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Life Reptes

Renewable bio-hydrogen production technologies from lignocellulosic waste and sewage sludge co-fermentation

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1. Introduction

During the proposal stage the values of the KPIs were estimated. At the current stage of the project, those values were updated based on improved data obtained during the first 9 months from grant signature (first snapshot).

2. Key-performance indicators (KPIs)

In the following section the key-performance indicators of the project are presented in eleven tables. The indicators were updated on the LIFE KPI Webtool (Figure 1) according to the guidelines for the compilation of the indicators.

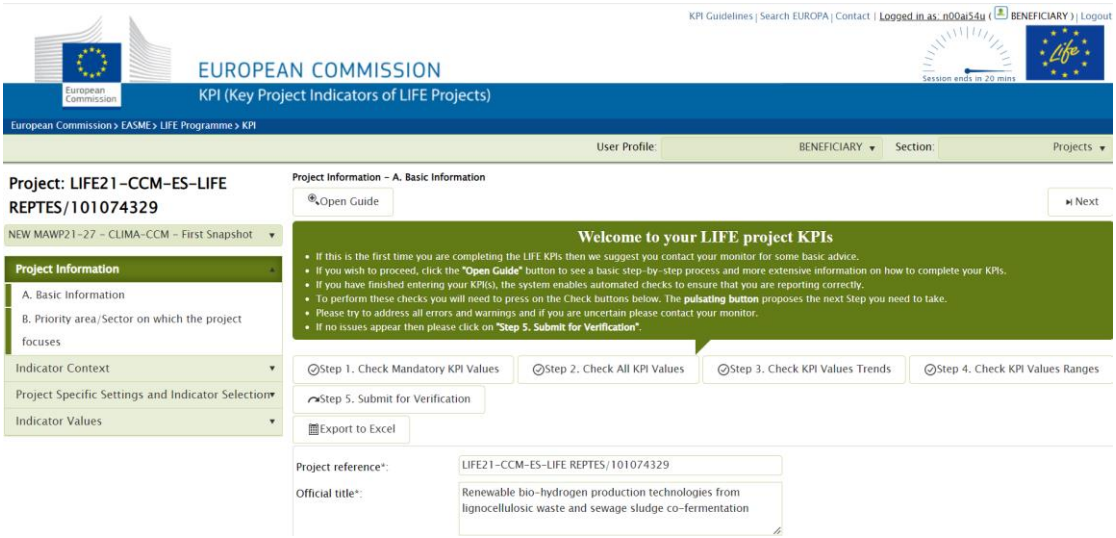

Figure 1 – Capture of the Interface of the KPI Webtool where the indicators of the LIFE REPTES were updated

Table 1. Indicator 1.5.B Project Area

Indicator descriptor	Area of environmental/climate implementation actions (e.g. development, testing, demonstration, application of best practices/innovations).		
Begin Value	**End Value**	**Beyond 5 years value**	**Unit**
0	0.15	0.9	Km^2
Comments			
The project will demonstrate the technology for producing bio-hydrogen, through the implementation of a pilot plant at the wastewater treatment plant located in Pinedo. Therefore, the actual work area is the area of the WWTP itself which corresponds to 0.15 km^2, approximately. Considering the expected replication of REPTES' technology in other 5 wastewater treatment plants (with similar treatment capacity of Pinedo), after 5 years an area of approximately 0.9 km^2 will correspond to the project work area (Total of 6 WWTP).			

Figure 2 – Area of Pinedo wastewater treatment plant

Table 2. Indicator 1.6.B. Humans impacted by the project

First indicator descriptor:	Type of impact: Persons whose quality of life was positively impacted by improved AIR QUALITY achieved by project actions
Second indicator descriptor:	Type of persons: Residents within or near the project area

Begin Value	End Value	Beyond 5 years value	Unit
0	1,154,000	5,669,000	Number of persons impacted

Comments

In the project area a total of 1,154,000 residents are affected by the poor air quality. At the end of the project, 214 tons of rice straw will use to produce renewable energy by means of the LIFE REPTES, and therefore they will not be burned, therefore, a number of 1,154,000 people who is living in Albufera region and their surrenders will be positively affected.

