UNIVERSIDAD DE GRANADA

TESIS DOCTORAL

Circular Economy and Circular Bioeconomy as pillars of the ecological transition for a worldwide enhanced sustainability

Economía y Bioeconomía Circular como pilares de la transición ecológica para favorecer la sostenibilidad a nivel global

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A continuación se resumen los artículos científicos utilizados en el compendio de esta memoria de tesis doctoral:

1. Bonoli, A.; Zanni, S.; Serrano-Bernardo, F. Sustainability in Building and Construction within the Framework of Circular Cities and European New Green Deal. The Contribution of Concrete Recycling. Sustainability 2021, 13, 2139. https://doi.org/10.3390/su13042139

2. Franzoni, E.; Volpi, L.; Bonoli, A. Applicability of life cycle assessment methodology to conservation works in historical building: The case of cleaning. Energy Build. 2020, 214, doi:10.1016/j.enbuild.2020.109844.

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4. Bonoli, A., Zanni, S. & Awere, E. Organic waste composting and sustainability in low-income communities in Palestine: lessons from a pilot project in the village of Al Jalameh, Jenin. Int J Recycl Org Waste Agricult 8, 253–262 (2019). https://doi.org/10.1007/s40093-019-0264-8

5. Midence Díaz, R.; Serrano-Bernardo, F.; Bonoli, A. Bioeconomía y biodiversidad preservada en Centroamérica. “Revista De Fomento Social”, 2022, (302), 7-21. https://doi.org/10.32418/rfs.2022.302.5188

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3	https://doi.org/10.3390/su14031661	3.889	Q1	Q2
4	https://doi.org/10.1007/s40093-019-0264-8	0.709	Q3	Q3
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SEGUNDO LUGAR en el concurso académico regional "La Integración Centroamericana hacia el Bicentenario de la Independencia y los 30 años del Sistema de la Integración Centroamericana (SICA)" por su articulo titulado: "Centroamérica: hacia una bioeconomía potenciada a través de una biodiversidad preservada"

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The thesis work is undoubtedly a significant milestone, but it also marks a fresh beginning and a new starting point for fruitful partnerships and future collaborative research projects. And to solidify our lovely friendship.
I'm very grateful

Education in environmental responsibility

can encourage ways of acting

that directly and significantly affect the world around us

reflecting a generous and worthy creativity

that brings out the best in human beings

Pope Francesco

Encyclical Letter Laudato Si'

Resumen General

Estamos viviendo una crisis mundial sin precedentes, un complicado y desconcertante escenario lleno de desafíos, y simbolizado por emergencias del medio ambiente, sociales y económicas.

Los desafíos ecológicos, como por ejemplo la crisis ambiental, la expansión de la población mundial, la demanda de recursos naturales, la sobreextracción de materias primas y la presión general sobre el medio ambiente que los humanos ejercen en la actualidad, están todos conectados y requieren acciones urgentes y efectivas. Al mismo tiempo que las ambientales, las desigualdades sociales y económicas están aumentando. El creciente uso de recursos naturales, junto con la producción de desechos y contaminación, ha hecho que los humanos rompan los límites críticos del planeta.

Por el bien del medio ambiente y de la justicia global, hay que favorecer la aplicación severa de medidas de reducción de emisiones, sustancias contaminantes y uso de recursos (por ejemplo energía, materias primas, agua, suelo, etc.), así como su consumo y uso.

Hay tres palabras clave que pueden ser difundidas en cualquier contexto, en regulaciones de carácter local y nacional, a nivel industrial y en la vida cotidiana: eficiencia, consistencia y suficiencia. La noción de eficiencia está referida a una optimización de los procesos, a la producción de los mejores resultados, y está conectada al uso de energía y de recursos. Es necesario referir a la idea de la eco-eficiencia, que implica minimizar los efectos negativos de cualquier proceso en el medio ambiente alargando la vida útil de los productos, promocionando el reciclado y aumentando el uso de recursos renovables. La consistencia, en general, es el intento de incorporar el material y los ciclos de producción en los ciclos naturales. Representa un enfoque constructivo integrado que crea flujos de materiales de bucle cerrado y una economía circular más extendida, con especial atención a la bioeconomía. Estar satisfecho con pocas comodidades materiales y más bienes sociales y colectivos intangibles es a lo que la suficiencia efectivamente se refiere. El principio de suficiencia, conocido también como consumo fuertemente sostenible, debería estar incorporado a los materiales y normas de uso de los recursos, así como en programas para separar los conceptos de bienestar desarrollo humano y prosperidad, del materialismo y elconsumo y agotamiento de los recursos.

El concepto de sostenibilidad ambiental entra dentro del contexto del crecimiento limitado en los recursos. Siguiendo esta definición, la sostenibilidad ambiental se refiere también a un grupo de restricciones sobre dos actividades esenciales - el uso de los recursos renovables y no-renovables por el lado de la producción, así como el incremento de la contaminación y la generación de residuos- que gobiernan las escalas del sub-sistema económico humano. Otra definición de sostenibilidad ambiental se enfoca sobre sus componentes bio-geofísicos. En cambio, con el término sostenibilidad biofísica, nos referimos al mantenimiento o mejora de los sistemas que apoyan nuestra vida. Entre estos, crear oportunidades para el progreso económico y social para la generación actual, así como las futuras, en el contexto de una variedad cultural preservando, al mismo tiempo, la diversidad biológica de la biosfera y la integridad bio-geo-química a través de la conservación y uso responsable de los recursos. La sostenibilidad y desarrollo ambiental están interconectados con la idea del ecosistema y los procesos naturales que mantienen la vida en el planeta, como, por ejemplo, la capa de ozono en la estratosfera, el clima, los ciclos hidrológicos y bio-geo-químicos, los recursos minerales, el agua dulce superficial y subterránea y los océanos, o el suelo. La preservación de la biodiversidad es uno de los componentes más criticos del contexto ambiental y un requisito fundamental para la vida en la Tierra. Cuidar la naturaleza misma, los ecosistemas de nuestro planeta y la biodiversidad, implican también cuidar los recursos y servicios que la naturaleza ofrece.

Por tanto, son necesarios cambios más radicales para poder mantener nuestro desarrollo entre los límites del planeta: hay que moverse hacía una economía donde la prosperidad y el bienestar no estén conectados con el uso indiscriminado de los recursos naturales.

El concepto de "economía circular" intenta abarcar los desafíos sociales y ambientales del uso de los recursos, centrándose sobre todo en la eficiencia y la consistencia, apoyado por el principio de la suficiencia. La economía circular propone un nuevo paradigma en la produción y consumo, un modelo diferente para transformar los residuos en recursos y redefinir el flujo de materiales.

Para poder ejecutra la visión de la Comisión Europea de una economía inteligente, sostenible e inclusiva que pueda liderar nuestra sociedad a un futuro sin dependencia de fuentes no renovables y sin contaminación, hay que pensar en iniciativas para prevenir la generación de residuos, promover la suficiencia y separar los conceptos de bienestar del consumismo y del uso abusivo de recursos naturales. Reducir, re-utilizar y reciclar son la base la idea de la economía circular, que se fundamenta en una base restaurativa y regenerativa debe

Basándose en los principios de economía circular, con un enfoque sobre el uso de recursos biológicos renovables, la bioeconomía circular se refiere fundamentalmente a un sistema económico orientado a la creación de alimentos, energía y otros biomateriales, que implica el uso y la gestión sostenibles de los recursos naturales, incluidos los bosques, la pesca y los suelos agrícolas.

Una bioeconomía tiene que ser sostenible para responder a los problemas ligados al medioambiente y la sociedad. Hay que favorecer el uso de recursos renovables, como puede ser, por ejemplo, la producción de energía a partir de biomasa, que permita convertir a esta en una fuente sostenible de obtención de recursos energéticos.. Incorporando las ideas de economía circular a la bioeconomía, la bioeconomía circular permite un uso y gestión más eficiente de los recursos denominados ”bio-based”. Asimismo, contribuye a recuperar la biodiversidad de la Tierra así como el capital natural y, al mismo tiempo, disminuir las consecuencias negativas de la extracción de recursosnaturales. . Por tanto, la bio-economia ayuda a evitar la pérdida de recursos naturales, fomentando la reutilización y el reciclado de residuos, subproductos y otros materiales.

Para evaluar los problemas medioambientales, económicos y sociales asociados a una actividad, se puede adoptar una perspectiva de ciclo de vida.

La Evaluación de la Sostenibilidad del Ciclo de Vida (Life Cycle Sustainability Assessment, LCSA) es el desarrollo de un ciclo de vida pensado para evaluar cómo un producto, un proceso o un servicio puede afectar al ambiente y la sociedad durante todo su ciclo de vida, desde la extración hasta el procesamiento de materiales, hasta la generación de residuos y reciclado. El LCSA considera el espectro completo de los impactos ambientales, económicos y sociales, incluyendo el uso de recursos, energía, emisiones, producción de residuos, e implicaciones socio-económicas. Proporciona un contexto amplio para la evaluación de la sostenibilidad de los productoss y los procesos, teniendo en cuenta los impactos positivos y negativos para cada etapa de su ciclo de vida.

Objetivos

El principal objetivo de esta tesis doctoral es el de llevar a cabo una profunda revisión del estado del arte en relación conla crisis ecológica mundial y la identificación de posibles soluciones, que además promuevan la perspectiva de la economía y bio-economía circular. Este estudio enfatiza también la importancia de la integración de los aspectos ecológicos y socio-económicos, adoptando la perspectiva del ciclo de vida, para evaluar las consecuencias ambientales, económicas y sociales en algunos sectores.

En particular, en la primera parte de esta investigación, se explora y analiza el campo de la edificación y el sector de la construcción, con el objetivo de poner en contexto su importancia tanto en el impacto económico como medioambiental. La edificación y la construcción forman parte de una industria que requiere y consume muchos recursos en una escala global y debe moverse a una economía circular para disminuir sus efectos sobre el medioambiente y preservar nuestros recursos limitados.

Como se podrá comprobar en el primer artículo (anexo 1), se tratará de poner de manifiestoel impacto significativo sobre el medioambiente a nivel global que la industria de la construcción tiene. Esta industria es responsable de la producción de, aproximadamente, el 50% de las emisiones globales que causan el efecto invernadero, y consume hasta el 40% de todas las materias primas extraídas de la litosfera. Desde la construcción hasta la demolición, pasando por el uso y el mantenimiento, la edificación es responsable de un porcentaje importante del uso general de la energia (en torno al 40%) y emisiones de carbono aproximadamente el 36%).

Por tanto, se pretende enfatizar la importancia del "diseño verde" de un producto, que se centre en la disminución del uso de materias primas, y la prevención de generación de residuos durante todo el ciclo de vida de los productos. La estrategia europea para un un entorno construido de forma sostenible, va a promover los principios de la circularidad de la construcción durante toda la vida útil de un edificio, empezando por una mejora en el reglamento sobre productos de construcción, adoptando también la idea de Life Cycle Assessment (LCA) en la contratación pública. Además, se investigará cómo los "Life Cycle Thinking" y "Life Cycle Assessment" son esenciales para la sostenibilidad y el Eco-Design, enfoques innovadores para la edificación y la construcción, y los procedimientos de reciclaje apropiados y eficientes para los residuos de construcción y demolición, centrados en el reciclaje de hormigón en línea con los estudios de caso examinados, que puedan apoyar la economía circular en este importante sector económico.

Por último, se quiere poner en valor los principios de economía circular, queafirman que la implementación de la eficiencia energética ofrece ventajas desde la optimización del ciclo de vida y aumentando la vida útil de las construcciones con valor histórico.

Con este propósito, y como objetivo fundamental del plan de investigación, el segundo documento (anexo 2) presenta un estudio de caso que involucra la aplicación del enfoque LCA a la restauración de edificios y enfatizará la importancia de los métodos basados en LCA en la evaluación y selección de materiales en el campo de la conservación y reparación de edificios históricos, que representan una parte importante del parque de edificios, especialmente en Europa.

Posteriormente, el objetivo principal de la segunda sección de la tesis será concentrarse en los fundamentos de una "bioeconomía circular", la importancia de la preservación de la biodiversidad, el uso de recursos biológicos renovables, y la gestión y el tratamiento adecuado y eficiente de los residuos orgánicos.

Se pretende conocer cuánto se acerca a políticas dea sostenibilidad la bioeconomía y cómo esta puede verse amenazada por diferentes riesgos ambientales y socio-económicos, como, por ejemplo, la competencia existente en ocasiones entre la industria alimentaria y la de los combustibles para el uso del suelo, los cambios directos o indirectos en estos, la utilización marginal de dicho suelo con efectos perjudiciales sobre la biodiversidado las emisiones de gases de efecto invernadero.

En este contexto, se realizará una descripción general de la gestión de residuos orgánicos, con un enfoque particular en algunas economías emergentes o países en desarrollo. Como se indica en los artículos 3 y 4 (ver los dos anexos correspondientes) una de las fracciones más grandes de los residuos es el desecho (residuo) orgánico. Se analizarán diferentes estrategias a nivel europeo, así como investigaciones detalladas en el contexto de América Central y del Sur, que den a conocer las infraestructuras "bio -based", tales como sistemas de recuperación del biogás, instalaciones para el compost, o el uso técnicas de biorremediación. y

Oriente Medio, y en particular los Territorios Palestinos ocupados, están experimentando una degradación ambiental cada vez mayor debido a la falta de recursos hídricos, los efectos dramáticos del cambio climático, el uso destructivo de la tierra y las malas prácticas de gestión de residuos. Esta degradación se ha visto agravada por años de conflicto. El objetivo del estudio, en este contexto, será el de implementar un proyecto piloto para optimizar la recolección de residuos orgánicos y el compostaje para la agricultura local.

Finalmente, como último objetivo y relacionado con el artículo 5 pone de manifiesto como, en términos de biodiversidad, América Central, representa un "punto caliente, por su riqueza en flora y fauna". Contiene más del 7% de la diversidad biológica del mundo, a pesar de cubrir solo el 1% de la área del planeta. Además, según Naciones Unidas, Europa, América Latina y la zona del Caribe son las regiones con la más altas cobertura de bosques (25 % cada una). En América Central, este porcentaje es aproximadamente el 38%. Según algunas proyecciones, 300 millones de hectáreas de suelo podrían estar disponibles en torno a 2050 para el desarrollo de industrias relacionadas con la bioeconomía.

Dada su tecnología actual y su potencial para la biodiversidad, la protección de la biodiversidad tiene que ser un objetivo condiviso para América Central, y llegar a una economía de base biológica, con un enfoque respetuoso para el ambiente.

En relación con estas cuestiones, el último paso en la comparación entre la Unión Europea y la América Central está en la relación entre Biocapacidad y gobernanza. Esta investigación está en la actualidad enviada para su publicación, y se centra en el sector del comercio de ganado utlizando las herramientas y las políticas ambientales disponibles tanto en la UE como en la región de América Central.

La huella ecológica de la UE ha superado los límites ambientales, tal y como se indica en el artículo, siendo en la actualidad un "importador neto" de biocapacidad. Fuera de las fronteras europeas, se producen el 31% de las emisiones de gas de efecto invernadero y el 42% de la huella hídrica. La UE publicó en 2010 la Comunicación sobre la Comercio, crecimiento y asuntos mundiales. La política comercial como elemento fundamental de la Estrategia 2020 de la UE, donde se enfatiza que las políticas del comercio tienen que seguir apoyando un crecimiento "verde", los objetivos del cambio climático, así como apoyar y promover diferentes áreas en el mundo en temas de energía, eficiencia en el uso de los recursos y la protección de la biodiversidad.

El último objetivo de este plan de trabajo será el de considerar los factores económicos y la sostenibilidad ambiental como un componente crucial de la buena gobernanza europea como uno de los principales resultados de este compromiso de apoyo al crecimiento verde y a la mejora de la sostenibilidad en el planeta.

Palabras clave: Impacto ambiental, Edificación y Construcción, Análisis de Ciclo de Vida, Biodiversidad, Biocapacidad, Residuos Orgánicos.

General Abstract

We are currently experiencing a worldwide crisis that is unprecedented, a complicated and perplexing scenario that is full of challenges, symbolized by environmental, social and economic emergencies.

Ecological challenges, such as the worldwide climate crisis, the expanding global population, the significant demand on natural resources, the over-extraction of primary materials, and overall pressures and impacts on the environment that humans are experiencing, are interconnected and require urgent and effective actions. Along with environmental ones, social and economic inequities are growing. The increasing use of natural resources, together with the production of waste and pollution, has caused humans to breach critical planetary boundaries.

For the sake of the environment and global justice, it has to be favored the severe enforcement of reduction for emissions, pollutants, and resources (i.e., energy, raw materials, water, land, etc.) consumption and utilization.

Three keywords can be declared and disseminated in any context, at urban and national policy, at the industrial level, and in common life: efficiency, consistency, and sufficiency. The efficiency notion is referred to an optimization of the processes, to produce the best results, and connected to optimization in energy consumption and in the utilization of resources. It is necessary to refer to the idea of eco-efficiency, which entails minimizing the negative effects of any process on the environment by lengthening the lifespan of the products, promoting material recycling, and boosting the use of renewable resources. Consistency, in general, is the attempt to incorporate the material and production cycles into the natural cycles as well. It represents an integrated constructive approach creating closed-loop material flows, and a more widespread circular economy, with attentive regard to the bioeconomy. Being satisfied with less material commodities and more intangible social and collective goods is what sufficiency ultimately entails. The sufficiency principle, also known as enoughness or strong sustainable consumption, should be incorporated into materials and resources management policies and plans in order to dissociate the concepts of life satisfaction from materialism, to decouple human development and prosperity from resources consumption and depletion.

The concept of environmental sustainability falls within the constraints of the resource-limited growth ecological economic framework. According to this definition, environmental sustainability also refers to a set of restrictions on two essential activities—the use of renewable and non-renewable resources on the source side and the assimilation of pollution and waste on the outcome—that govern the scales of the human economic subsystem. Another definition of environmental sustainability emphasizes its bio-geophysical components. The maintenance or improvement of the systems that support our life is referred to as biophysical sustainability. Providing opportunities for economic and social advancement for present and future generations within the context of cultural variety, while preserving the biosphere's biological diversity and biogeochemical integrity through resource conservation and sensible use, is part of this. Environmental sustainability and development are inextricably linked to the idea of the ecosystem and the natural processes that sustain life on our planet, such as the ozone layer in the stratosphere, the climate, the hydrological or biogeochemical cycles, mineral resources, water and oceans, the land on the surface, and the space below and above the Earth. The most crucial component of the environmental framework and a fundamental prerequisite for human life is biodiversity. Taking care of nature itself, the world's ecosystems, and biodiversity entails taking care of the goods and services that nature offers.

A more fundamental change is required in order to stay within the limits of the planet: a shift to an economy where prosperity is no longer predicated on the consumption of natural resources.

The “circular economy” conceptual framework addresses resource use-related social and environmental challenges, mainly focusing on efficiency and consistency, complemented by the principles of sufficiency. The circular economy proposes a new paradigm in production and consumption, a different model to transform waste in resources and to redesign materials flows.

In order to realize the European Commission's vision of a smart, sustainable, and inclusive economy that can lead our society to a decarbonized and pollutant-free future, it must be accompanied by initiatives to prevent waste, promote sufficiency, and decouple the concepts of well-being from consumerism and the depletion of natural resources. Reducing, reusing, and recycling are the cornerstones of the circular economy idea, that has to be restorative and regenerative by intention and design.

Based on the principles of a circular economy, with a focus on the use of renewable biological resources, the circular bioeconomy refers basically to an economic system food, energy, and other biomaterials creation oriented, entailing the sustainable use and management of natural resources, including forests, fisheries, and agricultural land. A bioeconomy must be sustainable in order to address issues of the environment and society. It is encouraged to employ renewable resources, produce sustainable biomass feedstock, and create goods and conversion methods using biomass. By incorporating circular economy ideas into the bioeconomy, a circular bioeconomy is easily seen as a more effective resource management of bio-based renewable resources. It can help restore the Earth's biodiversity and natural capital while significantly lowering the negative consequences of resource extraction and utilization on the environment. It should also avoid the loss of natural resources by encouraging the reuse and recycling of wastes, byproducts, losses, and other materials.

To assess the environmental, economic, and social issues related to any activity, a life-cycle perspective can be adopted. The Life Cycle Sustainability Assessment (LCSA) is a development of life cycle thinking for evaluating how a product, process, or service will affect the environment and society over the course of its full life cycle, from the extraction and processing of raw materials to disposal or recycling. It considers the complete spectrum of environmental, economic, and social impacts, including resource use, energy use, emissions, waste production, and socioeconomic implications. It provides a comprehensive framework for evaluating the sustainability of products or processes, taking into account both the positive and negative impacts of each stage of their life cycle.

Objectives

The main objective of this doctoral dissertation has been a deep description of the state of the art of the worldwide ecological crisis and the identification of possible solutions, promoting circular economy and circular bioeconomy perspectives. The importance of integrating ecological and socio-economic issues by adopting a life-cycle thinking perspective, to assess the environmental, economic, and social consequences in some sectors, has been highlighted.
In particular, in the first part of the research, the buildings and construction sector has been explored, because of its importance both in terms of economic and environmental impacts.

Building and construction is a very resource-intensive industry on a global scale and it must transition to a circular economy in order to lessen its effects on the environment and safeguard our finite resources.

As stated in the first paper (annex 1), it is well acknowledged that the built environment has a significant impact on the environment globally. This industry is in charge of producing about 50% of the world's greenhouse gas emissions, and it consumes up to 40% of all the raw materials taken from the lithosphere. Along the entire chain from construction to destruction, passing through utilization and maintenance, buildings and construction are responsible for a significant portion of the overall energy consumption (approximately 40%) and carbon emissions (36%)..

It is important to emphasize the significance of a product's "green design," which must be focused on a decrease in the consumption of raw materials and waste prevention along the full life cycle of products. The European strategy for a Sustainably Built Environment will promote circularity principles of construction over a building's lifespan, beginning with an update in the Construction Product Regulation, also adopting a Life Cycle Assessment (LCA) approach in public procurement. In addition, it was investigated how Life Cycle Thinking and Life Cycle Assessment, as essential tools for sustainability, Eco-design, an innovative approach to building and construction, and appropriate and efficient recycling procedures for Construction and Demolition Waste, with a focus on concrete recycling in line with the case studies examined, can support circular economy in building and construction. Finally, Circular Economy principles state that implementing energy efficiency is anticipated by optimizing lifecycle performance and extending the lifespan of historically significant construction.

For this purpose, and as a fundamental goal of the study activities, the second paper (annex 2) presents a case study involving the application of the LCA approach to building restoration and emphasizes the significance of LCA-based methods in the assessment and selection of materials in the field of conservation and repair of historical buildings, which account for a sizable portion of the building stock, particularly in Europe. Subsequently, the main goal of the thesis' second section was to concentrate on the fundamentals of a circular bio-economy, the importance of protecting biodiversity, the use of renewable biological resources, and the proper and efficient treatment of organic waste.

The sustainability of the bioeconomy could be threatened by a number of environmental and socioeconomic risks, including rising land-use competition between food and fuel crops, direct and indirect changes in land use, marginal land use with detrimental effects on biodiversity, and greenhouse gas emissions, among others.

In this context, an overview of organic waste management, with a particular focus on some emerging economies or developing countries has been conducted. According to papers 3 and 4 (see both corresponding annexes), one of the largest portions of the global waste management system is made up of organic waste. It will be analysed different strategies at the European level, as well as researches carried on in the context of South and central America, shows that in the area there are many bio-based infrastructures, including biogas recovery systems, composting facilities, and bioremediation techniques..

The Middle East, and particularly the Occupied Palestinian Territories, are experiencing increasing environmental degradation due to a lack of water resources, the dramatic effects of climate change, destructive land use, and poor waste management practices. This degradation has been made worse by years of conflict. The objective of the study, in this context, will be to implement a pilot project to optimize organic waste collection and composting for local agriculture.

Finally, as the last objective related to Paper 5, it was significant to highlight how, in terms of biodiversity, the Central America area, represents a "hotspot", rich in flora and fauna species. It contains over 7% of the world's biological diversity despite covering only 1% of the planet's area. Additionally, according to the United Nations, Europe and Latin America and the Caribbean are the regions with the highest forest cover (25% each). In Central America, this percentage is roughly 38% of its surface. According to certain projections, 300 million hectares of land could be made available by 2050 for the development of bioeconomy-related industries.

The protection of biodiversity must also be a shared goal for Central America and the region can move toward a bio-based and circular economy with an environmentally friendly approach, given current technology and Central America's potential for biodiversity.

On the same subjects, the last step in the comparison between the European Union and Central America is represented by the issue of "Biocapacity and governance". The research is on the way to being published, concentrating on the livestock trade sector and utilizing the environmental tools and policies available in both the European Union and the Central American Region. The EU's ecological footprint has surpassed environmental limits, as indicated in the paper, and it is now a net importer of biocapacity. Outside of the EU's boundaries, 31% of the continent's greenhouse gas (GHG) emissions and 42% of its water footprint are produced. The EU adopted the Communication on Trade, Growth, and World Affairs in 2010, which emphasizes that the EU trade policy should continue to support green growth and climate change objectives as well as to support and promote various areas around the world, in terms of energy, resource efficiency, and biodiversity protection.

The last objective of this work plan will be to consider economic factors and environmental sustainability as a crucial component of good European governance should be one of the main results of this commitment to support green growth and improve sustainability in the planet.

Keywords: Environmental impact, Building and Construction, Life Cycle Analysis, Biocapacity, Organic Waste.

