M. Baranowski, M. Tkaczuk-Serafin, A. Magdziarz *"Hydrothermal carbonization of agricultural and municipal solid waste*

digestates - Structure and energetic properties of the solid products" **Fuel 2020**, vol. 275, ISSN: 0016-2361
DOI:10.1016/j.fuel.2020.117837
https://www.sciencedirect.com/science/article/pii/S0016236120308334

9.4. S. Wang, H. Persson, W. Yang, P. G. Jönsson *"Pyrolysis study of hydrothermal carbonization-treated digested sewage sludge using a Py-GC/MS and a bench-scale pyrolyzer"* **Fuel 2020**, vol. 262, DOI: 10.1016/j.fuel.2019.116335
https://www.sciencedirect.com/science/article/abs/pii/S0016236119316898

9.5. A. Urbanowska, M. Kabsch-Korbutowicz *"Analysis of the pre-treatment efficiency of digestate liquid fraction from a municipal waste biogas plant"* **Environment Protection Engineering 2019**, vol. 45, issue 4, pp. 103-113,
DOI: 10.5277/epe190408
https://dbc.wroc.pl/dlibra/publication/143545/edition/74977/content

9.6. H. Pawlak-Kruczek "RECOWATDIG – Waterworks 2017 RDI Funded Projects Booklet" 2019
http://www.waterjpi.eu/joint-calls/joint-call-2018-waterworks-2017/booklet/recowatdig/recowatdig-booklet.pdf

10. Problems Encountered during Project Implementation

There has been a delay on the completion of activities due to restrictions caused by Covid-19 Pandemics. E.g. from April to July the laboratory was closed and no new experiments were possible to conduct at UT. Afterwards, due to available space and social distancing regulations, access to laboratories was limited, as only limited amount of staff could work at the same time. Therefore, it was not possible to exploit the research stands to their full capacity. For that reason, a delay of about 3-4 months is expected for the tasks realised in UT. The data from UT was needed, in order to select optimum working conditions in bigger scale rig at WUST, which was supposed to be used to produce feedstock for pyrolysis, drying and water purification experiments. Proper contingency plan was made and it was decided that parameters for agricultural digestate will be based on the previous experience of WUST, whereas parameters for wet MSW digestate from the project partner (ZGO) will be determined by a detailed mass and energy balance, based on the experiments at UT. This way it was possible to maximise working capacity of all the remaining laboratories (KTH, AGH, WUST), during the time that the laboratories could work. A valuable experience was gained on agricultural digestate, which will be useful during work with the digestate from ZGO. Complete set of data for wet MSW digestate will be used for the model of the proposed installation (WP7) and front-end engineering design (WP8). Further problems might occur, due to second wave of Covid-19 pandemics, which has recently started.

11. Suggestions for improvement regarding project implementation?

It is not possible to suggest any improvements, as all the problems mentioned in the section 10, were caused by force majeure. It is not possible to avoid such problems.