It is assumed that the selected WWTPs for applying the technology have residual rice biomass in their area of influence that could be used as a cosubstrate in dark fermentation. It is assumed that it can be treated the same amount of biomass as in the case of Pinedo. So, 5 years beyond the project end, a replication of REPTES full-scale plant at 5 additional areas (and Pinedo WWTP) is expected too. It is considered that the facilities will have a similar treatment capacity to Pinedo WWTP. In the proposal, some WWTP with suitable size for LIFE REPTES model were suggested. So, we can have as a reference areas with similar size and problems as the ones addressed by LIFE REPTES:

1. Marsella area: 861,000 inhabitants
2. Milan area: 1,300,000 inhabitants
3. Zaragoza: 666,000 inhabitants
4. Sevilla: 688,000 inhabitants
5. Thessaloniki: 1,000,000 inhabitants

Table 3 . Indicator 4.1.B Energy

Begin Value	End Value	Beyond 5 years value	Unit
18	18.20	164	GWh/y

Comments

In the current situation, Pinedo WWTP achieves 18 GWh/year coming from sewage sludge anaerobic digestion (DA) at the plant. The implementation of the demo plant will transform approximately 214 tonnes of rice straw (during 28 months) into biohydrogen and biogas.
Based on bibliography data, around 0.40 m^3 (Guo et al., 2010) and 80 m^3 (Bundhoo, 2019) of biohydrogen can be produced per ton of sludge and rice straw, respectively. Regarding biogas, 11.4 m^3, and 492 m^3 are expected to be produced per ton of sludge and rice straw, respectively, based on previous data obtained from studies performed by the partners DAM and AINIA. Considering these data and that the Dark Fermentation will be fed with 1.2 m^3 of sludge and 0.3 tons of rice straw daily, an annual production of total biohydrogen of 8,935 m^3/y and total biogas of 61,606 m^3/y is expected. Nevertheless, 60% of the biogas produced may correspond to methane, which is the gas of interest for energy production (36,963.80 m^3/y of biomethane).

Since the PCI of hydrogen is 33.33 kWh/Kg (Yue et al., 2021) and the density of hydrogen is 0.0899 kg/m^3, the volume of biohydrogen can be represented as the corresponding energy. Therefore, 7,483 m^3 of biohydrogen produced yearly corresponds to 22,423 Kwh/y.
From the biogas produced, around 166,888 Kwh/y is expected. That amount of energy is achieved since 1 Nm^3 of natural gas represents 9.76 Kwh. Nevertheless, the CHP motors implemented at Pinedo WWTP have an electrical performance of 40%, resulting in the 166.888 kWh produced yearly above mentioned.

Based on the renewable energy produced by the biohydrogen and the biogas (biomethane) during 28 months (464,727.11 Kwh), a total of 202,055.27 kWh will be generated yearly (0.20 Gwh/y).

5 years after the project end, with the full-scale model installed in 6 plants, with a capacity to treat 15,000 tonnes of lignocellulosic waste each year (and keeping the proportion of sewage sludge and rice straw), a production of 164 GWh/year is expected.

References

Bundhoo, Z. M. A. (2019). Potential of bio-hydrogen production from dark fermentation of crop residues: A review. International Journal of Hydrogen Energy,

44(32), 17346–17362. https://doi.org/10.1016/j.ijhydene.2018.11.098
Guo, X. M., Trably, E., Latrille, E., Carrre, H., & Steyer, J. P. (2010). Hydrogen production from agricultural waste by dark fermentation: A review. International Journal of Hydrogen Energy, 35(19), 10660–10673. https://doi.org/10.1016/j.ijhydene.2010.03.008

Yue, M., Lambert, H., Pahon, E., Roche, R., Jemei, S., & Hissel, D. (2021). Hydrogen energy systems: A critical review of technologies, applications, trends and challenges. In Renewable and Sustainable Energy Reviews (Vol. 146). Elsevier Ltd. https://doi.org/10.1016/j.rser.2021.111180