Summary

Introducción

La crisis mundial

Nos enfrentamos a una crisis mundial sin precedentes, una situación compleja y confusa, llena de dificultades, representada por emergencias ecológicas y ambientales, y una delicada situación social y económica. Todas estas cuestiones están interconectadas y deben considerarse desde una perspectiva completa, y, dada la complejidad de la difícil situación y sus múltiples causas, se necesitan soluciones complejas y multidisciplinares. Según el Papa Francisco tenemos que hablar de [1]una ecología integral, considerando las dimensiones ambiental, económica, humana y social.

Los desafíos a los que nos enfrentamos son anormales y extraordinarios: cambio climático, agotamiento de los recursos naturales, escasez de agua, pérdida de biodiversidad, emergencia en el suministro de energía, sequía, pandemia, conflictos y guerras relacionados principalmente con cuestiones ambientales, fuentes de energía y flujos de materiales, suministro de agua y explotación de recursos, gestión y eliminación de residuos [2]

Al mismo tiempo, está claro que también los impactos económicos están relacionados con estos problemas. El impacto económico relacionado solo con el cambio climático, por ejemplo, se supone que crece infinitamente, afectando globalmente a todos los países[3].

Durante las últimas décadas, desde el final de la Segunda Guerra Mundial, habíamos estado viviendo en una perspectiva de crecimiento (crecimiento, no desarrollo humano), más aún, de crecimiento económico que parece representar el único objetivo político importante para todos los gobiernos del mundo. Como indicó Jackson[4], la economía global, conectada con aproximadamente el 60% de la degradación de los ecosistemas del mundo, es casi cinco veces el tamaño que tenía hace medio siglo. Este extraordinario aumento de la actividad económica mundial no tiene precedentes históricos. Está totalmente en contraste con nuestro conocimiento científico de la finitud de los recursos naturales y la frágil ecología y el medio ambiente del que dependen los humanos para sobrevivir. El desafío para nuestra sociedad es crear las condiciones para vivir y florecer dentro de los límites ecológicos de un planeta finito.

Parece claro, por tanto, que el crecimiento económico conduce a la falta de “hospitalidad” de la Tierra para los seres humanos y el resto de seres vivos.

Se necesitan medidas urgentes: transición ecológica y energética, reducción de las emisiones de Gases de Efecto Invernadero (GEI), actitud resiliente ante los efectos adversos al clima, principalmente a escala urbana y suburbana, reducción del consumo de materias primas y producción de residuos.

Algunas palabras clave son ahora obligatorias para ser consideradas, comprendidas y puestas en práctica en todos los contextos ambientales, sociales y económicos: mitigación, adaptación, eficiencia, consistencia, suficiencia.

Solo para aclarar lo que se abordará más adelante en el siguiente párrafo, una breve definición de todos ellos:

Mitigación, actuando sobre las causas de un problema crítico. Por ejemplo, en relación con el cambio climático, la mitigación significa actuar reduciendo tanto las emisiones de GEI como el uso de combustibles fósiles. Al mismo tiempo, también en otros contextos y diferentes problemas (es decir, explotación y agotamiento de materias primas, escasez de agua, emisiones en el aire y contaminación del aire, consumo de suelo, descarga de aguas residuales, producción de desechos sólidos, liberación de plásticos en los océanos, etc.) es necesario adoptar una actitud de "mitigación", reduciendo y resolviendo cada problema en su origen.

Adaptación, implementando todas las acciones y estrategias que puedan prevenir, contener y contrarrestar los riesgos, relacionados, por ejemplo, con el cambio climático, o con la reducción de la biodiversidad, la fragilidad del medio ambiente urbano, enfrentando y resolviendo los riesgos relacio

nados con cualquier tipo de alteración ambiental. Es necesario neutralizar tanto y más rápidamente como sea posible los efectos en las personas y entornos más vulnerables, aumentando su resiliencia a través de intervenciones locales y acciones específicas de resiliencia[5]. Pero no solo en temas relacionados con el cambio climático. La adaptación significa también reducir o resolver algunos otros problemas relacionados con la enorme cantidad existente de producción de residuos sólidos y su presencia en vertederos tan enormes o en áreas no controladas en todo el mundo, o conectados con el uso generalizado del suelo ya existente y la urbanización desmedida, o asociados con la presencia de plásticos en los mares y océanos. Adaptarse significa, en resumen, encontrar soluciones alternativas, como el reciclaje de los residuos existentes, la valorización de los plásticos, la concesión de nuevas soluciones respetuosas con el medio ambiente a las zonas existentes degradadas.

La eficiencia está orientada principalmente a mejorar todos los procesos a través de la innovación tecnológica, por ejemplo, mediante una reducción en el consumo de materias primas y la producción de residuos.

La consistencia se puede definir como una especie de "retorno" a los ciclos naturales (es decir, la implementación de energía limpia o recursos renovables y biodegradables).

Finalmente, *suficiencia* significa revertir el modo de vida de las últimas décadas, en cuanto a necesidades y estilos de vida, tasa de consumo, actitudes sociales y económicas, en un cambio sustancial de paradigma tanto a nivel político como de sistemas productivos. En resumen, vivir vidas plenas con menos recursos.*Suficiencia*, se refiere a las necesidades y estilos de vida y se trata de nuevas formas de vivir con menos recursos. Los principios de suficiencia, tales como restricción, precaución, quien contamina paga, cero (residuos, energía, km, etc.) están en relación con la moderación y la parsimonia [6]tienen que ser redescubiertos en cada contexto: vida común y hábitos domésticos, política y gobernanza, producción e industria, agricultura. Definitivamente, suficiencia significa utilizar menos (energía, materias primas, agua, etc.), producir menos (residuos, aguas residuales, emisiones atmosféricas, contaminantes), para evitar impactos adversos sobre el ambiente, la biodiversidad y los ecosistemas naturales, y reducir los impactos sociales y las desigualdades económicas en poblaciones frágiles..

Antropoceno, Ecoceno, Capitaloceno

Desde la Revolución Industrial, en relación con la enorme utilización de combustibles fósiles y las emisiones de GEI relacionadas, el crecimiento de la población mundial, la agricultura intensiva, el consumo de recursos y la contaminación, una era diferente se hizo presente, en la cual las acciones humanas se han convertido en el principal impulsor del cambio ambiental global [7]. El origen antrópico de la crisis ambiental ha sido reconocido y destacado por muchos científicos, que comenzaron a llamar "el Antropoceno", la era de los humanos, a la nueva era en la que vivimos. El término Antropoceno fue acuñado por primera vez en la década de 1980 por el biólogo Eugene Stoermer, y adoptado en 2000 por el ganador del Premio Nobel de química Paul Crutzen, junto con Stoermer, en su libro "Bienvenido al Antropoceno" [8] .

La idea del Antropoceno indica una especie de asunción de responsabilidad: es necesario tener en cuenta todas las actividades humanas en los sistemas naturales y se pide a la comunidad mundial que reduzca los impactos en la Tierra y resuelva todos los problemas ambientales existentes ya reconocidos o posiblesen el futuro [9] . La humanidad ha alterado varios ciclos naturales (es decir, nitrógeno de carbono, agua, etc.) y el ciclo del agua, que produjeron impactos ambientales en todos los ecosistemas planetarios e indujeron desastres ecológicos [10].

El crecimiento económico produce impactos irreversibles y un estado sustancial de estar en la Tierra pesado y arduo para vivir, si está (como está) estrictamente ligado a la explotación y consumo de los recursos naturales, a la pérdida o empobrecimiento del capital natural y la biodiversidad, y a problemas graves como el cambio climático, la contaminación, etc. En esta perspectiva, debido al "peso" del crecimientoi interminable de la economía (es decir, la comercialización extrema, la amplia externalización de los costos sociales y ecológicos, la productividad infinita y la creación de dinero y riqueza), la era actual puede denominarse Econoceno[11].

Pero, una definición más política y efectiva es la del historiador ambiental y geógrafo histórico Jason W. Moore. ¿La era actual no tiene que ser considerada como Antropoceno (que es una perspectiva eurocéntrica y tecno-determinista) o Ecoceno (sólo un punto de vista parcial) sino que tiene que ser nombrada como Capitaloceno – la edad del capital – "la era histórica moldeada por la acumulación interminable de capital?. Sólo en esa perspectiva es posible reconocer y comprender las crisis globales del presente. Según Moore: *"el Antropoceno es una historia reconfortante con hechos incómodos. Encaja fácilmente dentro de una descripción convencional – y lógica analítica – que separa a la humanidad de la red de la vida. [...] Aquí,* la *periodización del Antropoceno se encuentra con un argumento ecologista de larga trayectoria sobre la Revolución Industrial como el punto de inflexión en los asuntos humanos* [12]

Interesante es la concepción y la reconstrucción de la historia humana por Moore: "*Los humanos transformaron los entornos desde el comienzo de la agricultura y variadas formas de civilización desencadenaron cambios aún mayores en la creación del entorno humanizado (pero siempre coproducido). Entre 1450 y 1750, comienza una nueva era de las relaciones humanas en la red de la vida: la Era del Capital. Sus epicentros fueron las sedes del poder imperial y el poder financiero. Sus tentáculos se envolvieron alrededor de los ecosistemas, incluidos los humanos, desde el Báltico hasta Brasil, desde Escandinavia hasta el sudeste asiático. Junto a las nuevas tecnologías, había una nueva técnica, un nuevo repertorio de ciencia, poder y maquinaria, que apuntaba a "descubrir" y apropiarse de nuevas naturalezas baratas. El principal de ellos fueron las nuevas formas de mapear y calcular el mundo"* [ídem].

Durante los siglos pasados, nuestra civilización evolucionó por los humanos junto con el resto de la naturaleza, generando cambios históricos, humanidad-en la naturaleza y naturaleza-en-humanidad y provocando una nueva concepción del valor: los bienes humanos y extrahumanos (esclavos, bosques, suelos) se vinculaban a la productividad laboral y las mercancías. Eso significó no solo una nueva perspectiva económica, sino establecer una ecología global multiespecie de capital, poder y reproducción. [13]

Economía del donut

Para reconsiderar nuestra sociedad dentro de los límites de los recursos de la Tierra, el "Donut de los límites sociales y planetarios" [14] propone una perspectiva fascinante como alternativa al crecimiento infinito. Kate Raworth, la creadora de este nuevo modelo económico comienza preguntándose qué objetivo debería fijarse la economía. De acuerdo con la definición de sostenibilidad, el principal desafío de la humanidad del siglo XXI es satisfacer los requisitos de todos dentro de los límites del planeta. En otras palabras, asegurarse de que todos tengan acceso a las necesidades de la vida (como alimentos, vivienda, atención médica, educación y participación pública), al tiempo que se garantiza que la humanidad en su conjunto no ejerza demasiada presión sobre los sistemas de soporte vital de la Tierra, como un clima estable, suelos fértiles, disponibilidad de agua, etc., de los que depende inherentemente. Esta tarea está enmarcada de una manera ilustrativa y seria por el "donut" de los límites sociales y planetarios, que sirve como una brújula para el avance humano en el siglo XXI.

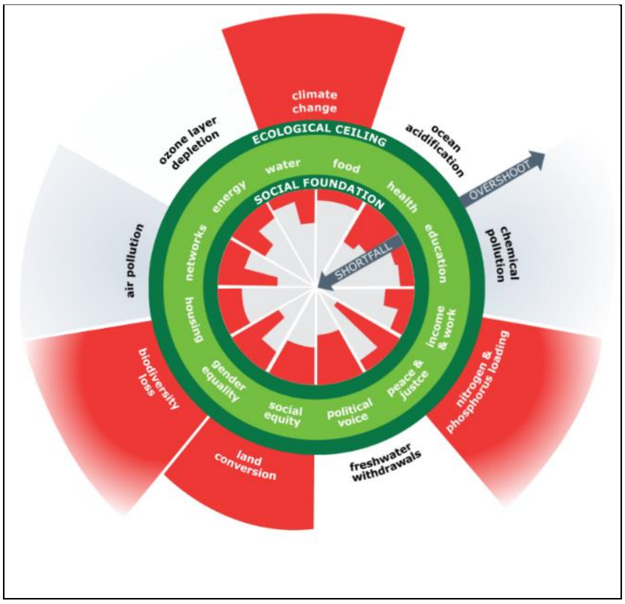

Figura 1 - El donut de los límites sociales y planetarios" [32]

El donut se compone de dos anillos concéntricos (Figura 1): un techo ecológico para evitar que la humanidad exceda colectivamente los límites planetarios que salvaguardan los sistemas de soporte vital de la Tierra, y una base social para garantizar que nadie se quede sin las necesidades de la vida. Hay una región en forma de "rosquilla" entre estos dos conjuntos de límites que es ecológicamente segura y socialmente justa: una zona donde la humanidad puede permanecer de modo sostenible.

El techo ambiental está compuesto por nueve límites planetarios (cambio climático, acidificación de los océanos, contaminación química, cargas de nitrógeno y fósforo, extracciones de agua dulce, conversión de tierras, pérdida de biodiversidad, contaminación del aire, agotamiento de la capa de ozono), según lo establecido por Rockström [15]una degradación ambiental inaceptable y posibles puntos de inflexión en los sistemas de la Tierra están presentes.

Las doce dimensiones de la base social (Seguridad alimentaria, Salud, Educación, Ingresos y trabajo, Paz y justicia, Voz política (participación pública), Equidad social, Igualdad de género, Vivienda, Redes, Energía, Agua) se derivan de estándares sociales mínimos que se han acordado a nivel mundial, como se describe en la Agenda 2030 de las Naciones Unidas y los Objetivos de Desarrollo Sostenible en 2015 [33]. Hay un lugar entre los límites sociales y planetarios donde la humanidad puede vivir y prosperar de una manera ética tanto a nivel social como ambiental. Es necesario desarrollar una nueva visión del mundo en la que cada persona viva con dignidad y sentido de comunidad dentro de los límites de los recursos de nuestro planeta.

El bienestar de la humanidad, el ambiente y la economía están sustancialmente moldeados por la forma en que la sociedad usa y cuida los recursos naturales. Un control eficaz de la contaminación requiere la mitigación de los peligros específicos de las sustancias y una reducción del uso de materias primas en toda la economía, a fin de reducir el volumen de residuos finales y las emisiones en la atmósfera y el agua [34].

Escasez y agotamiento de recursos

El uso global de recursos materiales se ha acelerado en la primera década del siglo XXI, aumentando así las presiones ambientales y los impactos como la contaminación. Se estima que cuatro de los nueve límites planetarios han sido ya superados, cambiando irreversiblemente el funcionamiento de los principales procesos del sistema de la Tierra, como el clima[16]. En las últimas décadas, una combinación de pérdida de hábitat, sobreexplotación y contaminación ha llevado a disminuciones catastróficas en la biodiversidad, conocida como la sexta extinción masiva de la Tierra, en forma de daños al funcionamiento del ecosistema y los servicios vitales para sostener la civilización[17].

En el último "Informe de brecha de circularidad 2021" [18] se destaca cómo la insaciable demanda de recursos de la humanidad y la correspondiente economía “desechable” (lineal) están amenazando el futuro del planeta y conduciendo a la humanidad por el camino hacia el colapso climático. Las estadísticas son bastante concluyentes: en 2021, se consumieron 101.400 millones de toneladas de materias primas, frente a los 100.000 millones de toneladas en 2019, mientras que la tasa de reutilización y reciclaje se mantuvo sin cambios en el 8,6%. Es acertado decir que el 70% de las emisiones globales están relacionadas con la extracción de dichas materias primas, la producción de bienes y el consumo de esos bienes, lo que llama la atención sobre la forma en que el consumo de recursos está vinculado a la catástrofe climática.

Para evitar que el uso global de materias primas alcance los 170-184 mil millones de toneladas anuales para 2050, el mundo tendrá que ponerle un límite. Eso está en línea con la trayectoria actual, pero es incompatible con limitar el aumento de la temperatura global a 1.5°C, según lo acordado en París en 2015[19]. Para 2030, el número de recursos que se integrananualmente a procesos vinculados con la economía circular deben al menos cuadruplicarse para seguir esta trayectoria de temperatura.

De acuerdo con un enfoque de sostenibilidad, solo se tendrían que utilizar recursos renovables, evitando el agotamiento y garantizando recursos suficientes para todas las personas y la humanidad. A este respecto, existe una profunda desigualdad en la distribución, disponibilidad y uso de los recursos naturales y en la exposición a factores de riesgo ambientales en las regiones del mundo y dentro de los países y ciudades, y en la cuestión de la riqueza, si consideramos que el 10% de la población mundial posee el 76% de toda la riqueza mundial[20].

A nivel mundial, existe una desigualdad significativa y una disparidad de oportunidades. Solo el 1% del consumo mundial es realizado por los 1.200 millones de personas más pobres, mientras que el 72% lo hacen los mil millones de personas más ricas[21]. Solo las naciones más ricas del mundo consumen 10 veces más material que las naciones más pobres, y la eficiencia en el uso de los recursos ahora está disminuyendo a medida que varias economías en ascenso se están expandiendo rápidamente. En muchas ciudades, más del 40% de la población vive sin acceso a los servicios e infraestructuras fundamentales, es decir, abastecimiento de agua y saneamiento o suministro de alimentos y transporte, lo que causa una angustia extrema a la población afectada y en particular a las mujeres [22]

Según datos del Banco Mundial, en la pasada década 2000-2010, la población mundial creció un 1,2% anual (a una tasa reducida en comparación con los cuarenta años anteriores), del mismo modo el PIB creció lentamente a un crecimiento anual promedio del 2,6%. Por el contrario, el aumento en el suministro y uso de materiales alcanzó el 3,7% anual, mientras que en el período 2010-2020 las emisiones totales de GEI en CO_2 eq (+ 12,5%), el uso del sueloestán en constante aumento (+ 0,06%) y las superficies forestales (-0,2%) se redujeron [23]

Es necesario disociar el crecimiento económico de los impactos ambientales y el uso de los recursos naturales.

En el transcurso de las últimas décadas, el crecimiento mundial ha aumentado continuamente el consumo de recursos y las emisiones de contaminación mucho más rápido de lo que no pudieron ser contenidos gracias a la innovación tecnológica [24]Durante el mismo período las desigualdades se han expandido fuera de control[25].

Hasta ahora, un aumento en el PIB mundial está estrictamente relacionado con un aumento en el consumo de materiales y los impactos ambientales [26]. Un desacoplamiento global del PIB y el consumo de recursos aún está lejos de ser una realidad.

Según Krausmann et al. [27], se puede demostrar que un crecimiento de la riqueza (PIB/cápita) es responsable del principal crecimiento en el consumo de materiales y recursos naturales.

Nuestro planeta es finito y finitos son los recursos que puede darnos para toda la vida antrópica. Durante las últimas décadas se han definido varios modelos para evaluar el consumo y el agotamiento de los recursos naturales.

El Día de la Sobrecapacidad de la Tierra es el día en que la cantidad de bienes y servicios ecológicos que necesita la humanidad en un año en particular excede lo que el planeta puede reponer en ese año. La fecha del 28 de julio se eligió como el Día de la Sobrecapacidad de la Tierra en 2022. Mediante el agotamiento de los suministros de recursos naturales y la acumulación de residuos, principalmente dióxido de carbono en la atmósfera, seguimos perpetuando este déficit. Global Footprint Network, una organización de investigación global que dota a los tomadores de decisiones con recursos para permitir el funcionamiento de la economía humana dentro de los límites ecológicos del planeta, patrocina y calcula el Día de la Sobrecapacidad de la Tierra El uso de áreas de superficie productiva se calcula a través de la Huella Ecológica. Estas áreas generalmente incluyen zonas utilizadas para la agricultura, el pastoreo de ganado, la pesca, el desarrollo urbano, la silvicultura y la tierra con alta demanda de carbono[28]. La Huella Ecológica mide la demanda y la oferta de la naturaleza, expresada en hectáreas estandarizadas globales con productividad promedio mundial.

La Huella Ecológica [28] cuantifica la necesidad de un área de población de infraestructuras urbanas, espacio para alimentos de origen vegetal y productos de fibra, ganado y productos pesqueros, madera y otros productos forestales, y bosques para absorber las emisiones de dióxido de carbono de los combustibles fósiles. Suma todas las áreas productivas en las que compite un grupo de personas, un individuo o un producto. Mide los recursos naturales que necesita una población o producto en particular para proporcionar los que consume (como productos animales, alimentos y fibras de origen vegetal, ganado y pescado, madera y otros productos forestales, etc.), y el espacio necesario para dotarse de infraestructuras urbanas, así como para gestionar sus residuos y emisiones, en particular las emisiones derivadas del carbono.

Por el lado de la oferta, la biocapacidad representa la productividad de sus activos ecológicos y su superficie terrestre y marítima biológicamente productiva, incluidas las áreas forestales, de pastoreo cultivo ypesca y las superficies edificadas. Estas regiones también se pueden utilizar para tratar los residuos y emisiones que producimos, en particular las emisiones de carbono provenientes de la quema de combustibles fósiles.. La Huella Ecológica de cada ciudad, estado o país se puede comparar con su biocapacidad.

Si la demanda de recursos naturales de una población excede la oferta disponible, el área experimenta un déficit ecológico y debe importar recursos, utilizar sus propios recursos , por ejemplo,a través de la sobrepesca o liberar dióxido de carbono a la atmósfera para compensar el déficit. Si no hay importación neta de recursos en la tierra, el déficit ecológico y el exceso son idénticos.

Según la definición de la OMS, una huella de carbono es una medida del impacto de cualquier actividad en la cantidad de dióxido de carbono (CO_2) producido, incluidas las emisiones directas, como las que se producen cuando se queman combustibles fósiles durante la fabricación, la calefacción y el transporte, así como las emisiones producidas cuando se produce electricidad en relación con el consumo de productos y servicios.

Además, la idea de una huella de carbono a menudo también tiene en cuenta otras emisiones de gases de efecto invernadero, como las del metano, el óxido nitroso o los clorofluorocarbonos (CFC).

La cantidad de agua dulce utilizada en general para generar los bienes y servicios que un individuo, comunidad o corporación produce y consume se conoce como su "huella hídrica" [36].

Las personas utilizan grandes cantidades de agua para beber, cocinar y lavar, pero aún más para producir bienes tales como alimentos, papel, ropa de algodón y casi cualquier otro producto físico. esta agua puede denominarse también agua “virtual", ya que representa el volumen de agua dulce utilizada para lograr un producto (o una mercancía, bien o servicio), en las diversas etapas de la cadena de producción, medida en el lugar donde se fabrica realmente el producto o en el lugar donde se consume (definición del lugar de consumo).

La huella material es un indicador basado en la demanda, que asigna todos los recursos materiales movilizados globalmente al consumidor final y rastrea los flujos incorporados o virtuales de materiales vinculados al valor. La huella material de los países es evidente. La huella material per cápita de los países de altos ingresos es de alrededor de 27 toneladas (por persona por año) un 60% más alta que la de los países emergentes y más de trece veces los niveles de los países de bajos ingresos[29].

Si bien los indicadores anteriores son muy útiles para comprender las presiones ambientales del consumo de materiales, la información sobre los impactos ambientales del uso y las prácticas de gestión puede ser realmente útil para apoyar la formulación de políticas para el uso sostenible de los recursos naturales.

Los indicadores basados en el impacto proporcionan una perspectiva diferente. El Plan Integrado de Recursos de la Agencia Internacional de la Energía [29](IRP, 2019) evalúa el impacto relacionado con los materiales desde las fases de extracción y procesamiento hasta el "listo para usar", incluida la eliminación de residuos, las emisiones y los impactos de los desechos mineros. Así, se estimaque la explotación y el tratamiento de los recursos naturales representan más del 90% de los impactos mundiales en la biodiversidad y el estrés hídrico, y aproximadamente la mitad de las emisiones mundiales del cambio climático (sin incluir los impactos climáticos relacionados con el uso del suelo). Estos resultados destacados ponen de relieve la necesidad de colocar los recursos en el punto focal de las políticas climáticas y de biodiversidad.

Introduction

The global crisis

We are dealing with an unprecedented global crisis, a complex and confused situation, full of difficulties, represented by ecological and environmental emergencies, and social and economic dire straits. All issues are interconnected and have to be considered in a whole perspective, and, given the complexity of the critical plight and its multiple causes, complex and multidisciplinary solutions are needed. According to Francis Pope[1] we have to talk about an integral ecology, by considering both environmental, economic and human and social dimensions.

The challenges we are facing are abnormal and enormous: climate change, natural resources depletion, water scarcity, biodiversity loss, energy supply emergency, drought, pandemic, conflicts and wars mostly related to environmental issues, energy sources and materials flows, water supply and resources exploitation, waste management and disposal [2].

At the same time, it is clear that also economic impacts are connected to these issues. The economic impact related just to climate change, for instance, is assumed to grow infinitively, affecting globally all countries [30]

During the last few decades, since the end of the second world war, we had been living in a perspective of growth (growth, not human development), nay, of economic growth that seems to represent the single important policy goal for all governments across the world. As indicated by Jackson [4]the global economy connected with an estimated 60% of the world's ecosystems degradation, is almost five times the size it was half a century ago. This extraordinary ramping up of global economic activity has no historical precedent. It's totally in contrast with our scientific knowledge of the finiteness of natural resources and the fragile ecology and environment on which humans depend for survival. The challenge for our society is to create the conditions to live and flourish within the ecological limits of a finite planet.

It is clear that the economic growth leads to the inhospitality of the Earth for humans.

Urgent action is needed: ecological and energy transition, abatement in greenhouse gases (GHG) emission, resilient attitude to climate adverse effects, mainly at urban and suburban scale, reduction in raw materials consumption and waste production.

Some key words are mandatory now to be considered, understood and put in practice in all environmental, social and economic contexts: mitigation, adaptation, efficiency, consistency, sufficiency.