Table 4 . Indicator 4.3.B Waste Management

First level indicator descriptor:	02 01 wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing		
Second level indicator descriptor & values:			
Mass of non-appropriately managed waste:			
Begin Value	**End Value**	**Beyond 5 years value**	**Unit**
15 000	14 909	0	Tons/year
g. Mass reduction due to energy recovery:			
Begin Value	**End Value**	**Beyond 5 years value**	**Unit**
0	91	15 000	Tons/year
Third level indicator descriptor:	Bio-waste/organics		
Comments			

The anaerobic digestors of Pinedo WWTP has a treatment capacity of 15000 tonnes/year rice straw, which is considered to be the baseline value recorded at the beginning of REPTES project study and will be used to evaluate the change brought about by REPTES technology. Therefore, in the context of REPTES' project an amount of currently inappropriately managed waste is 15,000 tonnes/year.

During the project this amount will be reduce due to the implementation of the demo-plant. According to the KPI table included in LIFE REPTES platform, among the indicators "a" to "i", the indicator "g: waste reduction due to energy recovery" is the one that better fits the scope of REPTES project. The reason of this choice is the technology of REPTES, which is based on bioconversion of rice straw (main inappropriately managed waste) in combination with WWTP sludge into hydrogen through dark fermentation reactor as well as biogas through anaerobic digestor.

The REPTES demo-scale plant is expected to transform 214 tonnes of rice straw throughout the implementation phase which is going to last 28 months. Therefore, this amount of rice straw treatment per 28 months leads to around 91 tonnes of treated rice straw per year. Therefore, at the end of the project inappropriately managed waste will be 15,000 – 91 tonnes/year which is 14,909 tonnes/year.

At last, considering the treatment capacity of Pinedo WWTP abovementioned in terms of rice straw waste, it is expected that the implementation of REPTES's technology at full scale will provide appropriate management of 15,000 tonnes of lignocellulosic waste yearly. Moreover, after 5 years, the commercialization and implementation of REPTES' technology in 5 more facilities (with treatment capacity similar to Pinedo WWTP) are expected, and this will result in a mass reduction of 90,000 tonnes of waste per year.

Table 5. Indicator 8.1. B. Reduction of greenhouse gas emissions

Indicator descriptor	Waste management		
Begin Value	**End Value**	**Beyond 5 years value**	**Unit**
1330.2 $\frac{19{,}954\ Tn\ CO_2eq/y}{15{,}000\ ton\ rice/y}$	1319.2 $\frac{19{,}789\ Tn\ CO_2eq/y}{15{,}000\ ton\ rice/y}$	0	$kgCO_2eq/unit$*
19,954	19,789	0	$TnCO_2eq/y$

Comments

For the calculation of the begin value were considered the following data: the treatment capacity of Pinedo WWTP (123,319,917 m3/year), the sludge production of 690,215 tonnes/year, and the WWTP energy consumption of 40,157,698 KWh/year. Nevertheless, the yearly production of 4,721,071 m^3 of methane in the WWTP corresponds to 17,845,647 kWh/year, which is used by the facility. Therefore, the total energy that represents equivalent-CO_2 is 40,157,698 KWh/year - 17,845,647 kWh/year = 22,312,051 KWh/year.

Regarding the rice straw, it was considered that 15,000 tonnes of rice straw can be used as substrate in Pinedo WWTP. For the rice plantation, the energy related to it (3,478,846 KWh/year) was calculated considering the amount of fuel required (6,700 MJ) and the rice production per hectare (7,80 tonnes/ha). Since 1 MJ corresponds to around 0,27 kWh, the total energy for the rice production was determined.

The following conversion factors for CO2eq were considered for calculations:
Rice straw burning: 0,60 TCO_2 eq/T rice straw
Diesel burning: 0,27 $KgCO_2$ eq/kWh
Electricity consumption: 0,41 $kgCO_2$/kW

At last, with all considerations above mentioned, the CO_2eq from the WWTP's energy is 10,040 tCO_2eq/year, the CO_2eq from the burned rice straw is 9,000 tCO_2eq/year and the COeq from the fuel is 914 tCO_2eq/year. Those values correspond to a total of 19,954 tCO_2eq/year.