Just to clarify what will be taken up later in the next paragraph, a short definition of all them:

Mitigation, acting on the causes of a critical issue. For instance, in relation to climate change mitigation means to act by reducing both GHG emissions and the use of fossil fuels. At the same time, also in other contexts and different troubles (i.e., raw materials exploitation and depletion, water scarcity, airborne emissions and air pollution, soil consumption, wastewater discharge, solid waste production, plastics release in the oceans, etc.) is necessary to adopt a "mitigation" attitude, by reducing et solve each problem at its source an;

Adaptation, implementing all actions and strategies that can prevent, restrain, and counteract risks, related for instance to climate change, or to the reduction of biodiversity, urban environment fragility, by facing and solving the risks related to any kind of environmental disruption. It is necessary to neutralize as much and fastest as possible the effects on most vulnerable people and environments, by increasing their resilience through local interventions and targeted resilience actions [5]. But not only in climate change related issues. Adaptation means also to reduce or solve some other troubles related with existing huge amount of solid waste production and their presence in so enormous landfills or in uncontrolled areas around the world, or connected to already existing pervasive land use and robust urbanization, or associated with plastics presence in the seas and oceans. To adapt means in short to find alternative solutions, such as recycling of existing waste, valorizing plastics, giving new environmentally-friendly solutions to degraded existing areas.

Efficiency is mainly oriented to improve all processes through technological innovation, for instance by a reduction in raw materials consumption and waste production.

Consistency can be defined as a sort of "coming back" to natural cycles (i.e., implementing clean energy or renewable and biodegradable resources). Finally, sufficiency means to reverse the last decades way of life, regarding needs and lifestyles, consumption rate, social and economic attitudes, in a substantial change of paradigm both at political and production systems levels. In short, to live fulfilled lives with fewer resources.

Sufficiency, regards needs and lifestyles and it is about new ways to live with fewer resources. Sufficiency principles, such as restraint, precautionary, polluter pays, zero (waste, energy, km, etc.) are in relation with moderation and parsimony[6], and have to be re-discovered in each context: common life and domestic habits, policy and governance, production and industry, agriculture. Definitely, sufficiency means to use less (energy, raw materials, water, etc.), to produce less (waste, wastewater, airborne emissions, pollutants), in order to avoid adverse impacts on the environment, biodiversity and natural ecosystems, and to reduce social impacts on fragile populations and economic inequalities.

Antropocene, Ecocene, Capitalocene

Since the Industrial Revolution, in relation with the huge utilization of fossil fuels and related GHG emissions, the global population growing, the intensive agriculture, resources consumption and pollution, a different age became apparent, in which human actions have become the main driver of global environmental change [7]. The anthropic origin of the environmental crisis has been recognized and highlighted by many scientists, that started to call "the Anthropocene", the age of humans, the new era we are living in. The term Anthropocene was coined for the first time in the 1980s by biologist Eugene Stoermer, and adopted in 2000 by Nobel Prize winner for chemistry Paul Crutzen, together with Stoermer, in their book "Welcome to the Anthropocene" [8].

The idea of the Anthropocene indicates a sort of assumption of responsibility: it is necessary to take into account all human activities on the natural systems and the worldwide community is asked to reduce impacts to the Earth and to solve all recognized already or probably in the future existing environmental issues [31]. Humanity has altered several natural cycles (i.e., carbon nitrogen, water, etc.) cycle and the water cycle, produced environmental impacts in all planetary ecosystems and induced ecological disasters[10].

The economic growth produces irreversible impacts and a substantial state of being on the Earth heavy and arduous to live in, if it is (as is) strictly coupled to natural resources exploitation and consumption, to the loss or impoverishment of natural capital and biodiversity, and to severe issues such as climate change, pollution, etc. In that perspective, because of the "weight" of the never-ending increasing of the economy (i.e. extreme commercialization, wide externalization of social and ecological costs, infinite productivity and money and richness creation), the current age can be named as Econocene [11].

But, a more political and effective definition is by the environmental historian and historical geographer Jason W. Moore. The current age has not to be considered as Anthropocene (that is a Eurocentric and techno-determinist perspective) or Ecocene (just a partial point of view) but it has to be named as Capitalocene – the age of capital– "*the historical era shaped by the endless accumulation of capital*". Just in that perspective it is possible to recognize and understand the global and whole crises of the present. According to Moore: *“the Anthropocene is a comforting story with uncomfortable facts. It fits easily within a conventional description – and analytical logic – that separates humanity from the web of life. […]Here, the Anthropocene’s periodization meets up with a longstanding environmentalist argument about the Industrial Revolution as the turning point in human affairs*”[12]

Interesting the conception and the reconstruction of human history by Moore: “*The humans transformed environments from the very beginning of agriculture and varied forms of civilization unleashed even greater changes in humanitiated (but always co-produced) environment-making. Between 1450 and 1750, a new era of human relations in the web of life begins: the Age of Capital. Its epicenters were the seats of imperial power and financial might. Its tentacles wrapped around ecosystems – humans included – from the Baltic to Brazil, from Scandinavia to Southeast Asia. Alongside new technologies, there was a new technics – a new repertoire of science, power and machinery – that aimed at ‘discovering’ and appropriating new Cheap Natures. Chief amongst these were new ways of mapping and calculating the world”* [idem].

During the past centuries, our civilization was co-produced by humans together with the rest of nature, generating historical changes, humanity-in nature and nature-in-humanity and causing a new value conception: human and extra-human goods (slaves, forests, soils) have to be in subject to labor productivity and commodities. That means not only a new economic perspective, but to establish a multispecies global ecology of capital, power and re/production [13]

Doughnut Economics

In order to reconsider our society within the Earth's limits of the resources, the "Doughnut of social and planetary boundaries" [14] proposes a fascinating perspective as an alternative to infinite growth. Kate Raworth, the creator of this new economic model, starts by asking what goal the economy should set itself. According with sustainability definition, the main challenge of the 21st century humanity's is to provide for everyone's requirements within the limits of the planet. In other words, to make sure that everyone has access to the necessities of life (such as food, shelter, healthcare, education, and political voice), while also making sure that humanity as a whole doesn't put too much strain on the Earth's life-supporting systems, such as a stable climate, fertile soils, availability of water, etc., on which it depends inherently. This task is framed in a humorously serious way by the doughnut of social and planetary boundaries, which serves as a compass for human advancement in the twenty-first century. The Doughnut of social and planetary boundaries.

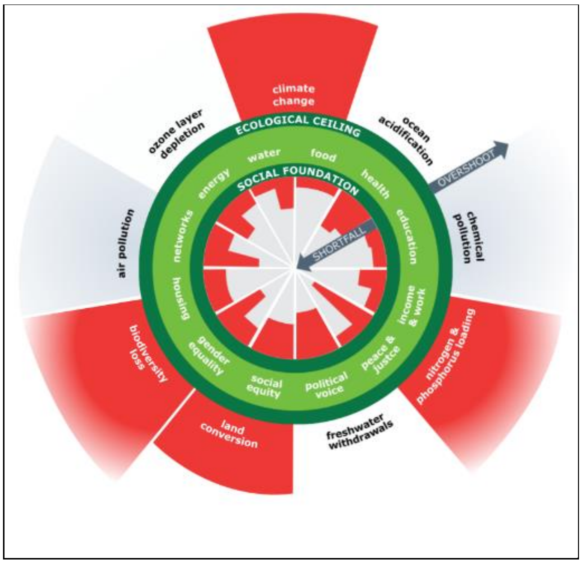

Fig. 1 - The Doughnut of social and planetary boundaries" [32]

The Doughnut is made up of two concentric rings (Fig. 1): an ecological ceiling to prevent humanity from collectively exceeding the planetary boundaries that safeguard Earth's life-supporting systems, and a social foundation to ensure that no one is left without the necessities of life. There is a doughnut-shaped region between these two sets of boundaries that is both ecologically secure and socially just: a zone where mankind can flourish.

The environmental ceiling is composed by nine planetary boundaries (Climate change, Ocean acidification, Chemical pollution, Nitrogen and phosphorus loading, Freshwater withdrawals, Land conversion, Biodiversity loss, Air pollution, Ozone layer depletion), as set out by Rockström [15], beyond which an unacceptable environmental degradation and potential tipping points in Earth systems are present.

The twelve dimensions of the social foundation (Food security, Health, Education, Income and work, Peace and justice, Political voice, Social equity, Gender equality, Housing, Networks, Energy, Water) are derived from minimal social standards that have been agreed upon globally, as outlined in the UN Agenda 2030 [33]and Sustainable Development Goals in 2015. There is a place between social and planetary boundaries where mankind can live and prosper in a way that is ethical on both a social and environmental level. It is necessary to develop a new vision of the world in which every person lives with dignity and a sense of community within the limits of resources of our planet.

Humanity's well-being, the environment, and the economy are substantially shaped by how society uses and cares for natural resources. Effective pollution control requires mitigation of substance specific hazards and a reduction of raw material use throughout the economy, in order to lower the volume of final waste and emissions in air and water [34].

Resources scarcity and depletion

Global material resource use has accelerated in the first decade of the 21st century, thereby increasing environmental pressures and impacts such as pollution. An estimated four out of the nine planetary boundaries have been surpassed, irreversibly changing the functioning of major Earth system processes, such as climate[16]. Over the last few decades, a combination of habitat loss, overexploitation and pollution has led to catastrophic declines in biodiversity – known as Earth's sixth mass extinction – in the form of damage to ecosystem functioning and services vital to sustaining civilization [17].

In the last "Circularity Gap Report 2021" [18] it is highlighted how the humanity's insatiable demand for resources and the corresponding throwaway economy are threatening the planet's future and driving the mankind down the road to climate breakdown. The statistics are quite impressive: In 2021, 101.4 billion tons of virgin materials were consumed, up from 100 billion tons in 2019, while the rate of reuse and recycling remained unchanged at 8.6%. It is conceivable to say that 70% of global emissions are related to the extraction of raw materials, production of goods, and consumption of those goods, bringing attention to the manner in which resource consumption is tied to the climate catastrophe.

In order to prevent the global use of virgin raw materials from reaching 170-184 billion tons annually by 2050, the world will need to set a cap on it. That is in line with the current trajectory, but it is incompatible with limiting the global temperature increase to 1.5°C, as agreed in Paris in 2015 [19]. By 2030, the number of resources entering the circular economy annually must at least quadruple in order to follow this temperature pathway.

According with a sustainability approach, just renewable resources would have to be used, avoiding depletion and guaranteeing enough resources for all people and mankind. But, there is a profound inequality in the distribution, availability and use of natural resources and in exposure to environmental risk factors across world regions and within countries and cities, and in richness issue if we considers that 10% of global population own 76% of all global wealth [35].

Globally, there is significant inequality and opportunity disparity. Just 1% of the world's consumption is made by the 1.2 billion poorest people, whereas 72% is made by the billion richest people [21]. The world's richest nations alone consume 10 times as much material as the world's poorest nations, and resource use efficiency is now declining as a number of rising economies are expanding quickly. In many cities, more than 40 per cent of the population is living without access to the fundamental services and infrastructure, i.e., water supply and sanitation or food supply and transports, causing an extreme distress on the poorest people and particularly on women [22].

According to world bank data [23], in the past decade (2000–2010), the global population grown at 1.2% annually (at a reduced rate in comparison with the previous forty years), likewise GDP growing slowly at an average annual growth of 2.6%. At the contrary, the increase in material supply and use reached 3.7% annually, while in the period 2010-2020 the total GHG emissions in CO_2 eq (+12,5%), and land use are constantly rising (+0,06%) and forest surface areas (-0,2%) were reduced.

It is necessary to decoupling economic growth from environmental impacts and use of natural resources.

In the course of last decades, worldwide growth has continuously increased resource consumption and pollution emissions much faster than they could not be contained thanks to the technology innovation [24]. During the same period inequalities have expanded runaway [25].

Until now, an increasing in the global GDP is strictly connected with an increase in material consumption and ecological impacts [26]. A global decoupling of GDP and resource consumption is still far from a reality.

According to Krausmann et al. [27], it can be demonstrated that a growing in richness (GDP/capita) is responsible of the main growth in materials and natural resources consumption.

Our planet is finite and finite are the resources it can give us for all anthropic human life. Several models have been defined during the last few decades in order to assess natural resources consumption and depletion.

The Earth Overshoot Day is the day when the amount of ecological goods and services needed by humanity in a particular year exceeds what the planet can replenish in that year. The date July 28 is chosen as Earth Overshoot Day in 2022. By the depletion of ecological resource supplies and the buildup of waste, principally carbon dioxide in the atmosphere, we continue to perpetuate this deficit. Global Footprint Network, a global research organization that equips decision-makers with resources to enable the operation of the human economy within ecological bounds of the planet, sponsors and calculates Earth Overshoot Day [28] Using productive surface areas is tracked by ecological footprint. These areas typically include areas used for farming, grazing livestock, fishing, urban development, forestry, and land with high carbon demand. Ecological Footprint measures the demand on and supply of nature, expressed in global standardized hectares with world average productivity.

The Ecological Footprint [28] quantifies the need for a population's area for urban infrastructure, space for plant-based food and fiber goods, livestock and fish products, lumber and other forest products, and forest to absorb carbon dioxide emissions from fossil fuels. It adds up all the productive areas which a group of people, an individual, or a product competes. It gauges the ecological resources needed by a particular population or product to provide the natural resources it consumes (such as animal products, plant-based foods and fibers, livestock and fish, timber and other forest products, etc.), and space for urban infrastructure), as well as to absorb its waste, particularly carbon emissions.

On the supply side, the biocapacity represents the productivity of its ecological assets and its biologically productive land and sea area, including forest lands, grazing lands, cropland, fishing grounds, and built-up land. These regions can also be used to absorb the garbage we produce, particularly our carbon emissions from burning fossil fuels, especially if they are left unharvested. The Ecological Footprint of each city, state, or country can be compared to its biocapacity.

If a population's demand for ecological resources exceeds the available supply, the area experiences an ecological deficit and must import resources, use its own ecological resources up through overfishing, or release carbon dioxide into the atmosphere to make up the shortfall.

As there is no net resource import into the earth, ecological deficit and overshoot are identical.

According to WHO definition, a carbon footprint is a measure of the impact any activity has on the amount of carbon dioxide (CO_2) produced, including direct emissions, such as those that are produced when fossil fuels are burned during manufacturing, heating, and transportation, as well as emissions produced when electricity is produced in connection with the consumption of products and services.

Moreover, the idea of a carbon footprint frequently takes into account other greenhouse gas emissions as well, like those from methane, nitrous oxide, or chlorofluorocarbons (CFCs).

The quantity of freshwater utilized overall to generate the goods and services that an individual, community, or corporation produces and consumes is referred to as its "water footprint" [36]

People use large amounts of water for drinking, cooking and washing purposes, but even more for producing things such as food, paper, cotton clothes, and almost every other physical product. This water can be named also as virtual water, representing the volume of freshwater used to achieve a product (or a commodity, good or service), in the various steps of the production chain, measured at the place where the product is actually manufactured or at the place where it is consumed (consumption-site definition).

Material footprint is a demand-based indicator, allocating all of the material resources globally mobilized to the final consumer, and tracking embodied or virtual flows of materials linked to value. Material footprint of countries inequalities are evident. High-income countries per capita material footprint are around 27 tons (per person per year) 60 per cent higher than emerging countries and more than thirteen times the low-income countries levels [29].

While the previous indicators are very useful for understanding the environmental pressures from material consumption, information about the environmental impacts of use and management practices can be really useful to support policymaking for the sustainable use of natural resources.

Impact-based indicators provide a different perspective. The same Integrated Resource Plan (IRP, 2019) [37] assesses the impact related to materials from extraction and processing phases to the “ready-to-use”, including the waste disposal and emissions and impacts of mine tailings. It results that resources exploitation and treatment account for more than 90 per cent of global biodiversity and water stress impacts, and approximately half of global climate change emissions (not including climate impacts related to land use). These prominent outcomes highlight the necessity to place resources at the focal point of climate and biodiversity policies.

International commitment and concepts

Sustainability

The concept of sustainable development was first introduced in 1987 by the UN World Commission on Environment and Development, also known as the Brundtland Commission, in “Our Common Future” report [38], defined as ‘*development that meets the needs of the present without comprising the ability of future generations to meet their own needs*’. At the same time, in terms of resources and pollution (with a particular regard to ecology and biology and natural ecosystems), it is defined as the rates at which renewable resources could be extracted or affected by pollution without threatening the underlying integrity of ecosystems.

Sustainability proposes a systemic interconnection between environmental issues and economy and society, usually depicted as a triangle or overlapping circles, in a common Venn diagram (Fig. 2), where all the elements must support or reinforce one another in a reciprocal relationship.

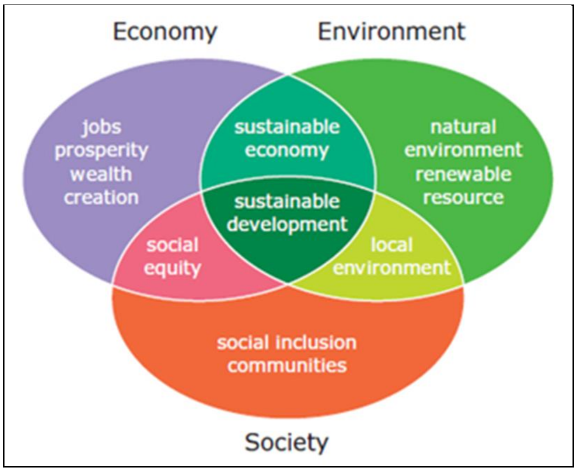

Fig. 2 – Sustainability as a connection between the Environment, the Economy and the Society [39]

In sustainability, it can be difficult to define the concept of nature, and the ethical relationship between humans and the natural world. The dominant paradigm separates humans and nature where nature is dominated by humans and exploited by humans as a source of raw materials and resources and the destination of waste and pollutants, with an only one driver represented by economy and market demand. Sustainability is oriented to consider humans and nature as one unit.

By the ontology of nature point of view, the amount of the nature that has to be valorized intrinsically defines the levels of sustainability. A low sustainability leaves just some of the nature out of market as it considers it intrinsically valuable. A more intensive sustainable approach looks for to put out of market a larger quantity of nature. It is commonly assumed that the portions of nature that are damaged because of economic growth will be compensated for in the future as the technology will find substitute for the used and depleted resources. This assumption shows an extraordinary confidence in technology or in a “technocratic” attitude. But, irreversible changes prevent future generations to relate with their true environment and when a certain habitat or species will disappear or will be exhausted, it has to be wondered if it would be possible a compensation, or if future generation will accept that change. Extensive pollution or intensive soil exploitation, for instance, increase the costs and decreases the ability of policies of future generations to choose their own destiny [40].

Sustainable Development is a core concept within global development policy and agenda. It provides a means for civilization to engage with the environment without jeopardizing the resource's long-term viability. As a result, it is a development challenge as well as a philosophy that advocates for raising living standards without endangering the earth's ecosystems or producing environmental concerns like deforestation and water and air pollution, climate change and species extinction. In other words, it suggests the proper attitude to use natural resources by preserving natural systems' ability to supply resources and ecosystem services for economy and society.

Sustainable Development would promote a balance between economic growth, environmental integrity, and social well-being. This supports the idea that intergenerational equity is embedded in the concept of sustainability recognizing both short and long-term consequences. Sustainable development mainly deals with three main issues: economic growth, environmental protection, and social equality and the three conceptual pillars are 'economic sustainability', 'social sustainability, and 'environmental sustainability'.

Sustainability has to be seen as the objective or the goal of a process. While sustainability refers to a condition, Sustainable Development refers to the process of obtaining that state [41].

Environmental Sustainability

The idea of environmental sustainability fits within the limits to growth ecological economic framework, which is resource-limited. This definition also identifies environmental sustainability as a set of limits on the fundamental activities that regulate the scales of the human economic subsystem: the use of renewable and non-renewable resources on the source side, and pollution and waste assimilation on the sink side.

Another definition focuses on the bio-geophysical aspects of environmental sustainability. Biophysical sustainability refers to the preservation or enhancement of the Earth's life-supporting systems. Allowing current and future generations to achieve economic and social improvement, within a framework of cultural diversity while maintaining biological diversity and biogeochemical integrity of the biosphere through conservation and proper use of air, water, and land resources, is part of sustaining the biosphere with adequate provisions for maximizing future options [42]

Human well-being is strictly linked to the ecosystem and nature's services. To ensure well-being, the ecosystem and nature's services must be maintained at an appropriate level. In that context, the EU Millennium Ecosystem Assessment Project [43] gives a fundamental contribution to clarify the concept of environmental sustainability. It recognizes four categories for ecosystem services: (1) provisioning (food, freshwater, wood and fiber, fuel, etc.); (2) regulatory (climate, flood, disease, water purification, etc.); (3) cultural (aesthetic, spiritual, educational, recreational, etc.); (4) supporting (nutrient cycling, soil formation, primary production, etc.).

The notion of ecosystem services can be extended to include the nature's services supporting global life (such as the stratospheric ozone layer, the climate, the hydrological or the biogeochemical cycles, etc.), mineral resources, the land on the Earth's surface and the space below and above the Earth. Ecosystems and global life support systems are called also environmental infrastructure. Providing the necessary services is only possible if global ecological systems are in a healthy state. Caring for the goods and services provided by nature means caring for nature itself, i.e., global ecosystems and biodiversity. Biodiversity is the most important element of environmental infrastructure and an overarching requirement for most services.

Agenda 2030

On 25 September 2015, the UN General Assembly adopted the Resolution "Transforming our world: the 2030 Agenda for Sustainable Development, a plan of action for people, planet and prosperity" [44] subscribed by all 193 Member Countries (UN, 2015) [45].

Fig. 3 - Agenda 2030 representation [45]

The United Nations 2030 Agenda, and its 17 Sustainable Development Goals (SDGs) (Fig. 3) offer a guideline in the implementation of sustainability policies fitting the collective needs of the local territory. Its universal nature addresses poverty, inequality and other global challenges, and its commitment to 'leave no one behind', tie it closely to supporting world peace. The intrinsic nature of the 2030 Agenda makes the SDGs in a strong interrelation, by considering the three dimensions of sustainability, economic, social and environmental, as key interpretation. With 169 targets and multiple indicators, the envisioned future of having a sustainable world by 2030 is clearly stated [46].

The Stockholm Resilience Center, Stockholm University [47], revisits it in a new perspective, highlighting the interconnected nature of the SDGs and suggesting to prioritize environmental issues and to place the biosphere at the bottom of the ideal pyramid of sustainability, supporting both society and economy.

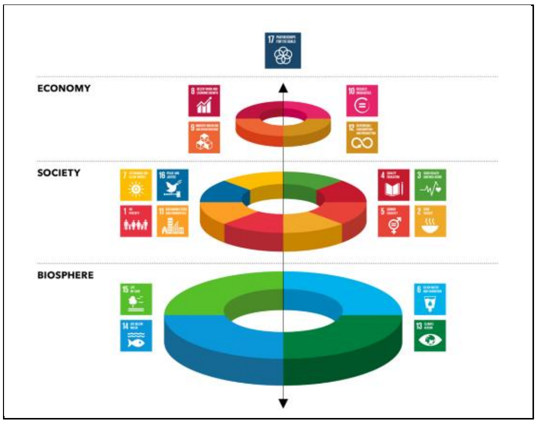

Fig. 4 – New representation of the 17 SDGs [47]

Efficiency, consistency, and sufficiency

Environmental sustainability identifies three potential pathways that can be applied in several context, at urban policy and domestic, at industrial level: efficiency, consistency, and sufficiency [48].

Efficiency is often used to describe a process' ability to be handled optimally in order to produce the best results and the most practical technological approach to problem-solving.

The efficiency notion, for instance, is connected to optimization in energy consumption and in the utilization of raw materials, or the overall expenses and financial repercussions.

However, according to many authors, is necessary to consider the risk of "a rebound effect", the occurrence where an increase in energy efficiency may result in lower energy savings than would be predicted by simply dividing the change in efficiency by the amount of energy used before the change[49] . In short, an example: get a better-performing vehicle and drive more. Due to secondary effects, improvements in resource efficiency provide smaller reductions in the consumption of energy or material resources than are expected—or even an overall net increase in resource use [50].

The "rebound effect" is also well known as the so-called Jevons paradox: a theory that was inspired by the economist William Stanley Jevons' discovery that technical advancements that boost a resource's efficiency can actually lead to more consumption of that resource rather than lower consumption. The paradox is explained in the book The Coal Question [51], where Jevons noted that coal usage had increased in England after James Watt popularized the coal-fired steam engine, which was more effective than Thomas's engine. Newcomen. In spite of the fact that his claim defies logic, it doesn't express an antinomy and is instead accepted in the framework of academic study, despite the contradictory appearance it gives off.

Today, it is necessary to refer to the idea of eco-efficiency, which means reducing environmental impacts for any kind of process, i.e. by an increase in the life cycle of the products or in the intensity of the service, by reducing natural resources and energy consumption, or the toxicity of substances, and waste and pollution, by promoting recyclability of materials and encouraging the utilization of renewable resources.

A popular definition of eco-efficiency, by the World Business Council for Sustainable Development (WBCSD) is "*being achieved by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the Earth's estimated carrying capacity*".

It is regarded as essential to use natural resources wisely, that is, without wasting them. In this context, efficiency should be interpreted in terms of social costs rather than individual or market costs that need to be reduced. Furthermore, it is not restricted to quantifiable components of human economic activity; many ecological services do not come with a "price tag," but that does not mean they should not be utilized effectively. Efficiency as a sustainability strategy is unquestionably the least contentious, despite having a slightly different connotation than in conventional economics. There is already a lot being done globally to increase the effective use of ecosystem services and natural resources.

Here, installing and promoting appropriate technologies and creating favorable economic incentives can achieve a great deal without requiring big changes in people's mindsets and daily habits (e.g., so as to minimize wastage in various branches of the economy). Technological and efficiency improvements are not sufficient to achieve truly sustainable development.