At the end of the project, with the implementation of the demo plant, we will avoid the burning of 91 tonnes/year of rice straw and we will generate renewable energy that will decrease the external demand for energy from the plant, meaning a reduction of an overall emission of 165 tCO2 eq/ year. Therefore, 19,954 tCO2eq/year - 165 tCO2

eq/ year = 19,789 tCO_2 eq/ year.
After 5 years, the implementation of REPTES' technology at a large scale in Pinedo WWTP, and 5 other facilities, will overcome the baseline, achieving an emission of 0 tCO_2eq/y.
*The reduction of CO_2eq normalised per unit of project product was also defined considering a unit as 1 Ton of rice straw. Therefore the normalised values of CO2eq reduction were calculated by dividing the Tn CO_2eq/y per 15,000Ton of rice straw/y.

Table 6. Indicator 11.1. B. Website

Begin Value	End Value	Beyond 5 years value	Unit
0	3,000	10,000	Visits

Comments

According to the deliverable D6.2 of the application form, each partner published an specific section in their website by the 15th February 2023. This KPI (11.1-website) indicates the total number of visits registered in the different specific urls linked to the LIFE REPTES project, from the beginning until April-2023. The urls linked to LIFE REPTES project in each partner website are:

Consorci de la Ribera (CRIB).
Visits: 344
https://energia.consorcidelaribera.com/life-reptes/

Depuración Aguas del Mediterráneo (DAM)
Visits: 63
https://www.dam-aguas.es/portfolio-posts/life-reptes/

AINIA
Visits: 139
https://www.ainia.es/proyectos-publicos/life-reptes/

GENIA
Visits: 249
https://geniabioenergy.com/life-reptes/

From 15th February 2023 to 18th April, a total of 795 visits were recorded. We expect that the publication of newsletter, participation in workshops, conferences and other dissemination activities, will bust the visits to the websites. Therefore, for the end value around 2000 visits can be expected. The web page of the project will remain accessible long after the project conclusion, so 5 years after the project it is expected to have 10,000 visitors due to success of the project and researches related to

biohydrogen and sostenible WWTP projects.

Table 7. Indicator 12.1. B. Networking and synergies with projects/initiatives

Indicator descriptor:	LIFE projects		
Begin Value	**End Value**	**Beyond 5 years value**	**Unit**
0	25	40	No. of projects/initiatives

Comments

Personnel from beneficiaries of REPTES project will attend to networking meetings, workshops and conferences in the last months to present the LIFE REPTES. Some of the networking activities has already been held in Spain, at international and national events.

Specifically, In October/2022, the partner AINIA presented the project at the 15th International Congress of Bioenergy (https://www.congresobioenergia.org/15a-edicion/).

This event made feasible the networking with LIFE projects (as other stakeholders).

- *LIFE NIMBUS: Metanación biológica de biogás de EDAR con bioH2 para movilidad sostenible.*
- *LIFE LANDFILL BIOFUEL. Valorización de biogás de vertedero para la producción de biometano y su uso como combustible en vehículos.*

In May/2023, DAM is going to present the project at a national event, in Spain (JORNADA IDEAS 2023 "Soluciones para nuevos retos ambientales"). Since it is a relevant conference in the national scenario that DAM has participated in before, it is expected the presence of around 100 stakeholders in the LIFE REPTES presentation. Moreover, according to the program, other 8 LIFE project will attend. We have identified as highly interesting for networking activities the following ones:

- *LIFE ZERO WASTE WATER. Validación de una solución innovadora, con balance energético positivo, en la depuración de aguas residuales de poblaciones*

menores de 50.000 h.e.

- *LIFE RENATURWAT. Integrating circular economy and biodiversity in sustainable wastewater treatments based on constructed wetlands*

The Spanish Technological Water Platform (that supported the project with a commintment letter), will organise a networking event specifically addressed to LIFE projects regarding WWTPs. It is expected to interact with at least 5 LIFE projects.