According with the UNEP [29], in order to separate economic growth from environmental degradation, a cohesive future for resource efficiency and sustainable production and consumption must be developed. This decoupling aims to satisfy basic human requirements for things like water and energy while preserving the natural and social capital that supports all life and the functioning of the earth system.

Consistency

Consistency is a lesser-known but no less important tactic for sustainability. Consistency, in general, is the attempt to incorporate the material and production cycles into the natural cycles as well. It is more than recycling because recycling merely involves using leftover pieces of previously-used materials and is frequently associated with unfavorable side effects such as waste or harmful substances.

Consistency is a much more thorough and integrated approach, where recycling is planned before production even starts. Consistency is the ability to mold material and energy flows in ways that are constructive rather than destructive to the environment. Circular economy, and clean production systems are notions that are related to consistency. Using renewable resources and energy, creating closed-loop material flows, and more general circular economy are a few examples of this approach [52].

The Cradle-to-Cradle concept serves as an illustration of how the consistency strategy may be effective. In this approach, commodities must be manufactured to reduce the amount of waste that must be disposed of. This means that products must either be entirely recyclable or have a design that makes it possible to return them to the natural cycles of the environment where they can also be "recycled." Then, there is the requirement to use only using renewable energy sources during production and adjusting the best production techniques to the needs and realities of the region.

Consistency is a considerably more challenging approach than Efficiency, requiring more creativity. And even consistency presents several limitations [53]. It is really difficult to “close” all material and production cycles. So far, the C2C and related principles have been only limitedly deployed and overconsumption of natural resources, environmental impacts, and wastage are inherent characteristics of the actual economic system.

Sufficiency

Some studies show that People usually look for additive transformations first, ignoring subtractive transformations in the process [54]. Thus, sufficiency must be promoted and supported by politics. Sufficiency politics aims at reshaping institutional and social context so as to make it easier to live sufficient lives. Only then will sufficient lifestyles become more common and contribute to a reduction of environmental and resource consumption. The notion of normative sufficiency, also known as enoughness or strong sustainable consumption, has taken center stage as it has become clear that consumption amounts rather than patterns determine how quickly the environment deteriorates [55]. The formula to start going towards a sustainable economy in the rich areas of the world is: “Better, different, less. Indeed, dematerialization alone does not ensure compatibility with nature; and biocompatibility does not avoid the effects of growth. This is why resource-conserving prosperity stems from the triad of dematerialization (efficiency), environmental compatibility (bio-coherence and consistency) and self-limitation (sufficiency).

Strategies for sustainability should embrace all three principles and be more creative, consequent, and daring in implementing sufficiency politics. Based on the “towards sustainability” scenario from the UNEP [29] that models a future by combining principles of efficiency, sufficiency and a shift to renewable resources, this would see a reduction of GHG emissions by at least 90% from 2015 levels, prevent the loss of at least 1.3 billion hectares of pristine nature, and restore a further 450 million hectares while stimulating economic development.

The word “sufficiency” comes from the Latin verb “sufficere”, meaning “to be enough. The term sufficiency was used in this sense first by Herman Daly in the context of the debate on economic growth [56]. Later, it was introduced to the environmental discourse by Wolfgang Sachs [57] in order to describe a complementary strategy to the established and technology-focused idea of efficiency. Efficiency and consistency, as their main strategies, are not enough. They have rebound effects, and they keep promoting economic growth. They are not showing that a drastic reduction of resource demand is achievable with a simultaneously increasing of national income [58]. Sufficiency is essentially the antithesis to the orientation to permanent “higher, further, faster, more”. It instead prioritizes quality of life in work, education, and leisure, as well as the freedom of responsible choice and the right to self-determination [59]. Sufficiency includes a social dimension, and it calls for a social protection floor which allows every inhabitant of each country to live a decent and good life, actively participating in the respective society, considering that individual action is always embedded in an institutional and societal context [60]. Sufficiency implies a restructuring of household consumption: being satisfied with less new material goods than usually consumed today, while enjoying the existing ones, plus immaterial social and collective goods: the aim is second order decoupling, that is, a clear focus on reducing the volume of the materials and energy resources consumed while maintaining levels of wellbeing.

Decoupling concept

In the IRP report [61], it is assumed that since the 1970s, both the world population and gross domestic product have doubled. Huge quantities of natural resources have been needed to support these trends' economic growth and the corresponding global increases in human welfare. But these improvements have come at a steep price for the environment, which has an effect on people's well-being and exacerbates disparities within and between nations.

The analysis and modeling presented in this report represent a first attempt to comprehend the effects of our expanding resource use and to create coherent scenario forecasts for resource efficiency and sustainable production and consumption that decouple economic growth from environmental degradation (Fig. 5). The use and management of natural resources are currently on an unsustainable course, according to a Historical Trends scenario. However, a Towards Sustainability scenario demonstrates how implementing resource-efficient and sustainable consumption and production policies encourages stronger economic growth, enhances well-being, supports more equitable income distribution, and decreases resource use across nations. This report ends with an optimistic and hopeful message. The International Resource Panel has a vast amount of information concerning the use of natural resources and their effects, while more research is still required. Our global aspirations for prosperity within planetary constraints can be realized through carefully considered and well-coordinated sustainability efforts. We can resource the future we want by working with multiple stakeholders, using the findings from this research, and developing creative solutions.

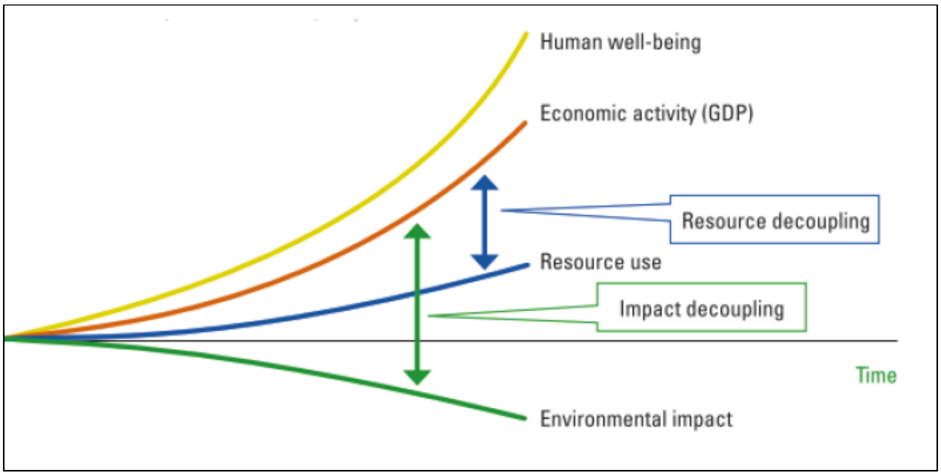

Figure 5 - Decoupling concept representation [62]

A true decoupling of the impacts related to natural resource use requires a systemic transformation of how natural resources are used and managed in our economic and social systems. All nations are urged to think of creative solutions to deal with the environmental issues brought on by the exploitation of natural resources and more environmentally friendly patterns of consumption and production. These innovative solutions can be thought of as “business unusual” approaches, as opposed to the traditional business-as-usual policies.

The organizing of the economy should improve the well-being of people instead of consumption per capita. This does not imply that no further economic development or innovation is necessary, merely that it needs consumption patterns that respect the planetary boundaries [63].

In this sense, it is pivotal to remember that well-being depends on four typologies of goods, as defined in economics, depending on two factors. Firstly, “excludability”, or whether someone may be discouraged from using the good, is the first quality. Secondly, if a good is competitor in consumption, or whether using it limits another person's capacity to utilize it.

1. Private commodities are excludable and competitive. Private commodities include things like food, clothing, and flowers.
2. Common goods: Common goods are non-excludable and rival. Fish stocks in foreign waters are a prime illustration of a common good. No one is prohibited from fishing, yet as more fish are taken without restrictions, the stocks for future fishermen become depleted. Common goods not only belong to everyone, but in order to be benefited they require a certain convergence of fruition, which can be material or spiritual depending on the case.
3. Club goods: Club goods are excludable but non-rival. For the benefits of this kind of good, a "membership" fee is frequently necessary. It is possible to restrict access to the items for non-payers. A prime example is cable television. Although it has a monthly fee, it no longer exists after payment.
4. Public products: they are non-excludable and non-competitive. They cannot successfully be used to exclude people from utilizing them, and one person's use of the good does not make it less available to others. Examples of public goods include the air we breathe, public parks, and streetlights.

Focusing on resources, economic sectors, or different environmental or human impacts as individual sectors will not encourage progress toward improved resource use or, more broadly, the achievement of international agreements and the SDGs. Addressing one area without consideration of the others may even have negative consequences. A systems approach is crucial to maximize benefits across sectors and mitigate trade-offs from natural resource use.

According to the UNEP report's authors [37], the Drivers-Pressures-State-Impact-Response (DPSIR) framework, one type of systems approach, to analyse natural resource use. The DPSIR framework is an appropriate tool for locating the flows of natural resources in global society's interaction with the environment, as the framework creates linkages and feedback loops between the different components.

Socioeconomic drivers from human activities are the first factors in the chain of causal links and they can cause pressures on the environment, which in turn affect the state of the environment. The changing state of the environment can be seen through environmental and human impacts.

Natural resource management benefits from a systems approach as it provides insight and enables policymakers to steer development toward the SDGs[61]. There was a moderate relative decoupling of impacts from extracted mass of resources between 2000 and 2015 as well as a relative decoupling of resource-related environmental consequences from GDP. Impacts did, however, continue to grow in absolute terms. Water stress and loss of biodiversity are primarily caused by agriculture, whilst the expansion of infrastructure has increased the negative effects of climate change.

The life cycle thinking and the Life Cycle Sustainability Assessment

Life cycle thinking is an approach to assessing the environmental and social impacts of a product or service over its entire life cycle, from raw material extraction and processing through to disposal or recycling. It considers the full range of environmental and social impacts associated with a product or service, including the use of resources, energy consumption, emissions, waste generation, and social and economic impacts.

Life Cycle Sustainability Assessment (LCSA) is an extension of life cycle thinking that incorporates not only environmental impacts, but also social and economic impacts. It evaluates a product or service's sustainability performance throughout its life cycle, considering its impacts on human health, ecosystems, and socio-economic systems [64].

LCSA takes into account a wide range of sustainability factors, including resource use, energy consumption, greenhouse gas emissions, water use, toxicity, biodiversity, social and economic impacts, and ethical considerations. It provides a comprehensive framework for evaluating the sustainability of products or services, taking into account both the positive and negative impacts of each stage of their life cycle.

By using life cycle thinking and LCSA, companies and organizations can identify opportunities to reduce their environmental and social impacts, improve the sustainability of their products or services, and make more informed decisions about their business practices.

While evaluating products and processes, it is important to take into account a number of factors, including the three pillars model, the triple bottom line, published by Elkington in 1998 [65] and the established notion of "Sustainability" as presented by the Brundtland report (United Nations General Assembly, 1987) [66].

A proper sustainability assessment must be expanded to include the horizontal and longitudinal dimensions of impacts brought on by human activity in order to address the implicit need for fairness at the intragenerational [67] and intergenerational levels. As a result, based on the various components touched and the order in which these effects manifest, the full range of impacts and effects must be evaluated. For these reasons, in order to address the horizontal dimension, the "intact environment, social justice, and economic prosperity" [68] should represent the end result of each application and the yardstick of the evaluation. The use of the Life Cycle Thinking lens, on the other hand, is necessary to explore the longitudinal dimension of the impacts and take into account both the direct and indirect effects triggered throughout the various stages of the product or process life as well as the time-scale of the impacts, taking into account the relationship between current needs and future opportunities. The EU Integrated Product Policy proposal emphasized how the Life Cycle perspective is inherently inherent to the greening of the product development process [69], but its systematic application is required to trigger the transition required at the level of the global market, and as a result, it must necessarily be verified through a quantitative approach.

The early development of the LCSA idea and its potential use, in a comprehensive sustainability framework, occurred in the late 1990s, almost concurrently with the first practical application of (environmental) LCA. Researchers supported a gradual expansion of the assessment boundaries toward LCSA starting from the very same sectors where LCA had made the first strides, as LCA was defined by SETAC in 1993 as "a process to evaluate the environmental burdens associated with a product or process by identifying and quantifying energy and materials used and wastes release to the environment" [70].

In fact, Selmes et al. (1997) [71] provided an early indication of the route toward conceptualizing sustainability assessment applied from a Life Cycle viewpoint. Walter Klöpffer [72] the author who developed the original theory underlying the LCSA framework and was profiled in the preceding section also highlighted the importance of chemistry in achieving the objectives of sustainable development. As a result, its prominence as a testing ground for the LCSA application is seen as a chance to operationalize sustainability in a field where both processes and products carry the potential for environmental hazard and where products are widely used in both the market and various industrial sectors [67].

According to several authors, LCSA can be represented as the following simple equation: As is widely acknowledged [73], LCSA can be viewed as the integration, or better yet, as the result of the addition of the three sustainability perspectives, i.e., economic, environmental, and social:

LCSA=LCC + SLCA + LCA

In example, LCA can serve as a valuable beginning point for creating an integrated methodology that incorporates all three factors. As LCA has demonstrated that quantification is feasible, it is important to maintain this advantage when incorporating the economic and social factors and creating an integrated LCSA.

The already-existing LCA standardization approach, which is notably founded in some key pillars and helpfully synthesized in the core few following definitions, can be implemented in this context to create a successful and beneficial LSCA standardization.

There is a strong connection, and similarities between LCSA and eco-efficiency. And the established and well-known eco-efficiency technique and standardization can be used to benefit LCSA standardization. A standard for product systems, ISO 14045 [74] described the fundamentals, specifications, and instructions for evaluating eco-efficiency.

The World Business Council for Sustainable Development [75], in 2011, coined the phrase "eco-efficiency analysis," which is characterized as "a management philosophy that pushes companies to explore for environmental improvements that offer parallel economic gains". It is founded on a practical and successful strategy that helps firms integrate environmental and social challenges into their practices, decisions, and strategies. Eco-efficiency can be seen of as a tool for measuring the relationship between the generation of economic value, social factors, and environmental impacts over the course of a product's whole life cycle.

Another important connection between LCA and the Environmental Product Declaration (EPD). In a certain sense, EPD can be identified. In a certain sense, can be seen as a kind of unique application of LCA. While an EPD's primary objective is to offer information on how products affect the environment, it may also be viewed as a standardizing tool for quantifying the overall effects of a system or a product [76]. For environmental labels and statements based on a whole life cycle approach, specific requirements are provided.

The LCA must meet a number of conditions in order to serve as the foundation for an EPD. This method can be improved upon by taking into account an LCSA and combining environmental impact assessment with cost and social assessment.

The EPD approach can serve as a guide when it comes to precise definitions of production modeling, data types, data gathering techniques, and indications. All requirements should be accurately stated and related to product category regulations [77], which are papers giving instructions for establishing an EPD for a given product category, with the purpose of achieving results comparability between items. In this approach, EPD develops into a helpful instrument for disseminating information about the performances of items and results.

The UN Environment Life Cycle Initiative [78] was born in 2017 as a public-private, multi-stakeholder partnership enabling the global use of credible life cycle knowledge. It is a Life Cycle approach oriented, supporting decisions and policies makers towards the “shared vision of sustainability as a public good” by engaging its multi-stakeholder partnership (governments, businesses, scientific and civil society organizations. A preeminent purpose of the Life Cycle Initiative is to encourage a life cycle thinking approach in the UN 2030 agenda actions in order to achieve SDGs in a faster and more efficient way.

The Life Cycle Initiative 2017-2022 Strategy document [78] suggests technical advice to improve the applicability of methodologies for specific applications, to orient scientific research and practical implementation by some actions oriented to implement a national hotspots analysis tool, working with certification schemes, and to develop data and methods on Life Cycle Costing supporting support Sustainable Public Procurement.

The Initiative is also working on Life Cycle Capacity Development aiming at generating the necessary skills and capacity for the global application of life cycle approaches and on Life Cycle Knowledge Consensus and Platform definition to ensure science-based global consensus building and to promote an access to Life Cycle Knowledge as a public good.

The theory of Change for the Life Cycle Initiative, linking its key deliverables with the expected impact as defined by the Initiative vision that can be considered as a fundamental example for LCSA methodology development.

Life Cycle Sustainability Assessment (LCSA) in building and construction

Because of the high responsibility in terms of environmental impact, construction and buildings represent one of the key topics for the green transition proposed by the European New Green Deal. Improving environmental attitude can play a key role to reach carbon neutrality in Europe which is expected to be achieved by 2050. The new Circular Economy Action Plan [79], adopted on March 2020, highlights the importance of a product's green design that has to be oriented to a reduction of raw materials consumption and waste prevention along the entire life cycle of products. The circular economy potential in cities and regions can be unlocked by implementing and demonstrating innovative circular actions at local and regional scales and facilitating their replication in other areas. A major challenge is to expand circularity beyond traditional resource recovery in waste and make circular solutions sustainable, regenerative, inclusive.

As part of the new Circular Economy Action Plan, the Circular Cities and Regions Initiative (CCRI) [80] focuses on the implementation of circular solutions, while the European strategy for a Sustainably Built Environment represents a whole and exhaustive plan aiming to guarantee a coherent integration between all the policy strategic areas such as climate change, energy and resource efficiency, CDW management, etc., promoting circularity principles of construction throughout the lifecycle of buildings starting from an update to the Construction Product Regulation. A robust waste prevention, the improvement of the recycling processes, a high quality and high efficiency in the secondary raw materials production represent the main goals of this new vision. The strategy includes the possibility to require appropriate recycled content for construction products, at the same conditions of quality and safety, and to adopt a Life Cycle Assessment (LCA) methodology in public procurement. Considerable efforts are underway to build global knowledge and capacity for understanding, developing, and promoting more sustainable construction processes on the base of comprehensive information on materials and products over their life cycle by evaluating energy, raw materials, land, and water consumption, and related emissions into water, air, and soil. A holistic observation is obtained by the use of LCSA, considering an integration in environmental, economic, social impact assessment, that can be considered as fundamental supporting tools in sustainability, can be applied in construction [81].

Also, the green building rating system LEED (Leadership in Energy and Environmental Design) promoted by the Green Building Council [82] in its last updated edition introduced the use of the Whole Building Life Cycle Assessment (WBLCA) as a compliance option for earning credits. In particular, a new credit named "building lifecycle impact reduction", supports Eco-design by using life cycle assessments in an effort to allow objective comparison of quantified environmental performance for various materials. A reduction of environmental impacts, for instance, can be carried on by evaluating building site options to select the lowest impact choice, comparing the environmental impacts of renovating rather than demolishing and building anew, comparing design alternatives to choose the lowest impact ones, identifying building's environmental hotspots and taking action to reduce them.

LCA can significantly contribute to certification credits gained in many certification schemes and to comply with whole-life carbon regulations in construction: governments are increasingly recognizing the need to legislate to reduce whole-life carbon (that is operational and embodied carbon emissions) and LCAs become a mandatory part of many of the new laws and policies. For new construction (buildings or portions of buildings), according to WBLCA, a life-cycle assessment of the project's structure and enclosure has to be oriented to demonstrate a minimum of 10% reduction, compared with a baseline building, and that no impact category assessed as part of the life-cycle assessment may increase by more than 5% compared with the baseline building. At least three of the following impact categories for reduction one of which must be global warming potential: global warming potential (greenhouse gases), in kg CO_2 eq; depletion of the stratospheric ozone layer, in kg CFC-11; acidification of land and water sources, in moles H+ or kg SO2; eutrophication, in kg nitrogen or kg phosphate; formation of tropospheric ozone, in kg NOx, kg O3 eq., or kg ethene; and depletion of non-renewable energy resources, in MJ.

In relation to demolition processes for end-of-life buildings, a life cycle analysis can quantify the environmental impacts by assessing how the demolition and subsequent recycling and reuse operations can bring clear environmental benefits. Considering the potential environmental impacts related to the end of life of residential buildings, it is possible to highlight how the choice of an adequate selective demolition technique can increase the quantity and quality of recyclable materials with excellent effects in terms of environmental sustainability. An example. Applying an attributional life cycle assessment able to highlight and quantify the contributions of each end-of-life phase (i.e., separation and collection of main components, sorting, and recycling of the waste, etc.). Steel components recycling results of primary importance, accounting for 65% of the total avoided impacts related to respiratory inorganics, 89% of those for global warming, a 73% of those for natural resources depletion.

In the ELCA, the inventory includes materials from demolition (steel, red brick, concrete, and CDW mix), technical equipment, energy consumption, and waste treatment. The cost categories for the ELCC follow UNEP-SETAC Environmental Life Cycle Costing. The main inventory costs are labor and equipment, energy, waste disposal, the sale of recyclable materials, and 12% overhead.

The SLCA indicators from UNEP-SETAC Guidelines for SLCA Products [83], are based on expert advice from the demolishing company and the company supervising the demolition operations. Company-specific data are irrelevant in SLCA decision-making because the processes are performed by the same company. Process-specific indicators (hours of work created, and quantity of secondary resources produced) produce different values for decision-making.

The Life Cycle Thinking methodologies (Life Cycle Assessment (LCA), Environmental Life Cycle Costing (eLCC), and Social Life Cycle Assessment (sLCA) [84] are excellent tools for evaluating the economic, environmental, and social aspects of a product or process also in the buildings and construction sector.

Hu et al. [85] employ LCC and LCA to identify the environmental and economic hotspots in demolition and waste management and recycling, and new building. The results show that for enhancing demolition's environmental and economic profiles as well as related material treatment, new buildings and demolition projects should be combined to optimize reuse potentials, particularly for metals. The life cycle costs might be cut by 23% using this best practice. Despite making up only 6% of the total recovered material by weight, the metal fraction recovery is a crucial step since it has the highest economic value. From an environmental standpoint, the impact categories under investigation fall most heavily on the demolition phase (52% to 90%). Recycling reduces the environmental impact by 36% as compared to landfilling. The primary environmental benefit of recycling is the avoidance of landfilling C&D waste and the replacement of recovered materials for natural resources. The recovery of materials (such as metals and wood) during the demolition process is the selective demolition method's most important advantage.

Finding hot spots, or the activities or processes that have the greatest impact on the chain's overall environmental performance, can be done in addition to the evaluation using LCA. A crucial problem is that cost information can be more erratic than physical units, and geographic location has a substantial impact on study outcomes due to cost unpredictability and market volatility [86].

Circular economy

At the beginning of industrialization, when mass production was not yet a reality, the linear economy evolved. Society and the means of production have changed since then. Production and consumption rates have significantly increased as a result of technical advancements, population growth, and urbanization. The rates of trash production and resource utilization both increased. The implementation of the linear economy throughout time has resulted in resource scarcity and environmental deterioration since it is founded on the false premises that there are inexhaustible resources available and the Planet has a limitless potential for regeneration.

A "linear" form of economic growth model based on the "take make discard" notion has typified the whole industrial system for the previous 150 years. Under this model, each good is produced, used (sometimes without completely realizing its potential), and then disposed away as waste. A "circular" economy model, in contrast, envisions the continuous recovery and reuse of resources within the production cycle, generating further value and, ideally, minimizing the use of non-renewable resources which continue to deplete over time. This model, which envisions the massive exploitation of non-renewable natural resources and their subsequent disposal in landfills at the end of their life, has become unsustainable over time [87].

In any production system, the entire product value chain, from its conception to disposal, must be revised in order to successfully apply the circular economy concept. To do this, it is crucial to foster collaboration between management and technology as well as between the many actors in the chain, or stakeholders, which will ultimately give rise to the idea of "industrial symbiosis."

The idea of circular economy reframes the idea of "end of life" to encourage re-use or restoration in order to minimize waste outside of system limits as much as feasible.

It is founded on a few straightforward concepts that lead to distinct sources of value creation. First and foremost, the concept of "designing out" waste eliminates excess by designing and producing components for a cycle of disassembly and re-use. The distinction between a product's consumable (made of biological materials) and durable (artificial) components is introduced by circularity in the second place. The latter ought to be built to be reused. Last but not least, the energy needed to power the product life cycle should come from renewable sources.

The circular economy (CE) idea has been put into practice in an effort to avert this situation, lessen its effects, and prevent disruptions in the supply of raw materials. By separating the concepts of economic growth and resource exploitation and promoting harmony between the economy, environment, and society, CE attempts to increase resource efficiency and sustainability of societies, cities, and industrial processes [88]. It might be seen as a prerequisite to achieving sustainable development [89].

According to the Ellen MacArthur Foundation [87], Circular Economy is “an industrial economy that is restorative or regenerative by intention and design”. The concept of Circular Economy relies on the principles of reducing, reusing and recycling (3R philosophy), also emphasizing the importance of properly designing products and processes, in order to phase out waste from the cradle, instead of only dealing with it at the End of Life phase [90].

To this end, processes should use mainly renewable sources of energy, avoiding hazardous components or additives, while products should be made to last and allow easy recovery of materials, reducing waste generation[87]. As stated in The Great Recovery project, “waste is a design flaw”, given that material and energy are lost when residues are discarded[91]. Following the Cradle-to-Cradle principle, “everything could be considered as a resource for something else” or as a source of secondary raw materials [92].

Several strategies can be used to implement the circular economy. For biological and technical objects, a variety of loops can be developed. Organic waste is either biologically processed to produce biogas and fertilizers like compost that are put back into the biosphere or it is cascaded back to the usage phase. Technological goods are created with high quality, keeping or increasing their economic value not only at their and of life, promoting upcycling in the secondary raw materials processing, but also over the course of their lifetime, by encouraging reliable maintenance and care, with the purpose to extend a product's life cycle and to prevent new natural resource exploitation and waste generation.

Therefore, it is necessary to adopt techniques like rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover. The so called “9R philosophy” [93].

The European Commission adopted the new Circular Economy Action Plan (CEAP)[79] in March 2020.

It is one of the cornerstones of the European Green Deal [94], the continent's new plan for sustainable development. The EU's transition to a circular economy will create jobs, promote sustainable growth, and lessen the burden on the planet's natural resources. Also, it is important to achieve the EU's 2050 goal of climate neutrality and stop the loss of biodiversity.

Initiatives are announced for every stage of a product's life cycle in the new action plan. It strives to prevent waste and keep the resources used as long as possible in the EU economy, targets product design, stimulates circular economy practices, and promotes sustainable consumption.

Making sustainable products, empowering consumers and public buyers, focusing on the industries that consume the most resources and have the highest potential for circularity (such as electronics and ICT, batteries and vehicles, packaging, plastics, textiles, construction and buildings, food, water, and nutrients), ensuring less waste, making circularity work for people, regions, and cities, and leading international efforts on circular economy are some of the goals of the new action plan's measures.

Circular economy and industrial symbiosis are closely related concepts that aim to promote a more sustainable and efficient use of resources.

Industrial symbiosis refers to the collaboration among different industries and organizations to share resources, assets, and expertise, thereby creating a closed-loop system that minimizes waste and maximizes resource efficiency. This approach to industrial development emphasizes the idea of "waste as a resource" and seeks to create a more sustainable economy.

In an industrial symbiosis network, one company's waste or byproduct becomes another company's raw material or input, reducing the need for virgin resources and minimizing the environmental impact of industrial activities. This approach can lead to significant economic, environmental, and social benefits, such as reduced waste generation and disposal costs, improved resource efficiency, enhanced competitiveness, and job creation.

Industrial symbiosis is a key enabler of the circular economy, as it promotes the exchange and reuse of resources, materials, and energy between different industries and organizations, creating a closed-loop system. By collaborating and sharing resources, companies can reduce their waste generation, environmental impact, and costs, while increasing resource efficiency and creating value for all stakeholders.

In order to increase the usage of alternative materials in building, construction, and restoration, regional industrial symbiosis (IS) agreements should be established. These agreements can help businesses become more competitive and have a smaller negative impact on the environment. Because of this, the EU only recently unveiled a mechanism for IS reporting and certification that is industry-led. Symbiotic relationships [95] can be used at several levels in this way. They can involve a single business or organization (micro level), businesses with close proximity to one another (meso level), and ultimately the entire regional or national production chain, according to Roberts [96] (macro level). The meso level, where the clustering of complementing businesses offers a complexity of functions, is where the biggest benefits are realized [97].

Building and construction are a worldwide high resource-intensive sector. In particular, historical buildings, especially in Europe, represent a high percentage of the building stock.

In order to reduce global impacts and protect our limited resources, the construction industry needs to adopt a circular economy approach that can benefit both businesses and customers by maximizing resource usage, lowering raw material consumption, and recovering waste through recycling or repurposing it as a new product. To close the cycle in this situation, it is crucial to consider the building's end of life, the production of construction and demolition waste, and their final destination.

The European Commission has implemented a number of policy initiatives to transform the European Union (EU) into a "circular economy" based on recycling and the utilization of trash as a resource, the overarching goal is to reconsider the entire life cycle of resources.

Economía circular

A principios de la industrialización, cuando la producción en masa no era todavía una realidad, se desarrolló la economía lineal. Desde entonces, la sociedad y los medios de producción han evolucionado. Los niveles de producción y consumo se han incrementado significativamente, debido al avance técnico, al crecimiento de la población y a la urbanización. Han crecido tanto los niveles de cantidad de residuos producidos como los de utilización de los recursos naturales. La implementación de la economía lineal a lo largo del tiempo ha ocasionado escasez de recursos y degradación ambiental, ya que esta se basa en la falsa suposición de que hay recursos renovables disponibles y que el Planeta cuenta con un potencial infinito de regeneración.

Todo el sistema industrial de los últimos 150 años ha estado caracterizado por un modelo de crecimiento "lineal" basado en el enfoque "extraer-producir-eliminar". Según este modelo, cada producto se fabrica y, una vez que se usa (a veces desaprovechando parte de su potencial), se tira, generando residuos. En cambio, un modelo de economía "circular" plantea la recuperación y el reciclaje continuos de recursos dentro del ciclo de producción, propiciando valor añadido y minimizando, idealmente, el uso de recursos no renovables que se siguen agotando con el paso del tiempo. Este modelo, que plantea la explotación masiva de recursos naturales no renovables y su consiguiente eliminación en los vertederos al final de su ciclo de vida, se ha vuelto insostenible con el paso del tiempo [84].

En cualquier sistema de producción, toda la cadena de valor de un producto, desde su concepción hasta su disposición final, ha de ser revisada para aplicar con éxito el concepto de economía circular. Para conseguirlo, es esencial fomentar la colaboración entre la gestión y la tecnología y entre los diferentes actores, o las partes interesadas de la cadena de producción, que al final darán lugar a la idea de "simbiosis industrial".

El concepto de Economía Circular (EC) representa una reformulación de la idea de "fin de vida" para fortalecer la reutilización o restauración de un producto, con el fin de minimizar en la medida de lo posible el derroche de recursos fuera de los límites del sistema.

Se basa en algunos conceptos sencillos que conducen a varias fuentes de creación de valor. En primer lugar, el concepto de eliminar los residuos diseñando y produciendo componentes para un ciclo de desmontaje y reutilización. En segundo lugar, la circularidad introduce la diferencia entre los componentes consumibles (hechos con materiales biológicos) y duraderos (artificiales) de un producto. Estos últimos deben construirse para poder ser reutilizados. Por último pero no menos importante, la energía necesaria para alimentar el ciclo de vida del producto debe proceder de fuentes renovables.

La idea de EC se ha puesto en práctica para evitar esta situación, paliar sus efectos y prevenir interrupciones en el suministro de materias primas. Al separar los conceptos de crecimiento económico y explotación de recursos y promover la armonía entre la economía, el ambiente y la sociedad, la EC pretende aumentar la eficiencia de los recursos y la sostenibilidad de las sociedades, las ciudades y los procesos industriales [85]. Podría considerarse un requisito previo para alcanzar el desarrollo sostenible [86].

De acuerdo a la Fundación Ellen MacArthur [84], la EC es "una economía industrial que es restaurativa y regenerativa por intención y diseño". El concepto de EC se basa en los principios de reducir, reutilizar y reciclar (filosofía de las 3R), destacando también la importancia de diseñar adecuadamente los productos y procesos, con vistas a eliminar progresivamente los residuos a partir de la conocida como "cuna" (momento de su producción), en lugar de tratarlos únicamente en la fase de fin de vida [87] (conocida como "tumba").

Para ello, los procesos deben utilizar principalmente fuentes de energía renovables, evitando componentes o aditivos peligrosos, mientras que los productos deben ser realizados para durar y permitir una fácil recuperación de los materiales, reduciendo la generación de residuos [84]. Como se afirma en el proyecto The Great Recovery, "el residuo es un defecto de diseño" (*waste is a design flow*), pues se pierde material y energía cuando se desechan[88]. Siguiendo el principio *Cradle-to-Cradle* (de la cuna a la cuna), todo puede considerarse un recurso para otra cosa o una fuente de materias primas secundarias [89].

Se pueden adoptar numerosas estrategias para aplicar la economía circular. Para los objetos de naturaleza biológica y técnicos, pueden desarrollarse diversos ciclos. Los residuos orgánicos se procesan biológicamente para producir biogas y fertilizantes como el compost, que se restituyen a la biosfera, o se devuelven a la fase de uso. La fabricación de los productos tecnológicos es de alta calidad, manteniendo o aumentando su valor económico no sólo en su punto óptimo de “vida”, promoviendo el suprarreciclaje o la reutilización creativa (*upcycling*) en el procesamiento de materias primas secundarias, sino también a lo largo de su vida útil, fomentando un mantenimiento y cuidado fiables, con vistas a ampliar el ciclo de vida de este y evitar la explotación de nuevos recursos naturales y la generación de residuos.

Por tanto, es necesario adoptar técnicas como, repensar, reducir, reutilizar, reparar, restaurar, refabricar, readaptar, reciclar y recuperar, según la llamada “filosofía 9R” [90].

La Comisión Europea adoptó el nuevo Plan de Acción de Economía Circular (PAEC) [76] en marzo de 2020.

Es uno de los pilares del Pacto Verde Europeo [91], el nuevo plan del continente para el desarrollo sostenible. La transición de la UE hacia una economía circular creará empleo, fomentará el crecimiento sostenible y aligerará la lacra que sufren los recursos naturales del planeta. Además, es fundamental lograr el objetivo de neutralidad climática de la UE para 2050 y detener la pérdida de biodiversidad.

El nuevo plan de acción plantea iniciativas para cada etapa del ciclo de vida de un producto. Lucha por evitar la generación de residuos y mantener los recursos utilizados el mayor tiempo posible en la economía de la UE, se centra en el diseño de los productos, impulsa el desarrollo de las prácticas de economía circular y fomenta el consumo sostenible.

Entre las medidas del nuevo plan de acción destacan los objetivos de fabricar productos sostenibles, capacitar a los consumidores y compradores públicos, centrarse en los sectores que producen más recursos y presentan un mayor potencial de circularidad (como la electrónica y las TIC, las baterías y los vehículos, los envases, los plásticos, los textiles, la construcción y los edificios, los alimentos, el agua y los nutrientes), reducir la producción de residuos, hacer que la circularidad funcione para las personas, las regiones y las ciudades, y liderar los compromisos internacionales en materia de economía circular.

La economía circular y la simbiosis industrial son dos conceptos que están íntimamente ligados entre sí y que buscan promover un uso más sostenible y eficiente de los recursos.

La simbiosis industrial se refiere a la colaboración entre diferentes industrias y organizaciones para compartir recursos, activos y conocimientos, creando de este modo un sistema de circuito cerrado que minimiza la generación de residuos y maximiza la eficiencia de los recursos. Este enfoque del desarrollo industrial hace hincapié en la idea de “residuo como recurso” (*waste as resource*) y apunta a crear una economía más sostenible.

En una red de simbiosis industrial, los residuos o subproductos de una empresa se convierten en materia prima o insumo de otra empresa, reduciendo de este modo la necesidad de materias primas y minimizando el impacto ambiental de las actividades industriales. Este enfoque puede propiciar importantes beneficios económicos, ambientales y sociales, tales como la reducción de los costes de generación y eliminación de residuos, le mejora de la eficiencia de los recursos, el aumento de la competitividad y la creación de empleo.

La simbiosis industrial es un motor clave de la economía circular, ya que fomenta el intercambio y la reutilización de recursos, materiales y energía entre industrias y organizaciones diferentes, creando un sistema de circuito cerrado. Al colaborar y compartir recursos, las empresas pueden reducir la generación de residuos, el impacto ambiental y los costes, al tiempo que aumentan la eficiencia de los recursos y generan valor para todas las partes interesadas.

Para aumentar el uso de materiales alternativos en la edificación, la construcción y la restauración, deberían establecerse acuerdos regionales de Simbiosis Industrial (SI). Estas alianzas pueden ayudar a las empresas a ser más competitivas y reducir su impacto negativo en el medioambiente. Para ello, la UE acaba de presentar un mecanismo de información y certificación de la SI.. De este modo, las relaciones simbióticas [92] pueden utilizarse a varios niveles, involucrando a una sola empresa u organización (nivel micro), a empresas muy próximas entre sí (nivel meso) y, en última instancia, a toda la cadena de producción regional o nacional (nivel macro), según Roberts [93].

Los mayores beneficios se obtienen en el nivel meso, donde la agrupación de empresas complementarias ofrece una complejidad de funciones [94].

La edificación y la construcción son sectores que consumen muchos recursos en todo el mundo. En particular, los edificios históricos, especialmente en Europa, representan un alto porcentaje del parque inmobiliario.

Para reducir su impacto global y proteger nuestros limitados recursos, el sector de la construcción debe adoptar un enfoque de EC que pueda beneficiar tanto a las empresas como a los consumidores, maximizando el uso de los recursos, reduciendo el consumo de materias primas y recuperando los residuos mediante el reciclaje o su reutilización como nuevo producto. Para cerrar el ciclo en este sector, es esencial tener en cuenta el fin de vida del edificio, la producción de residuos de construcción y demolición y su destino final.

La CE ha puesto en marcha una serie de iniciativas políticas para transformar la UE en una EC basada en el reciclaje y la utilización de los residuos como recurso; el objetivo general es reconsiderar todo el ciclo de vida de los productos y procesos.

Paper 1- Sustainability in Building and Construction within the Framework of Circular Cities and European New Green Deal. The Contribution of Concrete Recycling

Sustainability in Building and Construction within the Framework of Circular Cities and European New Green Deal. The Contribution of Concrete Recycling

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(The full paper in Annex 1)

Abstract: Climate change and ecological crisis are a huge threat to Europe and the world. To overcome these challenges, Europe adopted the New Green Deal as a strategy transforming the Union into a competitive resource-efficient economy, without greenhouse gas emissions and become carbon neutral in a few decades. The European Green Deal includes the new circular economy action plan, highlighting the importance of a products' "green design", saving raw materials and waste prevention oriented along the entire life cycle of products. Construction and buildings represent one of the key topics for the green transition. In the European Union, buildings are responsible for 40% of our energy consumption and 36% of greenhouse gas emissions, which is mainly caused by construction, usage, renovation and demolition. Improving environmental efficiency can play a key role to reach carbon neutrality of Europe that is expected to be achieved by 2050. In this research, it was explored how Eco-design, as innovative approach in buildings and construction, Life Cycle Thinking and Life Cycle Assessment, as fundamental supporting tools in sustainability, and finally appropriate and effective Construction and Demolition Waste recycling processes, particularly oriented to concrete recycling according to the case studies analyzed, can promote circular economy in buildings and construction.

Resumen: El cambio climático y la crisis ecológica constituyen una enorme amenaza para Europa y el mundo. Para superar estos retos, Europa adoptó el Nuevo Pacto Verde (New Green Deal) como estrategia para transformar la Unión en una economía competitiva y eficiente en el uso de los recursos, sin emisiones de gases de efecto invernadero y neutra en carbono en pocas décadas. El Pacto Verde Europeo incluye el nuevo plan de acción de economía circular, que destaca la importancia del "diseño verde" de los productos, el ahorro de materias primas y la prevención de residuos orientada a lo largo de todo el ciclo de vida de los productos. La construcción y los edificios representan uno de los temas clave para la transición ecológica. En la Unión Europea, los edificios son responsables del 40% de nuestro consumo de energía y del 36% de las emisiones de gases de efecto invernadero, lo que se debe principalmente a su construcción, uso, renovación y demolición. La mejora de la eficiencia ambiental puede desempeñar un papel clave para alcanzar la neutralidad de carbono de Europa que se espera conseguir para 2050. En esta investigación, se exploró cómo el ecodiseño, como enfoque innovador en los edificios y la construcción, el concepto y la evaluación de ciclo de vida, como herramientas de apoyo fundamentales en la sostenibilidad, y, finalmente, los procesos de reciclaje de residuos de construcción y demolición apropiados y efectivos, particularmente orientados al reciclaje de hormigón según los casos de estudio analizados, pueden promover la economía circular en la edificación y la construcción.

The context: an introduction

The built environment is commonly recognized as a major contributor to global environmental impacts. Up to 40% of all raw materials extracted from the lithosphere are consumed by this sector responsible for roughly 50% of global greenhouse emissions [98]. In the European Union, buildings and construction are responsible of a large part of the total energy consumption (about 40%) and of greenhouse emissions (36%) [99], along the entire chain from construction to demolition, passing through utilization and maintenance.

A more efficient use of materials, both at the beginning and at the end of their life, would make a major contribution to reducing the environmental impacts of construction. This benefit would be achieved principally by a depletion reduction of finite natural resources and a reduced dependence on landfill.

The construction industry is also one of world's largest consumers of natural resources, with an annually usage of circa 50 billion tons of sand and gravel. As the main component of concrete, they are essential for all kinds of construction work and considering the growing world population and urbanization, their demand will further increase in the following years. The global natural inert materials' usage already have a considerable impact of the environment and human lives. Most

of the used sand is mined from fluvial or coastal areas with several severe environmental impacts risk in terms of various rivers or beaches and islands ecosystems preservation, and hydrological balance [100].
The need for a more sustainable and improved use of natural resources in this sector has been recognized at the EU level by the Raw Material Initiative [101]. This is reflected in the challenging target that has been set to increase the recovery and recycling of Construction and Demolition Wastes (CDW) across Europe.
Approximately 1 billion tonnes of waste, that is around one third of the total amount generated in EU 27 each year, comes from Construction and Demolition (C&D) activities [102]. However, at present, large quantities of these materials eventually end up in landfills, without any form of recovery or re-use. CDW have to be urgently managed in an appropriate and efficient way. Because of the impacts, not only on the environmental but also by economical and social points of view, the Buildings and Construction (B&C) represent a hot spot related to all the other sectors [103].

According with by UNEP definition [104], the Green Economy takes into due account all the natural resources from which the human species benefits without any compensation paid. This is a holistic approach, not only economic, involving all community activities, particularly addressed in two crucial areas: procurement and sustainable use of natural capital and resources. In this context, a fundamental role is played by government policies on sustainability, first of all declined at worldwide level by UN Agenda 2030, in 2015 [105], and four years later, by the EU New Green Deal [106]. This represents an intensive and effective roadmap for making sustainable the EU economy, by transforming ecological and climate issues and environmental challenges into opportunities. The European Green Deal refers construction as one of the key topics for the green transition, contributing in a fundamental way to the carbon neutrality of Europe that has to be achieved by 2050 [107]. As pillar of that process, the new Circular Economy Action Plan was adopted on March 2020, highlighting the importance of a products' "green design" that has to be oriented to a reduction of raw materials consumption and waste prevention along the entire life cycle of products [108]. The main goal was identified in a robust reduction of CDW pursued by waste prevention and improvement in recycling processes allowing a high quality and high efficiency secondary raw materials production. The EU Commission will act in several directions, considering many production fields, with a particular attention to B&C. The European strategy for a Sustainably Built Environment [109] represents in fact a whole and exhaustive plan aiming to guarantee a coherent integration between all the policy strategic areas such as climate change, energy and resource efficiency, CDW management, etc. This strategy will promote circularity principles of construction throughout the lifecycle of buildings starting from an updating in the Construction Product Regulation. The strategy includes the possibility to require appropriate recycled content for construction products, at the same conditions of quality and safety, and to adopt a Life Cycle Assessment (LCA) methodology in public procurement. Furthermore, according to Circular Economy (CE) principles, new goals in CDW recovery targets a part, an energy efficiency implementation is expected by a lifecycle performance optimization and a longer lifespan of construction heritage.
New EU policies are promoting energy performances in buildings, by considering financial leverages, making easier financing access for building assets renovation. In that direction, also the "Clean energy for all Europeans package" [110] promoted a robust revision of the previous energy in buildings directives with the aim to drive the EU clean energy transition. Each country will integrate its national energy and climate plans (NECPs) by adopting an energy in buildings strategy for the period 2021-2030, including nearly zero-energy buildings, energy performance certificates, and smart technology in new buildings actions, with the aim to reach the 32.5% EU target in energy efficiency by 2030 [111].
The European Green Deal has been recently supported by the new EU Action Plan "Towards a Zero Pollution Ambition for air, water and soil – building a Healthier Planet for Healthier People" [112], having the purpose to act in particular in climate change and pollution issues promoting prevention, remediation and monitoring activities.
Finally, the Circular Cities and Regions Initiative (CCRI)[113] represents an innovative focal point of the Circular Economy Action Plan, highlighting the importance to pursue advanced solutions and actions at local and regional level. B&C can represent an excellent field of interest of Circular Cities strategies for minimizing environmental and social impacts in compliance with the sustainability principles. They can put into practice a more appropriate behavior in consumption and resources supply as well as in waste prevention, recovery and recycling, contributing to achieve UN Agenda 2030 SDGs 11 ("Make cities and human settlements inclusive, safe, resilient and sustainable") and 12 ("Ensure sustainable consumption and production patterns").
CDW management has outlined over time the strategies through which waste must be treated; these methods are positioned within a hierarchical scale, in relation to the preference given to them from an environmental point of view, that is, from the impact they can determine on the environment. The environmental impact resulting from the use of these strategies is in increasing order, from lowest to highest. The principles underlying the hierarchy are the minimization of resource consumption and the prevention of environmental impact, which represent the two pillars of sustainability in construction [114]. The three strategies 'Reduce, Reuse, Recycle' are well known in the field of waste management as the 3Rs of the hierarchy of CDW management methods [115] CE in B&C. The waste reduction strategy offers two major benefits: minimizing the generation of CDW waste and reducing the costs for the transport of waste. The reduction method is considered the most efficient and effective for optimizing CDW management and eliminating many environmental and disposal problems. It must be seriously estimated in the case of refusal from C&D activities is inevitable and the 'zero

waste' condition is not achievable. It could be, nevertheless, approached by improving the efficiency dematerialization of the processes. Reuse generally means the use of the same component in the construction process more than once. It can be done both considering an 'old life' reuse, with the possibility of using a material or a component for the same previous function (i.e the wooden formwork), and a 'new life' reuse for a new function (such as the use of concrete fractions or tiles for basic materials for the streets). Reuse requires minimal treatment of the material and in addition to low energy consumption. Recycling is recognized today as the most practicable and preferable CDW management strategy compared to all the others, as well as desirable from an environmental point of view. The goal is to reprocess the waste to obtain secondary raw materials to be used mostly as aggregate for the production of mortars and concretes. This not only fulfills the goal of recycling, but also results in economic benefits. The production of secondary raw materials implies a series of well recognized advantages, such as the reduction of demand for new resources and of transport and energy costs, the exploitation of waste that otherwise would be landfilled, and the preservation of land areas and of the general conditions of the environment. Reused and recycled raw materials represent also an added value in terms of sustainability in construction. Appropriate material selection, in fact, plays a crucial role in reducing the embodied energy and other environmental impacts of a building and it can constitute additional value also in labeling and environmental certification achievement. For instance, the green building rating system LEED (Leadership in Energy and Environmental Design) [116], the buildings classification method based on energy consumption and ecological footprint evaluation, includes a complete category (Materials and Resource) that aims at selecting materials that are assumed to be "green" including material with recycled content and reused materials. In the effort to quantify the whole impacts of materials arising during each step in the whole supply chain (i.e. manufacturing, transportation, construction, operation), including end of life management and valorization, several national and international regulation and labeling systems are considering a life cycle thinking approach. It allows a holistic evaluation of all environmental, social and economic impacts deriving from B&C activities. For instance, in Italy, the so called "CAM" (Minimal Environmental Criteria) plan, related to buildings, introduced by the Environmental Ministry in 2017 [117], and in Spain, the buildings certification system ("Código Técnico de la Edificación" [118], support the Public Sector Contracts and Procurement regulations. Both these two policies assume environmental life cycle assessment (ELCA) and life cycle costs assessment (LCC) as sustainability evaluation and validation method. Also the already mentioned LEED, in its last updated edition [119], introduced the use of whole building life cycle assessment (WBLCA) as a compliance option for earning credits. In particular, it was introduced a new credit named "building lifecycle impact reduction" supporting eco design by using life cycle assessments in an effort to allow objective comparison of quantified environmental performance for various materials [120]

The literature review performed highlighted the presence of two pillars underpinning the academic conversation. One is more oriented to the systemic view required for policy formulation, referring to the topics of sustainable development in general, circular economic systems and the recycling as fundamental approach to waste management. The other tends to ground the researches into a more product-oriented approach, rooted into performance and efficiency evaluations and the application of advanced tool for the impact assessment of products and processes, as well as the development of ecodesign methodologies and products. This last topic, in particular, configures as the natural bridge between the two frameworks, as it takes advantage from product-oriented tools to develop solutions integrated with more systemic views.

The two frameworks:

Product-oriented framework

A remarkable stream of research deals with product-oriented approches, typically promoting the efficiency and performance of products, in terms of environmental impacts, and the tools supporting both assessment and product development, such as Life Cycle Assessment and sustainability Assessment and Carbon Footprint. Environmental Product Declaration, Ecodesign in constructions

Policy-oriented framework

A wider perspective characterise the policy-oriented framework identified within the body of literature included into the review. This more systemic approach toward the study of sustainable management of CDW encompassess elaborations about their role within the Circular Economy, the recycling options technologically available and its contribution to the design of new materials, twinning, in this sense, the focus on Ecodesign.

In conclusion, according to the literature, the attention in B&C sustainability is definitively growing. This sector represents one of the most natural-resources (raw materials, energy) demanding and contributes to a huge greenhouses gas emissions and solid waste production. For these reasons, the European Commission has been developing a long-term strategy to tackle the issue. All last policies and action plans, such as the New Green Deal, the Circular Economy Action Plan and the Circular Cities and Regions Initiative, just to mention the most important, are rowing in the same direction. A coherent and integrated approach is required to achieve ambitious goals in a few decades, by 2050: European carbon neutrality, zero pollution, low resources consumption, zero energy buildings, whole and perfect circularity zero-waste and prevention oriented.

Paper 2- Applicability of life cycle assessment methodology to conservation works in historical building: The case of cleaning

Applicability of life cycle assessment methodology to conservation works in historical building: The case of cleaning.