Moreover, In March/2023 DAM presented the project at ATEGRUS Conference on Waste Management and Circular Economy 2023 (https://www.ategrus.org/jornada-tecnica-lodos-edar-2023/) for around 50 stakeholders. In June/2023 the same partner is going to present at X Ibero-American Symposium on Waste Engineering (https://www.fue.uji.es/en/conferences/EX220262), and at the 6th IWA International Conference on eco-Technologies for Wastewater Treatment also celebrate in Spain (https://www.ecostp2023.org/index.php).

Considering the abovementioned comments, the end value was estimated considering the total number of projects and initiatives that we have networked with so far, plus the ones we expect to interact with until the end of the project. Therefore, 25 networking with projects/initiatives have been defined for the end value.

At last, 5 years after the end of the project it is expected a less active participation in networking events, thus a total of 40 networking may be considered for this stage.

Table 8. Indicator 13. B. New jobs created

Indicator descriptor	News jobs created		
Begin Value	**End Value**	**Beyond 5 years value**	**Unit**
0	2	22	No. of FTE
Comments			
The LIFE project partners have estimated that 2 jobs will be created at the end of the project in their companies thanks to the LIFE REPTES project implementation. The number of jobs created 5 years beyond the project end has been estimated considering the LIFE REPTES technology commercialization plan (5 facilities more). Several kinds of jobs have considered: seller of the technology (commercialization stage), design engineers and construction workers (design and construction stage) and operators of the technology (operational stage). Direct and indirect jobs.			

Table 9. Indicator 14.1. B. Revenue during or after project end, due to project outcomes

Indicator descriptor	Revenue from fees		
Begin Value	**End Value**	**Beyond 5 years value**	**Unit**
0	0	75,000	Euros
Comments			
No revenue is expected during the execution of the project. A conservative estimate would be to assume that after the project concludes, 5 years from its completion, we will be able to license the outputs of the developed technology (e.g., utility design) to at least 5 interested entities. The direct results from the operation of the full-scale pilot at the WWTPs are expected to have a significant impact on the financial results of the industrial project partners of the project (e.g., the biohydrogen or biogas generated may be used for self-consumption at the facilities managed by DAM), as well as the public administrations that own the water treatment plants. However, it should be noted that this cannot be considered as revenue from sales, and therefore, it is excluded from the calculation of the KPI.			

Table 10. Indicator 14.2. B. Catalytic effect - Financial - Cumulative investments triggered or finance accessed

Indicator descriptor	Grants, subsidies		
Begin Value	**End Value**	**Beyond 5 years value**	**Unit**
0	0	2.5	Million Euros
Comments			

We do not anticipate receiving any additional financial funding apart from the resources from the beneficiaries or the LIFE Programme, which are already included in the project budget. Approximately 5 years after the project concludes, it would be reasonable to mobilize an estimated investment of 2.5 million euros for the industrial implementation of the pilot at WWTP in full-scale. The main anticipated sources of funding, apart from the beneficiaries' own resources, are expected to come primarily from the following actors (in order of importance): (i) public administrations (through innovative public procurement calls or investment innovation calls), (ii) bank loans, and (iii) private investors.

Table 11. Indicator 14.3.1.B. Continuation after the project-end in the same premises/area(s) as those used during the project

Indicator descriptor	Continuation at higher scale (compared to the scale during project implementation).
Comments	
During the LIFE REPTES a demo plant, with a treatment capacity of around 91 tonnes of rice straw yearly, will be tested to prove the feasibility of producing biohydrogen and biogas using lignocellulosic waste and sewage sludge in a dark fermentation process. It is expected that the studied and developed technology in the project LIFE REPTES will be commercialized to other facilities with a treatment capacity of 15,000 tonnes of lignocellulosic waste (similar to the Pinedo WWTP). Therefore, the validation of REPTES technology in the LIFE project will promote its spread and continuation through the application at full scale.	

Conclusions

The values reported in this deliverable will be updated at the final report stage, when the actual measured values of the baseline, the end value and the projection for 5 years beyond the project end will be described.

Renewable bio-hydrogen production technologies from lignocellulosic waste and sewage sludge co-fermentation

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