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(The full paper in Annex 2)

Abstract: The Life Cycle Assessment (LCA) represents a suitable methodology to evaluate quantitatively the environmental impact related to a product or a process and it can be used as a guiding tool to make effective environmental sustainability choices. While the LCA-based methods are more and more diffused in the assessment and selection of materials for new constructions, they are still scarcely applied in the field of conservation and repair of historical buildings, although these buildings, especially in Europe, represent a high percentage of the building stock. In the present paper, the LCA method was applied to the field of the restoration, with particular reference to cleaning technologies and materials, in order to investi- gate if LCA can be applied in this field. The analysis of results pointed out the different environmental impact of the cleaning methods investigated (ascribed to different im pact categories), but also the short- comings and proxies arising from the lack of specific database. The impact of the waste treatment stage was also analysed, in order to highlight the main impact spots related with the end of life of materials and equipment. Results showed that, for some cleaning methods, the impacts related to manufacturing and disposal are very similar, which emphasizes the importance of performing LCA including the end of life scenarios. Finally, an evaluation of externalities was performed, to provide a monetary value of the environmental damage.

Resumen: El Life Cycle Assessment (LCA) representa una metodología adecuada para evaluar cuantitativamente el impacto ambiental relacionado con un producto o un proceso y puede usarse como una herramienta de guía para tomar decisiones efectivas sobre sostenibilidad ambiental. Si bien los métodos basados en LCA están cada vez más difundidos en la evaluación y selección de materiales para nuevas construcciones, todavía se aplican escasamente en el campo de la conservación y reparación de edificios históricos, aunque estos edificios, especialmente en Europa, representan un alto porcentaje. del parque inmobiliario. En el presente artículo, el método LCA se aplicó al campo de la restauración, con particular referencia a las tecnologías y materiales de limpieza, con el fin de investigar si la LCA se puede aplicar en este campo. El análisis de los resultados señaló los diferentes impactos ambientales de los métodos de limpieza investigados (adscritos a diferentes categorías de impacto), pero también las deficiencias y proxies derivados de la falta de una base de datos específica. También se analizó el impacto de la etapa de tratamiento de residuos, con el fin de resaltar los principales puntos de impacto relacionados con el fin de vida de los materiales y equipos. Los resultados mostraron que, para algunos métodos de limpieza, los impactos relacionados con la fabricación y la eliminación son muy similares, lo que enfatiza la importancia de realizar LCA que incluya escenarios de fin de vida útil. Finalmente, se realizó una evaluación de externalidades, para dar un valor monetario al daño ambiental.

The context: an introduction
"Sustainable cities and communities" is one of the seventeen Sustainable Development Goals that United Nations adopted within the "Agenda 2030 plan of action, in order to promote a global sustainable development by the integration of its three dimensions: environmental, social and economic. Cities play a key role in achieving this goal, also because more than 60% of humanity presently lives in cities and this number is expected to grow, so it is crucial to make them prosperous, safe and inclusive. Furthermore, the cities, especially through their architecture and buildings, maintain the historical and cultural value of society and keep the heritage of the past. As opposed to demolition of existing buildings and construction of new ones, restoration and rehabilitation can represent a viable alternative to reduce the environmental impacts of the building industry. For instance, in terms of consumption of raw materials for new constructions and treatment of the waste derived from demolition; moreover, architectural rehabilitation preserves and valorizes architectural heritage that otherwise would be irreversibly lost [121] . In addition, the integration of these preservation issues into public policies and strategic plans can transform cultural heritage from a "static object" to be purely safeguarded and preserved into an active driver for the development of sites or clusters [122]. However, it is undeniable that historical buildings are responsi- ble for a high energy consumption during their operational phase, due to low thermal insulation of the envelope, low efficiency of existing Heating, Ventilation and Air Conditioning (HVAC) systems, etc. [123], and they also require maintenance and repair interventions. This impact cannot be neglected, especially in Europe, where historical buildings

represent a high percentage of the building stock; a better understanding of this impact is of paramount im- portance towards the improvement of the overall sustainability of existing buildings. The evaluation of the environmental impact of conservation practices have been carried out in some literature papers [124], while the assessment of the impact of conservation works carried out in heritage buildings is still quite limited. A first attempt towards such evaluation was made by the Green Building Council (GBC) Italy, a no profit organization founded in 2008 with the aim of implementing sustainable practices into the Italian building sector. In addition to the promotion of the LEED certification system (where LEED is the acronym of "Leadership in Energy and Environmental Design") and the development of a certification specific for the Italian context, the GBC Italy has established a new rating system for historical buildings, named 'GBC Historic Buildings' [125]. The GBC Historic Building represents an innovative tool that allows to link sustainability issues to cultural and historical aspects of restoration, based on the common goal of promoting and pre- serving cultural heritage for the future generations. However, this protocol is a qualitative rating system and it does not provide any quantitative information about the environmental impacts associated to the human activities. Conversely, the Life Cycle Assessment (LCA) represents a suitable methodology to evaluate quantitatively the environmental impact related to a product or a process and it can be used as a guiding tool to make effective sustainability choices. The impact of historic buildings in terms of energy consumption and saving [122] and environmental loads [126] and the strategies aimed at reducing such impact [127] were investigated in several papers, considering the entire life cycle of buildings from the LCA perspective. Also several studies in building refurbishment [128] and restoration [129], repair mortar and concrete[130] [131] and recycled material use [132,133], or generally in sustainable maintenance for heritage buildings [134] have been performed. It should be pointed out that there are many obstacles in applying the LCA methodology in the field of conservation works, which derive from the specificity of the subject of the study. First of all, each restoration operation is completely case-specific and it depends on the physical, chemical and mechanical proper- ties of the substrate, the history of the building, any previous conservation interventions, etc. It may involve the use of a wide variety of materials and technologies and sometimes, due to a lack of specific inventory data on them, it is difficult to precisely represent each particular operation. In addition, it is important to highlight that many restoration activities are craftsmanship activities and therefore there are many variables that are difficult to control, if compared to standard industrial activities. It is noteworthy that these methodological issues should not represent an obstacle for a correct and wide LCA implementation. On the contrary, they can represent a challenging starting point for the setting up of ad hoc databases in order to make the LCA totally applicable in this sector. The LCA approach in restoration works should be increasingly developed in the future to support design, buildings' environmental certification and all kind of construction-related activities evaluation, such as public procurements. As a contribution towards the LCA implementation in the conservation field, a first study was carried out by the authors to evaluate the environmental impact of cleaning procedures, which are commonly performed in any repair work and hence represent an important step in the repair process [135]. In the previous analysis, the research was focused on the evaluation of a high number of different cleaning technologies, investigating how the different types materials and equipment that can be used by the professionals (supporting mixtures, solvents, mechanical equipment, hand tools, etc.) contribute to the environmental impact. Starting from that previous analysis, the present work is aimed at investigating the applicability and reliability of the Life Cycle Assessment to the field of the restoration, with particular reference to cleaning. In this paper, only a limited number of cleaning techniques was selected, and the research was focused on the possible short- comings and proxies arising from the lack of a specific database, on a sensitivity analysis concerning LCA application and on the influence of the waste treatment stage. Including the waste treatment stage allowed to highlight the main impact spots related with end of life of materials and equipment, and the relative weight of the end-o-f life stage with respect to the manufacturing and operational stages. Furthermore, an evaluation of externalities was performed by using the EPS 2015dx (Environmental Priority Strategies) assessment method, to provide a monetary value of the environmental damage.

In conclusion, the results of the study show that the LCA is actually applicable to conservation works, with particular reference to cleaning, although some limitations still exist, such as the limited data availability in the databases. This research also showed how critical is the selection of the "functional unit" is in the conservation field, as the working operations are dependent on the skillfulness and experience of the conservators involved. The functional unit used in this study, namely the cleaning of one square meter of a plain vertical surface affected by a 'normal black crust', was selected on the basis of the experience of the authors and some professionals working in the conservation field since many years, but this aspect should be improved in the future. The extension of the LCA analysis to other stage of the conservation work, such as repointing with repair mortars and renders, consolidation and protection are presently under investigation. The diffusion of the environmental impact assessment may largely contribute to a more sensible selection of materials and technologies in the conservation and repair of historic buildings, but also to the set-up of improving measures to reduce the environmental impact, thus promoting the sustainability awareness also in this important field.

Paper in progress - Life Cycle Assessment of concrete hollow blocks: a comparison between natural and recycled aggregates

Starting from the second half of the 20th century, there has been a remarkable world population growth which has been followed by an increase of urbanization. Over time, it has been observed that the urbanization phenomenon is closely linked to the waste generation problem and it is estimated to double by 2045, following the actual growth rate [136].
Construction and demolition wastes has become the largest and increasing [137] waste fraction in industrialized countries. The extraction and processing of raw materials has been estimated that it could almost double by 2060, affecting a great quantity of earth and environmental aspects such as pollution of soils, air and water, generating acidification, severe impacts on human health and toxicity of water and land, contributing remarkably to climate change [138].
Recent studies demonstrated that concrete is one of the most heavily used materials in construction sector and the second most heavily consumed substance on earth, after water [139].
Construction sector is one of the most demanding of raw materials among economic sectors, in recent literature regarding emissions produced from the sector, it is common to find several authors that agree on the paths that should be covered at the same time to make more sustainable constructions, increase the efficiency of the machinery and the processes involved, promoting use of renewable energies and recycled materials, are among the most common solutions [140], [141]
The European standard EN 771-3 allows the production of non-structural dry-mixed concrete hollow blocks (CHBs) with the incorporation of fine and coarse recycled aggregates. The introduction of recycled materials shall allow to reduce the amount of raw material required for block making and reducing the amount of construction and demolition wastes (CDW) disposed to landfill at the same time. The incorporation of recycled aggregates is feasible in percentages up to 100% for the production of non-structural concrete pieces [142], [143]
Life cycle assessment (LCA) is a tool in which the impacts related to products and/or human activities can be measured and compared, returning the environmental impacts in relation to a functional unit chosen as the quantitative measure of the product or the service generated by the system considered [144]. Several studies conducted by applying LCA on building materials and more in general to construction sector demonstrated that this tool could be ideal, especially for comparations where recycled components are involved [145], [146], [147] These studies showed recycled aggregates could reduce significantly the environmental impacts of concrete, especially in terms of greenhouse gas emissions.
The LCA procedure is characterized by a well-defined structure [148], goal and scope definition, inventory analysis, impact assessment and results, all stages accompanied by interpretation. All the stages of the procedure are crucial for obtaining reliable outputs from the analysis, the completeness and the robustness of the life cycle inventory (LCI) requires the highest efforts since the results are derived directly from the outputs of this stage [149].
The bibliography reviewed, is characterized by works where the substitution of natural aggregates with recycled aggregates was partial or total [150], [139,151] and in all cases the practicability of the substitution has been demonstrated. The main factors highlighted affecting the results in terms of environmental impact are the type of C&DW treatments performed, the transport distances present throughout the whole process and the rate of substitution.
A work in progress aims to investigate whether the introduction of recycled aggregates in the production of non-structural concrete hollow blocks can alleviate or aggravate the environmental impacts related to the product. This scope has been pursued through a comparative LCA among three different types of aggregates and two combinations of partial substitutions.
In particular, the analysis focused on the differences generated from the use of natural aggregates (NA), mixed recycled aggregates (MRA), concrete recycled aggregates (CRA) combined in several series. The natural aggregates used throughout the process are obtained from dolomitic rock extracted and processed in Granada province, Spain, while recycled aggregates used are produced starting from C&DWs collected in construction sites present in Granada and processed in a plant placed few kilometers away from the collecting basin. All the crafting processes studied in the analysis are still in force nowadays (2023).
In accordance with the recent research stream, the analysis highlighted that the substitution with recycled aggregates is convenient under all the environmental aspects, consumption of abiotic resources and land occupation for construction sector can be reduced significantly using recycled aggregates. The design of the process layout can influence the environmental impact of the produced aggregates hence it is an aspect that should be taken into primary consideration during the designing and construction of treatment plants. Differences in the quantities of material discarded during the production of recycled aggregates and differences in specific material consumption per block generate effects on environmental impacts that are not negligible.
Despite all the blocks series considered perform in the same mechanical class, those made with NA have the best mechanical performances with the worst environmental impacts, blocks made with CRA performs comparably in mechanical terms with much better environmental performances.
A common factor in almost every scientific analysis, it is important to bring to the fore that uncertainty linked to data variability and choices and/or assumptions made during the study can be minimized, nevertheless is always present, then a dedicated analysis should be carried out to continue along the path generated by the analysis and increase the overall robustness of the results.

Circular Bioeconomy

Circular bioeconomy refers basically to an economic system that is based on the principles of a circular economy, but with a focus on the use of renewable biological resources as inputs. In order to create food, fuel, energy, and other materials, it entails the sustainable use and management of natural resources, including forests, fisheries, and agricultural lands.

The bioeconomy, in accordance with the European Commission, is made up of those economic sectors that use renewable biological resources to create food, materials, and energy [152]. The German Bioeconomy Council similarly defined the bioeconomy as all industrial and economic sectors that produce or process biomass or utilize biological resources [153]. The Biomass Research and Development Board in the US, for its bioeconomy initiative, has adopted the definition from Golden and Handfield [154] which defines the bioeconomy "*as the global industrial transition of sustainably utilizing renewable aquatic and terrestrial biomass resources in energy, intermediate products, and final products for economic, environmental, social, and national security*".

But it is clear that there is not a single definition of "circular bioeconomy".

The circular bioeconomy is seen as a framework by the European Commission's bioeconomy strategy, as a way to grow new industries and jobs while reducing reliance on natural resources, changing manufacturing, and promoting sustainable production of renewable resources from lands, fisheries, and aquaculture [155]. By incorporating circular economy ideas into the bioeconomy, a circular bioeconomy is easily seen as a more effective resource management of bio-based renewable resources [156] and it should prevent the loss of natural resources like carbon, nutrients, and water, minimize the depletion of resources like phosphate rock, fossil fuels, or soils, and promote regenerative practices like restoring fish stocks. It should also encourage the reuse and recycling of inevitable by-products, losses, or wastes in a way that maximizes system value [153]. The circular bioeconomy can help restore the Earth's biodiversity and natural capital while drastically reducing the harmful effects of resource extraction and usage on the environment.

A circular bioeconomy is inevitably constrained by the biosphere's built-in cycles and sinks. In addition to anthropogenically manipulated ecosystems, it is basically obvious to refer to natural ecosystems, related to biomass production, which include terrestrial agriculture, marine fisheries, and aquaculture [157].

In a circular bioeconomy, even in line with the definition of the circular economy, waste is minimized and resources are reused, recycled, or regenerated, which helps to reduce greenhouse gas emissions and other environmental impacts. For instance, organic waste can be converted into compost or bio-based fertilizers, which can be used to enhance soil health and crop production, and agricultural waste can be used to create biogas, which can be utilized as a sustainable energy source.

The EU economy depends heavily on its biological resources, which will become increasingly more crucial in the next years [79]. Among the different actions to put in practice a circular bioeconomy, it is worth highlighting the EU Strategic Deployment Agenda for sustainable food and farming systems, forestry and bio-based production and some strategies for inclusive bioeconomies in rural areas and to develop urban bioeconomy through piloting circular bioeconomy cities [158].

Significant effects of agriculture, forestry, and fisheries on soil, water, and air quality, biodiversity, and landscape amenity value [159]. Sustainable bio-based product production is dependent on practices that protect natural ecosystems, biodiversity, soil fertility, and water quality.

Healthy ecosystems carry out a number of crucial tasks and offer key services for life on Earth. Healthy ecosystems not only produce food, fibres, and fuel but also clean the air, create oxygen, control water flow, avoid floods, control global temperatures, and act as a gene and species repository, promoting biodiversity. Healthy soils and oceans operate as a global carbon sink, potentially slowing down climate change and its consequences. The circular bioeconomy can reduce the environmental effects of resource use, but a systems approach is needed to manage social, economic, and environmental factors concurrently [159].

Biowaste makes up a significant amount of biomass, which can be used for both brand-new uses and the resupply of nutrients in biomass production systems. Recycling biowaste is a key tactic in a circular bioeconomy for maximizing the utilization of the biomass resource base.

The bioeconomy is seeing significant innovation and market growth, particularly in the fields of bioplastics and bio composites, as seen by media coverage of cutting-edge technology and bio-based goods. The main goals of innovation are to replace fossil fuels with non-renewable resources (commodity plastics), provide new or enhanced functions (composites), and make products biodegradable for use in high-volume products like carrier bags and single-use packaging or in agricultural applications like soil cover. Moreover, research and development activities are more and more focused on the creation of bioplastics from non-edible biomass and biowaste.

The bioeconomy covers all sectors and systems that rely on biological resources (animals, plants, micro-organisms and derived biomass, organic waste), their functions and principles. The concepts of bioeconomy and of bioeconomy policy have evolved. The updated EU Bioeconomy Strategy [152] was accompanied by a targeted Action Plan along three main action areas: strengthen and scale-up the bio-based sectors, unlock investments and markets; deploy local bio-economies rapidly across Europe; and understand the ecological boundaries of the bioeconomy. By taking steps in accordance with the Bioeconomy Strategy and Action Plan, the Commission will work to ensure the sustainability of renewable bio-based materials.

The bioeconomy relies on renewable resources, but it is not always sustainable [160]. A non-sustainable bioeconomy can really lead to a number of sustainability conflicts [161]. For instance, a rise in the demand for biofuels will raise the need for biomass, which in turn may increase competition for food production, freshwater usage, and social discontent or sustainability concerns.

Due to the increased need for land for biomass production, there will also be negative environmental effects, such as an increase in greenhouse gas emissions (which are responsible for global warming) as a result of indirect land-use changes (e.g., deforestation for growing energy crops [162]. Another illustration is a recent study that shows bio-based packaging and other bio-based products don't always show signs of being good for the environment [163].

To address environmental and social challenges, a bioeconomy must be sustainable. The use of renewable resources, the production of sustainable biomass feedstock, and the development of products and processes for converting biomass are all encouraged. A sustainable bioeconomy might also be developed by merging with other interdisciplinary topics like the circular economy.

Bioeconomía circular

La bioeconomía circular se refiere básicamente a un sistema económico basado en los principios de una economía circular, pero enfocado al uso de recursos biológicos renovables como insumos. Para crear alimentos, combustible, energía y otros materiales, implica el uso y la gestión sostenibles de recursos naturales, incluidos los bosques, la pesca y los suelosagrícolas.

Según la Comisión Europea, la bioeconomía está formada por aquellos sectores económicos que utilizan recursos biológicos renovables para crear alimentos, materiales y energía [152]. El Consejo Alemán de Bioeconomía ha definido de forma similar la bioeconomía como el conjunto de todos los sectores industriales y económicos que producen o procesan biomasa o utilizan recursos biológicos [153]. El Consejo de Investigación y Desarrollo de la Biomasa de EE.UU., para su iniciativa de bioeconomía, ha adoptado la definición de Golden y Handfield [154], que definen la bioeconomía "*como la transición industrial global de la utilización sostenible de recursos renovables de biomasa acuática y terrestre en energía, productos intermedios y productos finales para la seguridad económica, medioambiental, social y nacional*".

Es por tanto evidente que no existe una definición única de "bioeconomía circular".

La estrategia de bioeconomía de la CE considera la bioeconomía circular como un marco para desarrollar nuevas industrias y puestos de trabajo, al tiempo que se reduce la dependencia de los recursos naturales, se modifica la fabricación y se promueve la producción sostenible de recursos renovables procedentes de la tierra, la pesca y la acuicultura [155]. Al incorporar las ideas de la EC a la bioeconomía, una EC se puede considerar como una gestión más eficaz de los recursos renovables de origen biológico [156] y debería evitar la pérdida de recursos naturales tales como el carbono, los nutrientes y el agua, minimizar el agotamiento de recursos como la roca fosfórica, los combustibles fósiles o los suelos, y promover prácticas regenerativas como la recuperación de las poblaciones de peces. Además, debería fomentar la reutilización y el reciclaje de subproductos, pérdidas o residuos de forma que se maximice el valor del sistema [153]. La bioeconomía circular puede ayudar a restaurar la biodiversidad y el capital natural de la Tierra, al tiempo que reduce drásticamente los efectos dañinos de la extracción y el uso de los recursos en el medioambiente.

Una bioeconomía circular se ve inevitablemente limitada por los ciclos y sumideros integrados en la biosfera. Además de los ecosistemas manipulados antropogénicamente, es prácticamente obvio referirse a los ecosistemas, relacionados con la producción de biomasa, que incluyen la agricultura, la pesca marina y la acuicultura [157].

En una bioeconomía circular, en línea con la definición de EC, los residuos se minimizan y los recursos se reutilizan, reciclan o regeneran, ayudando de esta manera a reducir las emisiones de gases de efecto invernadero y otros impactos ambientales. Por ejemplo, los residuos orgánicos pueden convertirse en compost o fertilizantes biológicos, utilizados para mejorar la salud del suelo y la producción de cultivos, y los residuos agrícolas pueden utilizarse para crear biogás, que representa una fuente de energía sostenible.

La economía de la UE depende en gran medida de sus recursos biológicos, que serán cada vez más cruciales en los próximos años [79]. Entre las diferentes acciones para poner en práctica una bioeconomía circular, cabe destacar la Agenda de Despliegue Estratégico de la UE para los sistemas alimentarios y agrícolas sostenibles, la silvicultura y la producción de origen biológico y algunas estrategias para las bioeconomías inclusivas en las zonas rurales y para desarrollar la bioeconomía urbana mediante ciudades piloto de bioeconomía circular [158].

Efectos significativos de la agricultura, la silvicultura y la pesca en la calidad del suelo, del agua y del aire, la biodiversidad y el valor recreativo del paisaje [159]. La producción sostenible de productos biológicos depende de prácticas que protegen los ecosistemas naturales, la biodiversidad, la fertilidad del suelo y la calidad del agua.

Los ecosistemas llevan a cabo una serie de tareas cruciales y ofrecen servicios clave para la vida en la Tierra. Los ecosistemas sanos no producen solo alimentos, fibras y combustibles, sino que también limpian la atmósfera, generan oxígeno, controlan el flujo de agua, evitan inundaciones, controlan las temperaturas globales y actúan como depósito de genes y especies, fomentando la biodiversidad. Los suelos y océanos actúan como sumideros globales de carbono, frenando potencialmente el cambio climático y sus consecuencias. La bioeconomía circular puede reducir los efectos ambientales del uso de los recursos, pero se necesita un enfoque sistémico para gestionar simultáneamente los factores sociales, económicos y ambientales [159].

Los biorresiduos representan una cantidad significativa de biomasa, que puede utilizarse tanto para nuevos usos como para el reabastecimiento de nutrientes en los sistemas de producción de biomasa. El reciclaje de biorresiduos es una estrategia clave en una bioeconomía circular para maximizar la utilización de la base de recursos de biomasa.

La bioeconomía está experimentando una innovación y un crecimiento del mercado significativos, sobre todo en los campos de bioplásticos y biocompuestos, como se desprende de la cobertura mediática de la tecnología puntera y los productos de origen biológico. Los principales objetivos de la innovación son sustituir los combustibles fósiles por recursos no renovables (plásticos básicos), proporcionar funciones nuevas o mejoradas (compuestos) y hacer que los bienes sean biodegradables para su uso en productos de gran volumen como bolsas y envases desechables o en aplicaciones agrícolas como la cobertura del suelo. Además, las actividades de investigación y desarrollo se centran cada vez más en la creación de bioplásticos a partir de biomasa no comestible y residuos.

La bioeconomía abarca todos los sectores y sistemas que dependen de recursos biológicos (animales, plantas, microorganismos y biomasa derivada, residuos orgánicos), sus funciones y principios. Los conceptos de bioeconomía y de política de bioeconomía han evolucionado. La Estrategia de Bioeconomía de la UE actualizada [152] estaba acompañada por un Plan de Acción específico en tres ámbitos de actuación principales: reforzar y ampliar los sectores de origen biológico; desbloquear las inversiones y los mercados; desplegar rápidamente las bioeconomías locales en toda Europa; comprender los límites ecológicos de la bioeconomía. Mediante la adopción de medidas acordes con la Estrategia de Bioeconomía y el Plan de Acción, la Comisión trabajará para garantizar la sostenibilidad de los materiales de origen biológico renovables.

La bioeconomía se basa en recursos renovables, pero no es siempre sostenible [160]. De hecho, una bioeconomía no sostenible puede provocar una serie de conflictos relacionados con la sostenibilidad [161]. Por ejemplo, un aumento de la demanda de biocombustibles incrementará la necesidad de biomasa, lo que a su vez puede aumentar la competencia en la producción de alimentos, el uso de agua dulce y el descontento social o las preocupaciones por la sostenibilidad.

Además, a causa de la mayor necesidad de tierras para la producción de biomasa, se producirán efectos medioambientales negativos, como un aumento de las emisiones de gases de efecto invernadero (responsables del calentamiento global), como consecuencia de cambios indirectos en el uso de la tierra (por ejemplo, la deforestación para el cultivo de plantas energéticas) [162]. Otro ejemplo se encuentra en un estudio reciente, que demuestra que los envases y otros productos de origen biológico no siempre son beneficiosos para el ambiente [163].

Para hacer frente a los retos medioambientales y sociales, la bioeconomía debe ser sostenible. Es necesario fomentar el uso de recursos renovables, la producción de materias primas de biomasa sostenibles y el desarrollo de productos y procesos para convertir la biomasa. Además, una bioeconomía sostenible podría desarrollarse fusionándose con otros temas interdisciplinarios como la economía circular.

Paper 3- Organic Waste Management and Circular Bioeconomy: A Literature Review Comparison between Latin America and the European Union

Organic Waste Management and Circular Bioeconomy: A Literature Review Comparison between Latin America and the European Union

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(The full paper in Annex 3)

Abstract: Worldwide, organic waste represents one of the most significant shares in the waste management system. Within the framework of circular bioeconomy, new and cutting-edge infrastructure has been developed at the European level to turn organic waste into valuable resources. The present paper aims to provide an exhaustive comparison between the European Union and Latin America regarding organic waste valorization. To this end, an introductive analysis about the state of the art circular bioeconomy in Latin America and Caribbean countries was developed. Subsequently, a systematic literature review in the context of South and Central America was conducted to detect differences and similarities in technologies and best practices for treating biowaste. The results show that the Latin American region is home to numerous bio-based infrastructures: biogas recovery, composting facilities and bioremediation strategies. Nevertheless, a conclusive remark underlines that some social, economic and political barriers are still encountered in the region, and therefore, new and locally-based studies are of paramount importance.

Resumen: A nivel mundial, los residuos orgánicos representan una de las participaciones más significativas en el sistema de gestión de residuos. En el marco de la bioeconomía circular, se han desarrollado infraestructuras nuevas y de vanguardia a nivel europeo para convertir los residuos orgánicos en recursos valiosos. El presente trabajo tiene como objetivo proporcionar una comparación exhaustiva entre la Unión Europea y América Latina en cuanto a la valorización de residuos orgánicos. Para ello, se desarrolló un análisis introductorio sobre el estado del arte de la bioeconomía circular en los países de América Latina y el Caribe. Posteriormente, se realizó una revisión sistemática de la literatura en el contexto de América del Sur y Central para detectar diferencias y similitudes en las tecnologías y mejores prácticas para el tratamiento de biorresiduos. Los resultados muestran que la región latinoamericana alberga numerosas infraestructuras de base biológica: recuperación de biogás, instalaciones de compostaje y estrategias de biorremediación. Sin embargo, una observación concluyente subraya que todavía se encuentran algunas barreras sociales, económicas y políticas en la región y, por lo tanto, los estudios nuevos y de base local son de suma importancia.

The context: an introduction

The birth of the bioeconomy, conceived as "the process of transforming life-science knowledge into new, sustainable, eco-efficient and competitive products"[164], has been the result of chance, necessity and evolution of several societies. This evolution and concern for sustainability also involves anthropological issues as ethics, an increasing delimiting factor in the modern context, as already mentioned by the Romanian economist and mathematician Nicholas Georgescu-Roegen on his treatise on bioeconomic and degrowth in 1975. For Georgescu-Roegen, it was clear that an unequal appropriation of natural resources (even for economic development) could trigger a social fracture and eventual economic degrowth [165].

In the same line, there is consensus that the transition towards a bioeconomy is often associated with a number of economic, environmental and social benefits; however, the bioeconomy is not sustainable per se. Various environmental and socio-economic risks could undermine the sustainability of the bioeconomy, such as increased competition for land between food crops and fuel crops, direct and indirect changes in land use, marginal land use with negative effects on the biodiversity and greenhouse gas emissions, among others [166]. At the Latin American level, in 2014, around 4.6 giga tons of CO_2 were registered, of which 50% were associated with agricultural activities and land use. On the other hand, in Central America between 1990 and 2017, about 20 million hectares of forests have been lost due to changes in land use [167].

For full bioeconomy application, ethics and other social rules have to be set in order to achieve sustainability. This is especially true in developing countries, where bioeconomy can enhance the dichotomy between food safety and industrial development, considering that there is consensus in the global scientific community that conventional technology will not, on its own, increase or diversify food production in sufficient quantity and quality to feed a population that will almost double in 50 years. This will directly influence the food security of several countries, especially those developing countries, where demands will be higher [168].

In terms of global bioeconomy development, while it is true that the European Union is one of the pioneers in the world in terms of application of the bioeconomy [169], the bioeconomy has found a niche of opportunities in other parts of the world including Latin American and the Caribbean (LAC).

In terms of a literature review, the state of maturity and development level of the bioeconomy in Europe is well documented, mainly by institutional organisms, while in LAC and especially in Central America (CA), the number of specialized publications is currently limited and rarely diffused. Additionally, the mentioned publications are mainly performed by international organisms that respond to its own necessities and agendas.

However, some actors have analyzed the current state of the technological context in LAC and CA also based on the number of scientific publications, where Brazil rose to first place with the highest number of scientific publications, accounting for 37% of the analyzed available documents [170]. The number of scientific publications—especially for Central American countries—regarding bioeconomy issues, including biofuels and enhancement of crops, is very limited; thus, one of the main objectives of the present paper is to contribute to the systematization of state-of-the-art biowaste valorization.

The following lines are intended to show a qualitative overview between the development level of bioeconomy at the European Union (EU) and the Latin America and Caribbean region (LAC).

Legal Framework for the Bioeconomy in EU and Latin America; Main Drivers of Bioeconomy Development in EU and Latin America; Limitation of Bioeconomy Development in Latin America

From the literature analysis described, it was possible to divide the obtaining sample in three main groups due to consistent analogies among the information gathered. The papers, indeed, tackle the topic considering three main different bio technologies recovery solutions. Some focused on diverse composting technologies, others on biogas generation and a small percentage on different biowaste valorization alternatives. This section divides the papers into three main recovery groups and aims to systematically describe current practices in the Latin American region for turning biowaste into bioresources: Composting Alternative, Waste-To-Energy Alternative and Biogas Production, Other Biowaste Valorizations.

The study stresses the difficulties that the LAC region still encounters in its transition towards a new bioeconomy, which is particularly clear in biofuels and bioproducts sectors. In the region, local specific and small-scale solutions were shown to be more appropriate for the geographical area (widely rich in biodiversity and natural ecosystems) and also better welcomed by the community.

From the present review, it appeared clear that organic waste management and circular bioeconomy are sectors in which new technologies still need to be consolidated, in opposition to the European context. This highlights the importance of developing public and business policies that prioritize waste reduction in production and organic waste recovery and valorization. Additionally, it is important to heed the great potential LAC region has in boosting circular economy strategies and policies. The case examples described emphasize this strong potential but also shed light on the difficulties the region is still encountering. In most of the cases, economic dependence should be reduced; this is likely, especially with the help of international cooperation. Therefore, it is necessary to advance in experimental studies to better develop more circular solutions for organic waste management to reduce huge organic fraction volumes and reduce potential environmental burdens. As a final recommendation, the authors stated that future research should address tailored training and participatory programs to maximize social acceptance and economic revenues from innovative bio-based alternative solutions.

Paper 4- Organic waste composting and sustainability in low-income communities in Palestine: lessons from a pilot project in the village of Al Jalameh, Jenin

Organic waste composting and sustainability in low-income communities in Palestine: lessons from a pilot project in the village of Al Jalameh, Jenin

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(The full paper in Annex 4)

Abstract: A pilot composting project was initiated as part of a 200 tons/day solid waste recycling plant with active involvement of several local stakeholders. The project aimed at introducing compost production and use in the village of Al Jalameh, Palestine. The paper describes the successes and lessons from the pilot project. Based on the data collected on the population, waste production and economic activities, the best production methodology and composting units were designed and piloted. The compost was produced from animal manure, farm waste and organic fraction of domestic solid waste. Approaches to increase profit and sustain the initiative was implemented. The facility managed by Al Jalameh Agricultural Cooperative Society, recycles 60% organic fraction of domestic waste reducing the quantity of waste to the landfill. An estimated 1425 m3/year of compost are required for local agriculture while 800 tons/year is produced. With most of their compost coming from Israeli sources, the composting facility is at a competitive advantage. To increase the profit, around 28,125 kg of waste plastic sheets from greenhouses are collected for recycling each year generating a stable income of 5625.00 JOD/year. The compost produced in the village is purchased by the local farmers increasing access to compost at competitive price. Farmers are economically encouraged by compost production that could solve the organic waste management issue and at the same time guarantee a sort of "self-production" of fertiliser useful for local agriculture. This initiative could be extended to other villages in Jenin and other developing countries where agriculture is their major occupation.

Resumen: Se desarrolló un proyecto piloto de compostaje como parte de una planta de reciclaje de residuos sólidos de 200 toneladas/día con la participación activa de varios actores locales. El proyecto tenía como objetivo introducir la producción y el uso de compost en el pueblo de Al Jalameh, Palestina. El documento describe los éxitos y las lecciones del proyecto piloto. Sobre la base de los datos recopilados sobre la población, la producción de residuos y las actividades económicas, se diseñaron y probaron la mejor metodología de producción y las unidades de compostaje. El compost se produjo a partir de estiércol animal, residuos agrícolas y fracción orgánica de residuos sólidos domésticos. Se implementaron enfoques para aumentar las ganancias y sostener la iniciativa. La instalación gestionada por la Sociedad Cooperativa Agrícola Al Jalameh, recicla el 60% de la fracción orgánica de los residuos domésticos reduciendo la cantidad de residuos que van al vertedero. Se estima que se requieren 1425 m3/año de compost para la agricultura local, mientras que se producen 800 toneladas/año. Dado que la mayor parte de su compost proviene de fuentes israelíes, la planta de compostaje tiene una ventaja competitiva. Para aumentar las ganancias, cada año se recolectan para reciclar alrededor de 28125 kg de láminas de plástico de desecho de los invernaderos, lo que genera un ingreso estable de 5625,00 JOD/año. Los agricultores locales compran el compost producido en el pueblo, lo que aumenta el acceso al compost a un precio competitivo. Los agricultores se ven alentados económicamente por la producción de compost que podría resolver el problema de la gestión de residuos orgánicos y al mismo tiempo garantizar una especie de "autoproducción" de fertilizante útil para la agricultura local. Esta iniciativa podría extenderse a otras aldeas en Jenin y otros países en desarrollo donde la agricultura es su principal ocupación.

The context: an introduction

The Middle East is marked by increasing environmental problems. The Occupied Palestinian Territories is no exception. In Occupied Palestinian Territories, the increasing environmental degradation is worsened by years of conflicts. The area is characterized by dense and rapidly increasing population coupled with scarce water resources, climate change and land degradation. Their environmental situation is regarded as alarming [171] and strictly intertwined with political background.
The decades of conflict have affected Palestinian authorities' efforts to safely and sustainably manage their environment and natural resources. Open dumping and burning of solid wastes, which is considered a primitive form of landfilling [172] is practiced in most areas of Palestine [173]. This practice poses several threats both to humans and the environment. For instance, open dumpsites are susceptible to open burning and exposed to scavengers and disease vectors [174,175]. Population living in the proximity of dumpsites are reported to suffer from various diseases (cholera, diarrhoea and malaria, where present), resulting from direct and indirect exposure to open dumping [176]. Leachate generated from decomposing organic matter in waste can contaminate surface and groundwater. Additional public health risks associated with open burning of wastes are air pollution and explosions. Methane and carbon dioxide which are major greenhouse gases are associated with anaerobic decomposition of waste [177]. The scattering of wastes by wind and scavenging by animals create aesthetic nuisance [178]. Not the least is the odour emanating from the degradation of the waste which could become a disturbing issue for the surroundings. Moreover, scavengers working on the dumpsites are constantly exposed to gaseous emission from wastes and obnoxious odour, overheating and disease carrying animals (like rats, reptiles and insects) [179]. To develop a proper waste management system, the Palestinian Development and Investment Limited (PADICO) incorporated the Palestinian Solid Waste Recycling Company (TADWEER) in 2009 to implement waste recycling in the country. JSC (the local Joint Service Council for Solid Waste Management in the Governorate of Ramallah and Al Bireh) and Municipality signed a contract making the JSC responsible for providing the main infrastructure required for the collection and transportation of the separated waste to the recycling plant whiles the municipality makes available at least 1 dunum (1000 m2) of land for the establishment of the agricultural waste recycling and composting station. The goal set for the project was to ensure 50% recycling of the municipal solid waste. The recycling plant was designed for a capacity of 200 tons/day of solid waste and composed of screening and mechanical and manual sorting lines. The waste is separated for cartoons, plastic bottles, glass, and metals and the residual mixed waste is sent to the landfill. The recyclable materials are bagged for easy shipping to Israel and Jordan due to the absence of companies in Palestine to reuse the materials. All the non-recyclable materials are shredded to reduce the size before landfilling with the residual mixed waste after separation. The recycling plant is unable to recycle all the daily amount of waste generated because of the presence of a robust mixture of dry and wet fractions with the wet fraction accounting for 60–70% by weight of the total waste stream. The JSC promoted the pilot project of recycling waste in the village of Al Jalameh with the aim of expanding the recovery and recycling ratio to all the villages in Jenin area by improving differentiated collection system and organic waste composting and reducing landfilled fraction. In this way, Al Jalameh could send to the landfill only 40% of the total urban waste as the remaining 60% organic waste would be composted. In this regard, containers for the wet waste fractions were strategically located in the surroundings of the houses in the village and organic waste is collected daily by the JSC. An Al Jalameh Agricultural Cooperative Society (ACJ) showed interest in the project, above all in the production of compost with municipal organic waste. For this reason, the ACJ, the municipality of Marij Ibn Amer and Palestinian Agricultural Relief Committee, an agricultural development association, signed an agreement to create a station for recycling and composting to be managed by Al Jalameh Agricultural Cooperative. In the composting station, wet waste from farms, mainly greenhouse residues and manure, is collected to produce compost that could be sold to farmers on the local market thereby helping to improve agricultural practices towards a more sustainable agriculture. The beneficiaries of the project are the about 2700 villagers who, thanks to a better organization of the waste collection system focused on recycling, can improve their living conditions both from the hygiene and environmental point of view. In this context, a pilot project was established to optimize organic waste collection and composting for local agriculture.

Conclusions

Given the large amount of biodegradable waste (about 60%) in the waste stream in Al Jalameh, composting for local agricultural use would provide considerable benefits for the solid waste management system. The organic waste composting is decentralized as the separation of organic fraction and composting is performed as near to the source of generation as possible. This reduces the cost and environmental and health risks associated with the collection and transportation of organic waste. In Al Jalameh village, the farmers are economically encouraged by compost production that could solve the organic waste management issue and at the same time guarantee a sort of "self-production" of fertilizers useful for local agriculture. An annual demand of about 1425 m^3 is required by local farmers for planted areas whiles 800 tons/year of compost is produced at Al Jalameh. Using the market price of compost as basis, farmers would still enjoy cheaper prices from the purchase of the compost produced (about 40–52%) compared to chemical fertilizer. The compost production at Al Jalameh was adequate and meets the needs of local farmers, but the financial returns is very small. To address the low financial returns from the sale of compost, a stable annual income of 5625.00 JOD (equivalent to 7900.00 USD) was obtained from the sale of 28,125 kg of plastic sheets from greenhouses to a local recycling company at

Jalbun. In addition, majority of the farmers are members of the Agricultural Cooperative Society and so the marketing approach of encouraging members of the cooperative to use the compost produced would ensure sustainability of the project. The strong local stakeholder involvement and the management of the composting plant by a local agricultural cooperative is one of the greatest strengths of the composting project in Al Jalameh. Based on the successes of the pilot composting project, the initiative could be extended to other villages in Jenin and generally to low-income communities in developing countries where agriculture is the major occupation. Research on this topic is of great importance within this region because of the political and environmental sensitivity, particularly due to the restrictions on the water supply and system imposed by the prevailing political context and the ongoing Palestinian-Israeli conflict. This project highlights the major factors determining solid waste policy making in a socio-political system in transition. The research investigated technical, economic, and socio-institutional factors that determine biological treatment of waste and it identifies the agencies involved in waste management, but the complexity of the internal and external forces and networks for the different actors and links for decision makers is left for future research.

Paper 5- Bioeconomía y biodiversidad preservada en Centroamérica

Bioeconomía y biodiversidad preservada en Centroamérica.

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(The full paper in Annex 5)

Abstract. The circular economy and the bioeconomy have turned out to be a worldwide alternative to linear production models based on fossil fuels and often non-renewable raw materials. Although in Central America there are initiatives of this type, mainly in the bioenergy sector, the application of these principles should be promoted in broader sectors such as bio-remediation, the manufacture of bio-fertilizers and even higher-value materials such as bio-polymers and bio-cosmetics. In the same way, the preservation of biodiversity must be a common Central American objective, in addition to this, the synergistic effect between the Central American countries must be added, where SICA can play a neutral institutional role, but not a passive one, of coordination and articulation. between countries. Migration towards a bio-based and circular economy with an environmentally sustainable approach is viable in the region considering current technologies and the biodiversity potential of Central America.

Resumen: La economía circular y la bioeconomía han resultado ser una alternativa a nivel mundial a los modelos de producción lineales y basados en combustibles fósiles y materias primas muchas veces no–renovables. Aunque en Centroamérica existen iniciativas de este tipo, principalmente en el sector bioenergético, se debe impulsar la aplicación de estos principios en sectores más amplios como la bio–remediación, la fabricación de bio–fertilizantes e incluso de materiales de más alto valor como bio–polímeros y bio–cosméticos. De igual manera, la preservación de la biodiversidad debe ser un objetivo común centroamericano, aunado a esto, se debe añadir el efecto sinérgico entre los países centroamericanos, en donde el SICA puede jugar un rol institucional neutro, más no pasivo, de coordinación y articulación entre los países. La migración hacia una economía bio–basada y circular con enfoque ambientalmente sostenible es viable en la región considerando las tecnologías actuales y el potencial de biodiversidad de Centroamérica.

The context: an introduction

The Central American region, like the rest of the world, faces serious global challenges. Food safety, energy supply and climate change are among the major retos for nations in the near future [180]. In the same way, there is a real risk of debasing essential raw materials for the industry.
The world reserves known for elements such as zinc, plata, oro, cobre, including the petroleum mix, are in danger of disappearing in the next 50 years if patrons of consumption continue to grow at the current rate [181].
In addition, there is a deep problem in terms of waste, mainly plastic.In 2017, more than 320 million tons of polymers were manufactured all over the world, excluding fibers [182], and it is estimated that for 2050 there will be (in weight) more plastic than fish in the ocean. Therefore, radical changes in the economy are necessary to address these challenges.
With regards to the changes in the economic systems, a restructuring of the mismas societies is necessary. The political and social stability of the nations has proven to be a trigger of economic prosperity. There are examples in which regional integration has served to solve imminent needs.
The name "The European Coal and Steel Community (ECSC)" created in 1951, the basis of the actual European Union, validates the potential for regional integration to safeguard common interests and objectives. "World peace can only be safeguarded by means of creative efforts proportional to the dangers that make it worse"[80,183]. In the Central American region, for one thing, they observe important integrationist hits.
From the calls "Acuerdos de paz Esquipulas I y Esquipulas II", in 1986 and 1987, the creation of the Mercado Común Centroamericano in 1960 hasta conformación del Sistema de Integración Centroamericana (SICA) [184].
In this framework of Central American integration, this document has the objective of providing a holistic vision of the perspectives and opportunities of the Central American region to apply alternative economic models such as the so-called

circular economy and bioeconomy, whose concepts are closely related between themselves. Conceptually, bioeconomy can be understood as the branch of the economy that includes any category of value that uses biomaterials and agricultural, aquatic or forestry fuel products as a starting point [153]. The change from non-renewable resources to biomaterials is an important aspect of innovation in a circular economy agenda, which it seeks to maintain in the market the value of the products and services as much time as possible by minimizing them use of raw materials and the revaluation of generated residues [185].

In the paper, some general proposals will be discussed with some regional elements to optimize and maximize the potential of the region in the application of the circular economy and the bioeconomy, transversely related to the Sustainable Development Goals (SDGs), called Agenda 2030. By decision of the Central American Parliament, the SDGs were incorporated into the strategic agendas of the different countries of the SICA held their approval at the 48th Reunion of the State and Government of the SICA, celebrated in Roatán, Honduras on June 30, 2016 (Sistema Económico Latinoamericano y del Caribe (SELA).

Bioeconomy can be conceived as "the production, use and conservation of biological resources, including knowledge, science, technology and related innovation, to provide information, products, processes and services in all economic sectors, with the aim of advancing to a sustainable economy" [186].

In summary, the bioeconomy is being conceptualized as one of the two pillars of sustainability, joint with the circular economy. The objective is to reduce the needs that can be developed in a productive way to generate new chains of aggregate value, and to promote efficiency in the use of the resources.

The circular economy is seen as an alternative to address the enfoque derrochador of "tomar, hacer, disposer"; and bioeconomy as an alternative to production from fossil materials substituted by biological materials (Aramendis, Rodríguez, & Krieger Merico, 2018). To emphasize the element of circularity in the bioeconomy, the term circular bioeconomy has been identified, which detaches the convergence between the circular economy and the bioeconomy, in relation to the full supply of biomass [187].

At the end of the viability of the circular economy in the most practical spheres, the first stages of the health crisis generated by the call COVID 19 prompted the alleviation of the fragility of many of the world's supply chains, and still not limited to the availability problems of medical teams, which highlighted the deficiency in the management of these areas in the middle of the crisis. Based on this concept, the circular economy offers the potential to rebuild at a lower cost, reduce the probability of future crises and create greater resilience within industry and society, which is more valuable than the current situation.

In terms of bioeconomy design perspectives, some authors estimate that approximately a third of the chemical products and materials that will be produced from biologic sources and advanced biocatalytic processes.

The anticipated inputs, including those of biofuels, would rise to a volume of 300,000 million euros worldwide [188].

However, it is important to mention that the transition to the global bioeconomy is associated with a series of economic, environmental and social benefits, however, the bioeconomy is not sustainable per se. Various environmental and socio-economic concerns could lead to the sustainability of the bioeconomy, such as the increase in competence for the land between food crops and combustible crops, direct and indirect changes in the use of the land, use of marginal lands with negative effects on the biodiversity, emissions of greenhouse effect among others [189]. At the Latin American level in the year 2014, 4.6 Giga tons of CO_2 were registered, of which 50% are associated with agricultural activities and land use. On the other hand, only in Central America between 1990 and 2017 have lost about 20 million hectares de woods due to exchanges in the use of soil [167].

For the reasons mentioned above, the bioeconomy must follow a holistic focus on sustainability based on environmental, economic and social aspects [189]. These are three aspects that give rise to the circular economy and the bioeconomy a conceptual framework to develop strategic strategies focused on fostering sustainable development networks for plants under the name Agenda 2030. These are the creation of alternatives to models based on petroleum, to the development of products, processes and systems replicating what is observed in already existing natural phenomena.

Central America has various structural factors, intrinsic to its eminently agricultural territorial vocation, which can foster an effective application of the pillars of a "greener" economy. These factors include: the high concentration of biodiversity in the territory, the high potential for biomass generation and the disposal of large amounts of biomass waste. This last factor, considered as a problem from the linear point of view of the economy, can be of great importance in the creation of new value chains [186].

In terms of biodiversity, the Mesoamerican area, comprised of southern Mexico, the countries of the Central American isthmus, and the Dominican Republic, is classified as a "hotspot" rich in flora and fauna species. With only 1% of the planet's surface, it houses close to 7% of the world's biological heritage [190]. In addition, the United Nations identifies Europe and Latin America and the Caribbean as the regions with the highest forest cover (25% each). In Central America, this figure is close to 19,499,000 hectares, 38% of its surface [191]. Regarding the availability of the territory, some studies estimate that by 2050, 300 million hectares could be available to develop activities related to the bioeconomy. Likewise, considering that the economies of the countries within the Central American Region are understandably dependent on natural resources [191], there is a potential space for the recovery of biomass residues that could be incorporated into other production processes, for example: rice husk, bovine waste and manure, mucilage, pulp and coffee and cocoa grounds, sugar cane waste, citrus peel, potato waste, pineapple waste, whey among others [192].

On the other hand, there is a significant potential for water resources in all the countries that make up SICA. In measurable terms of water stress (relationship between quantity, quality, and access to water), with the exception of Guatemala and El Salvador, which present "medium-high" and "medium-low" stress levels, respectively, the rest of the countries of the bloc enjoy levels of water stress considered "low", indicating on average good "water health" [167].

Additionally, a social opportunity factor to consider is the native indigenous population present in the Central American Region, which amounts, according to various studies, to almost 8 million people, which can contribute, through its historical wealth, to understand the potential of existing crops in the region and its potential use in the bioeconomy value chains [193].

Within the bioeconomy, the structures for transforming raw materials into higher-ranking products in value chains are known as biorefineries. The main process around biorefineries is the so-called biotransformation, which, when integrated with biomass pretreatment processes (bio-inputs), allows obtaining biogenic chemical products, such as biopolymers or biocosmetics with high added value on the market [194].

Regarding public policies of an environmental nature, in general terms, these can be classified as explicit or implicit policies; the former are those that have declared environmental objectives, while the latter are those that have undeclared environmental consequences, generally negative and that are very often fostered by the lack of necessary attributions on the part of the environmental authorities to influence the big infrastructure projects [167].

Within SICA, there are integrated policies explicitly related to the bioeconomy, including the "Agricultural Policy of the SICA region 2019-2030"[195], which directly indicates the term bioeconomy among its 5 action programs [192]. Similarly, a "Central American Sustainable Energy Strategy 2020"[196] is observed, which clearly alludes to the promotion of biofuels and renewable energy from biomass, the latter responsible for covering about 38% of the total energy demand in Central America.

On the other hand, although there is a "Fishing and Aquaculture Integration Policy 2015-2015 [197]" where good practices for fishing and aquaculture are encouraged, there is no explicit indication of the use of marine resources directly linked to the bioeconomy.

Other relevant policies observed around the bioeconomy are evident in Nicaragua and Costa Rica. In the case of Nicaragua, the creation of a National Biotechnology Plan [198] is observed, with a public-private partnership.

In the case of Costa Rica, it is evident with more clarity and relevance, with an ad hoc bioeconomy strategy since August 2020 [199]. It can be observed that, although there are triggering elements, the state of public policies in terms of circular economy, biotechnology and bioeconomy are still incipient [200]. In particular, limitations are observed in the absence of harmonization in the classification criteria for new products related to the bioeconomy, including by-products that, due to their lack of analytical classification, cannot be used in a timely manner as inputs for recovery and recovery processes.

In terms of access to information and financing of the circular bioeconomy, various initiatives at different scales are dedicated to this end. Spaces such as the Global Forum for Food and Agriculture and the Global Bioeconomy Summit provide a platform that allows obtaining a global vision of the current state of the application of these two approaches [189]. In terms of managing large volumes of data and information (BIG DATA) on productivity indicators in the bioeconomy, platforms such as "databio"[201] can be consulted, which provide geospatial information for monitor and promote bioeconomy applications. Another access point is the COPERNICUS program, of the European Space Agency, whose work is dedicated to generating high-resolution satellite images in the areas of coverage of the earth's surface (land cover), climate prediction and monitoring of the oceans.

With reference to financing mechanisms and initiatives for the application of the circular economy and bioeconomy, there is a growing trend towards the availability of resources for this purpose. In some sectors, there is a 10-fold increase in the number of private market funds with a focus on the circular economy. Similarly, organizations such as the Economic Commission for Latin America and the Caribbean (ECLAC) have identified and classified these options into 5 categories: national mechanisms, multilateral banks, international organizations, funds and mechanisms for international cooperation for development, bilateral cooperation and financial mechanisms [202]. The main institutions identified as facilitators of financial resources are: World Bank, United Nations Development Program (UNDP), United Nations Industrial Development Organization (UNIDO), Global Environmental Facility–GEF, Green Climate Fund (FVC), Fund for Sustainable Development Goals-SDG Fund among others.

Another good market opportunity to place "bio-based" products is the common market of the European Union (EU), through the established mechanisms of the Association Agreement signed between the Central American countries and the EU.

In conclusion, a real potential is observed in the region, however, the bases must still be consolidated for the migration towards a sustainable circular bioeconomy. Some recommendations divided by sectors: Regional public policies – Harmonization of the system of waste classification. Establish normalization mechanisms through certification of specialized laboratories with analytical capacity for the precise classification of materials with potential uses in the circular bioeconomy (genetic material, biomass residues, etc.). Professional training strategies - Summary of regional experiences. Establish highly trained regional mechanisms to facilitate access, use and application of data from platforms such as the Copernicus program of the European Space Agency. Financial access strategy - Synthesize dispersed information on financing initiatives. Prepare a database of projects already financed and executed.

Paper in progress- Biocapacity and governance between the European Union and Central America

(paper in progress under review)

Biocapacity and governance between the European Union and Central America

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Environmental Research Journal

Abstract. The European Union's position in the world economy represents 15,6% of the global export and imports, being the largest economy worldwide. Its ecological footprint has exceeded the environmental boundaries though, becoming a net importer of biocapacity. 42% of the European water footprint and 31% of the European greenhouse gases (GHG) emissions are located outside the EU borders. A review of the environmental impacts associated with the livestock trade sector was analyzed in both, the European Union and the Central America Region, making use of environmental tools and measures available in both regions to achieve the Agenda 2030 goals. And a special focus of the Agenda 2030 is covered by international partnership and cross – countries relationships (Sustainable Development Goal number 17). The current worldwide economy is forced to be agreement, deal and accord based. These alliances commonly include the participation of very distant regions and economics blocks. It was found that the association agreements between the two regions - considered a sustainable pillar - can be a platform to replicate the functional instruments of environmental regulation and promotion to achieve sustainability through governance in the Central America region.

Resumen. La posición de la Unión Europea (UE) en la economía mundial representa el 15,6% de las exportaciones e importaciones globales, siendo la economía más grande del mundo. Sin embargo, su huella ecológica ha superado los límites ambientales, convirtiéndose en un importador neto de biocapacidad. El 42 % de la huella hídrica europea y el 31 % de las emisiones europeas de gases de efecto invernadero (GEI) se encuentran fuera de las fronteras de la UE. Se analizaron los impactos ambientales asociados al sector comercial ganadero tanto en la UE como en Centroamérica, haciendo uso de herramientas y medidas ambientales disponibles en ambas regiones para alcanzar las metas de la Agenda 2030, siendo una de ellas la asociación internacional y las relaciones entre países (Objetivo de Desarrollo Sostenible número 17). La economía mundial actual se ve obligada a basarse en acuerdos, tratos y acuerdos. Estas alianzas comúnmente incluyen la participación de regiones y bloques económicos muy distantes. Se encontró que los acuerdos de asociación entre las dos regiones -considerados un pilar sostenible- pueden ser una plataforma para replicar los instrumentos funcionales de regulación y promoción ambiental para lograr la sostenibilidad a través de la gobernanza en la región centroamericana.

The context. Introduction

The appearance of new instruments at the service of the recently called "sustainable development policies" has increased considerably in the last 30 years, especially since the Stockholm Conference in 1972 and the contextual creation of the United Nation Environment Program (UNEP) in all areas (international, national, regional and local). These instruments seek to respond to the three dimensions of the theoretical framework of sustainable development: 1) environmental; 2) social; 3) economic, integrating, therefore, environmental, social, economic, human, technological, political and cultural aspects. Together with the implementation of the ambitious 17 SDGs of the Agenda 2030 adopted by all UN Member States in 2015, it is essential the presence of different legal instruments that allow walking as close as possible towards sustainability.

A special focus is covered by international partnership and cross – countries relationships (SDG17). The current worldwide economy is forced to be agreement, deal and accord based. These alliances commonly include the participation of very distant regions and economics blocks. This linkage has allowed to obtain cheaper commodities, enlarge the participation of different economic actors and increased the efficiency in how the resources are allocated. However, the expansion of international trade can also have negative effects on the environment. In fact, "international trade is much more than the exchange of goods between one country and another; it is an intricate network that cannot be rent without loss" [203].

The main reasons for the environmental "price" of international trades in that "commodities" are produced and harvested in areas where the economic profit can be easily achieved, but the environmental aspects of production are normally ignored. The economic growth normally overpowers the protection and conservation of water, soil and biodiversity (European Commission, 2013).

In terms of global commerce of commodities, the position of European Union (EU) (EU-27) represents the 15, 6% of the global imports and exports through different alliances and commercials agreements worldwide..

A first approximation of the associated "environmental costs" of the EU position in the world's economy can be measured by the so-called "ecological footprint", performed as a tool to ascertain the surplus or deficit of the environmental impacts related to the biocapacity of a specific country or region. The EU's environmental footprint is considerably larger than the global average and it is unsustainable when compared with indicative targets that aim to ensure that planetary limits are respected. The EU is also more heavily dependent upon embodied imports of environmental resources than any other region in the world [204].

Within the ecological footprint, a main topic is the displacement effects of trade. For example, the 42% of the water footprint and the 31% of the green houses gases emissions (GHG) caused by consumption within the EU actually occurred in countries outside the EU.

At domestic level, the EU has established different instruments to achieve the goals listed on the 2030 Agenda. These instruments include the definition of an Efficiency Roadmap, the accomplishment of the European Green Deal [106], the application of the Green Public Procurement and the Production Action Plan [108] that includes the application of circular economy and bioeconomy principles. Related to all of the above, agriculturally speaking, it is necessary to introduce one of the most important policies in the EU: The Common Agricultural Policy (CAP). It was created in 1962 and mainly represents the link between agricultural and livestock activities and society. As its name suggests, the CAP is a common policy for all EU countries and its management and financing depend on the EU budgets. Some of the main environmental objectives of CAP are "help tackle climate change and the sustainable management of natural resources" and "maintain rural areas and landscapes across the EU".

At global level, instead, EU adopted in 2010 the Communication on Trade, Growth, and World affairs that stresses that the EU trade policy should continue to support green growth and climate change objectives and to support and promote different areas worldwide e.g., energy, resource efficiency and biodiversity protection. Maybe, therefore, the economic aspects and environmental sustainability considered as a key tool for an effective European governance?

The paper provides a review of the agricultural context both in the EU and in Central America (CA), converging on a common space within the framework of the current Association Agreement. Its purpose is to analyze the potential replication of the environmental instruments applied in Europe in the context of the Association Agreement between the European Union and the member states of the Integration System (SICA) that entered in force in 2003. The scope of the analysis is to focus on the environmental impact of livestock industries in CA.

Conclusions and Future Lines of Research

The exponential increase of the population together with uncontrolled global consumption and depletion of natural resources, inflicts huge stress upon the Earth and severe impact on the environment. Unfortunately, the world has only a limited number of resources, minerals, metals, biotic and abiotic, and the current demand for them exceeds what is available from the Earth. Undoubtedly, a significant shift in human behavior is required to protect and sustain the environment. Resources do not regenerate at a rate that allows for their recreation in the period required to reach an equilibrium between supply and demand. The current system produces imbalances, which hinder economic growth and have negative effects on society and the environment.

The circular economy and circular bioeconomy can contribute to worldwide sustainability, suggesting a new paradigm, based on renewable and reproductive resources, biodiversity, natural ecosystems and biocapacity, recycling, and valorizing waste.

In this issue a research activity has been carried on starting from a general perspective of the actual ecological crisis and trying to apply the new perspective for a future sustainability.

Circular economy has been considered in particular in the buildings and construction, that actually represents one of the most impacting sectors in terms of resources depletion, greenhouse gas emissions, waste production.

About this subject the research is in progress mainly oriented to develop and apply instruments for sustainability assessment, i.e., economic, environmental and social impact assessment, by a life cycle thinking perspective.

The bioeconomy can contribute to a more sustainable future but it is not sustainable per se. Various environmental and socio-economic concerns could lead to the sustainability of the bioeconomy, such as the increase in competence for the land between food crops and combustible crops, direct and indirect changes in the use of the land, use of marginal lands with negative effects on the biodiversity, emissions of greenhouse effect, agriculture and livestock, organic waste management. In that way a circularity approach is mandatory.

The circular bioeconomy was declined in a comparison study between Europe and Central America, because of the huge engagement of Europe towards bio-based economy strategies with a robust environmentally sustainable approach, and the biodiversity potential and biocapacity of Central America.

In this context, new research initiatives are ongoing to examine how circular bioeconomy can support the ecological transition, in a wide perspective involving both natural systems and anthropic activities. The SDGs and sustainability can be implemented along with various international instruments, partnerships, and cross-national linkages. The modern global economy is compelled to be founded on agreements, deals, and accords. This connection would enhance resource availability and allocation, people involvement, the effectiveness of the circular economy model, our planet's preservation, and above all to attempt the the long-awaited sustainability.

Conclusiones y perspectivas futuras de investigación

El aumento exponencial de la población, junto con el consumo mundial incontrolado y el agotamiento de los recursos naturales, inflige un enorme estrés a la Tierra y un fuerte impacto en el ambiente. Desgraciadamente, el mundo sólo dispone de un número limitado de recursos, minerales, metales, bióticos y abióticos, y su actual demanda es mayor que la disponibilidad de la Tierra. Sin lugar a dudas, es necesario acometer un cambio significativo en el comportamiento humano para proteger y sostener el medioambiente. Los recursos no se regeneran a un ritmo que les permite volverse a recrear en el periodo necesario para alcanzar un equilibrio entre oferta y demanda. El sistema actual produce desequilibrios que dificultan el crecimiento económico y tienen efectos negativos en la sociedad y el medioambiente.

La economía circular y la bioeconomía circular pueden contribuir a la sostenibilidad mundial, planteando un nuevo paradigma, basado en los recursos renovables y reproductivos, la biodiversidad, los ecosistemas naturales y la biocapacidad, el reciclaje y la valorización de los residuos.

Sobre este tema se ha llevado a cabo un trabajo de investigación a partir de una perspectiva general de la actual crisis ecológica y tratando de aplicar la nueva perspectiva para favorecer una sostenibilidad futura.

Le economía circular se ha tomado en cuenta en particular en los edificios y la construcción, que en realidad representa uno de los sectores con más impacto en términos de agotamiento de los recursos, las emisiones de gases de efecto invernadero y la producción de residuos.

En relación con esta cuestión, la investigación en curso está orientada principalmente a desarrollar y aplicar herramientas de evaluación de la sostenibilidad, esto es, la evaluación del impacto economico, medioambiental y social, desde la perspectiva del concepto del ciclo de vida.

La bioeconomía puede contribuir a un futuro más sostenible, pero no es sostenible por sí sola. Diversas preocupaciones medioambientales y socioeconómicas podrían llevar a la sostenibilidad de la bioeconomía, como el aumento de la competencia sobre cultivos alimentarios y cultivos sostenibles, los cambios directos e indirectos en el uso de la tierra, el uso de las tierras marginales con efectos negativos en la biodiversidad, las emisiones de efecto invernadero, la agricultura y la ganadería, la gestión de residuos orgánicos. Por eso es necesario adoptar un enfoque circular.

La bioeconomía circular se trató en un estudio comparativo entre Europa y América Central, debido al enorme compromiso de Europa hacia estrategias de bioeconomía con un sólido enfoque sostenible desde el punto de vista ambiental, y al potencial de biodiversidad y biocapacidad de América Central.

En este contexto, se están llevando a cabo nuevas iniciativas de investigación para examinar cómo la bioeconomía circular puede apoyar la transición ecológica, desde una perspectiva amplia que abarque tanto los sistemas naturales como las actividades antrópicas. Los ODS y la sostenibilidad pueden aplicarse junto con diversos instrumentos internacionales, colaboraciones y vínculos transnacionales. La economía global moderna está obligada a basarse en acuerdos, pactos y convenios. Esta conexión propiciaría la disponibilidad y asignación de recursos, la implicación de las personas, la eficacia del modelo de economía circular, la conservación de nuestro planeta y, sobre todo, el intento de alcanzar la la tan ansiada sostenibilidad.

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Annexes

Annex 1

Paper 1

Sustainability in Building and Construction within the Framework of Circular Cities and European New Green Deal. The Contribution of Concrete Recycling

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Review

Sustainability in Building and Construction within the Framework of Circular Cities and European New Green Deal. The Contribution of Concrete Recycling

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Abstract: Climate change and ecological crisis are a huge threat to Europe and the world. To overcome these challenges, Europe adopted the New Green Deal as a strategy transforming the Union into a competitive resource-efficient economy without greenhouse gas emissions and become carbon neutral in a few decades. The European Green Deal includes the new circular economy action plan, highlighting the importance of a products' "green design", saving raw materials, and waste prevention oriented along the entire life cycle of products. Construction and buildings represent one of the key topics for the green transition. In the European Union, buildings are responsible for 40% of our energy consumption and 36% of greenhouse gas emissions, which are mainly caused by construction, usage, renovation, and demolition. Improving environmental efficiency can play a key role in reaching the carbon neutrality of Europe that is expected to be achieved by 2050. In this research, it was explored how Eco-design, as an innovative approach in buildings and construction, Life Cycle Thinking and Life Cycle Assessment, as fundamental supporting tools in sustainability, and finally appropriate and effective Construction and Demolition Waste recycling processes, particularly oriented to concrete recycling according to the case studies analyzed, can promote a circular economy in buildings and construction.

Keywords: eco-design sustainability; LCA; circular economy; Circular Cities; EU Green Deal; CDW; buildings and construction

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1. Introduction

The built environment is commonly recognized as a major contributor to global environmental impacts. Up to 40% of all raw materials extracted from the lithosphere are consumed by this sector, responsible for roughly 50% of global greenhouse emissions [1]. In the European Union, buildings and construction are responsible for a large part of the total energy consumption (about 40%) and of greenhouse emissions (36%) [2], along the entire chain from construction to demolition, passing through utilization and maintenance.

More efficient use of materials, both at the beginning and at the end of their life, would make a major contribution to reducing the environmental impacts of construction. This benefit would be achieved principally by a depletion reduction of finite natural resources and a reduced dependence on landfills.

The construction industry is also one of the world's largest consumers of natural resources, with an annual usage of 50 billion tons of sand and gravel. As the main component of concrete, they are essential for all kinds of construction work, and considering the growing world population and urbanization, their demand will further increase in the following years. The global natural inert materials' usage already has a considerable impact on the environment and human lives. Most of the used sand is mined from fluvial or coastal areas with several severe environmental impacts risk in terms of various rivers or beaches and islands ecosystems preservation, and hydrological balance [3].

The need for more sustainable and improved use of natural resources in this sector has been recognized at the EU level by the Raw Material Initiative [4]. This is reflected in the challenging target that has been set to increase the recovery and recycling of Construction and Demolition Waste (CDW) across Europe.

Approximately 1 billion tonnes of waste, which is around one-third of the total amount generated in EU 27 each year, comes from Construction and Demolition (C and D) activities [5]. However, at present, large quantities of these materials eventually end up in landfills, without any form of recovery or reuse. CDW have to be urgently managed in an appropriate and efficient way. Because of the impacts, not only on environmental but also from economic and social points of view, Buildings and Construction (B and C) represent a hot spot related to all the other sectors [6].

According to the UNEP—UN Environment Programme definition [7], the Green Economy takes into due account all the natural resources from which the human species benefits without any compensation paid. This is a holistic approach, not only an economic one, involving all community activities, particularly addressed in two crucial areas: procurement and sustainable use of natural capital and resources. In this context, a fundamental role is played by government policies on sustainability, first of all, by a decline at a worldwide level put forward by the UN Agenda 2030 in 2015 [8], and four years later, by the EU New Green Deal [9]. This represents an intensive and effective roadmap for making sustainable the EU economy by transforming ecological and climate issues and environmental challenges into opportunities. The European Green Deal refers to construction as one of the key topics for the green transition, contributing in a fundamental way to the carbon neutrality of Europe that has to be achieved by 2050 [10]. As pillar of that process, the new Circular Economy Action Plan was adopted in March 2020, highlighting the importance of a products' "green design" that has to be oriented to a reduction of raw materials consumption and waste prevention along the entire life cycle of products [11]. The main goal was identified in a robust reduction of CDW pursued by waste prevention and improvement in recycling processes allowing a high quality and high efficiency secondary raw materials production. The EU Commission will act in several directions, considering many production fields, with particular attention given to B and C. The European strategy for a Sustainably Built Environment [12] represents in fact a whole and exhaustive plan aiming to guarantee a coherent integration between all the policy strategic areas such as climate change, energy and resource efficiency, CDW management, etc. This strategy will promote circularity principles of construction throughout the lifecycle of buildings starting from an update to the Construction Product Regulation. The strategy includes the possibility to require appropriate recycled content for construction products, at the same conditions of quality and safety, and to adopt a Life Cycle Assessment (LCA) methodology in public procurement. Furthermore, according to Circular Economy (CE) principles, new goals in CDW recovery targets, in part, an energy efficiency implementation that is expected by a lifecycle performance optimization and a longer lifespan of construction heritage.

New EU policies are promoting energy performances in buildings by considering financial leverages, making easier financing access for building assets renovation. In that direction, also the "Clean energy for all Europeans package" [13] promoted a robust revision of the previous energy in buildings directives with the aim to drive the EU clean energy transition. Each country will integrate its national energy and climate plans (NECPs) by adopting an energy strategy in buildings for the period of 2021–2030, including nearly zero-energy buildings, energy performance certificates, and smart technology in new buildings actions, with the aim to reach the 32.5% EU target in energy efficiency by 2030 [14].

The European Green Deal has been recently supported by the new EU Action Plan "Towards a Zero Pollution Ambition for air, water, and soil—building a Healthier Planet for Healthier People" [15], having the purpose of acting on particular climate change and pollution issues promoting prevention, remediation, and monitoring activities.

Finally, the Circular Cities and Regions Initiative (CCRI) [16] represents an innovative focal point of the Circular Economy Action Plan, highlighting the importance of pursuing advanced solutions and actions at the local and regional level. B and C could represent an excellent field of interest for Circular Cities strategies for minimizing environmental and social impacts in compliance with the sustainability principles. They can put into practice more appropriate behavior in consumption and resources supply as well as in waste prevention, recovery, and recycling, contributing to achieving UN Agenda 2030 SDGs 11 ("Make cities and human settlements inclusive, safe, resilient and sustainable") and 12 ("Ensure sustainable consumption and production patterns").

CDW management has outlined over time the strategies through which waste must be treated; these methods are positioned within a hierarchical scale, in relation to the preference given to them from an environmental point of view, that is, from the impact they can determine on the environment. The environmental impact resulting from the use of these strategies is in increasing order, from lowest to highest. The principles underlying the hierarchy are the minimization of resource consumption and the prevention of environmental impact, which represent the two pillars of sustainability in construction [17]. The three strategies, 'Reduce, Reuse, Recycle', are well known in the field of waste management as the 3Rs of the hierarchy of CDW management methods [18], and CE in B and C. The waste reduction strategy offers two major benefits: minimizing the generation of CDW waste and reducing the costs for the transport of waste. The reduction method is considered the most efficient and effective for optimizing CDW management and eliminating many environmental and disposal problems. It must be seriously estimated in the case of refusal from C and D activities it is inevitable and that the 'zero waste' condition is not achievable. It could be, nevertheless, approached by improving the efficiency dematerialization of the processes. Reuse generally means the use of the same component in the construction process more than once. It can be done both considering an 'old life' reuse, with the possibility of using a material or a component for the same previous function (i.e., the wooden formwork), and a 'new life' reuse for a new function (such as the use of concrete fractions or tiles for basic materials for the streets). Reuse requires minimal treatment of the material and in addition to low energy consumption. Recycling is recognized today as the most practicable and preferable CDW management strategy compared to all the others, as well as desirable from an environmental point of view. The goal is to reprocess the waste to obtain secondary raw materials to be used mostly as aggregate for the production of mortar and concrete. This not only fulfills the goal of recycling but also results in economic benefits. The production of secondary raw materials implies a series of well recognized advantages, such as the reduction of demand for new resources and of transport and energy costs, the exploitation of waste that otherwise would be landfilled, and the preservation of land areas and of the general conditions of the environment. Reused and recycled raw materials also represent an added value in terms of sustainability in construction. Appropriate material selection, in fact, plays a crucial role in reducing the embodied energy and other environmental impacts of a building, and it can constitute additional value in also labeling and environmental certification achievement. For instance, the green building rating system LEED (Leadership in Energy and Environmental Design) [19], the building classification method based on energy consumption and ecological footprint evaluation, includes a complete category (Materials and Resource) that aims at selecting materials that are assumed to be "green" including material with recycled content and reused materials. In the effort to quantify the whole impacts of materials arising during each step in the whole supply chain (i.e., manufacturing, transportation, construction, and operation), including end of life management and valorization, several national and international regulation and labeling systems are considering a life cycle thinking approach. It allows a holistic evaluation of all environmental, social and economic impacts deriving from B and C activities. For instance, in Italy, the so called "CAM" (Minimal Environmental

Criteria) plan, related to buildings, introduced by the Environmental Ministry in 2017 [20], and in Spain, the buildings certification system ("Código Técnico de la Edificación" [21], support the Public Sector Contracts and Procurement regulations. Both these two policies assume environmental life cycle assessment (ELCA) and life cycle costs assessment (LCC) as sustainability evaluation and validation methods. Also, the already mentioned LEED, in its last updated edition [22], introduced the use of whole building life cycle assessment (WBLCA) as a compliance option for earning credits. In particular, it was introduced a new credit named "building lifecycle impact reduction", supporting Eco-design by using life cycle assessments in an effort to allow objective comparison of quantified environmental performance for various materials [23].

In order to understand in which way Life Cycle Thinking and Eco-design approaches can be successfully addressed in B and C, a preliminary explorative literature review has been performed.

2. Materials and Methods

The literature review was accomplished by an initial search of more than 250 papers. The research string used included the following terms: Sustainability, Construction, LCA, Life Cycle Thinking, Eco-design, Circular Economy, and CDW (Construction and Demolition Waste).

The initial set of results included 130 papers. Screening was performed based on more effective keywords each other related, resulting in 73 papers. The final selection was carried out by reading all the abstracts and excluding 57 papers not fitting with the main topics.

Therefore, the final set of articles included 73 papers, 57 published in peer-reviewed Journals, six book chapters, and 10 conference papers.

The literature available testifies and interest toward these topics increasing sensibly over the last twenty years, with more than 53% of the papers published since 2017 (Figure 1).

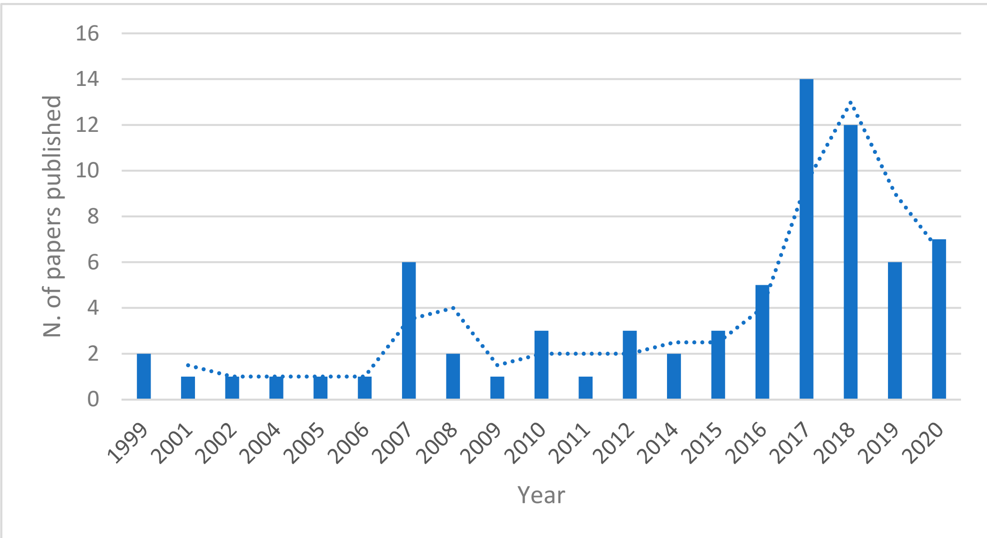

Figure 1. Number of paper published over the years.

These articles were, then, clustered based on the topic into nine classes, describing the macro-themes, i.e., Sustainable Development, Circular Economy, Eco-efficiency of product and processes, Performance and material Recycling, or more methodological ones, as techniques for impact assessment, i.e., Carbon Footprint, Life cycle Assessment (LCA), Life Cycle Sustainable Assessment (LCSA), or for sustainable product development, i.e., Eco-Design (Figure 2).

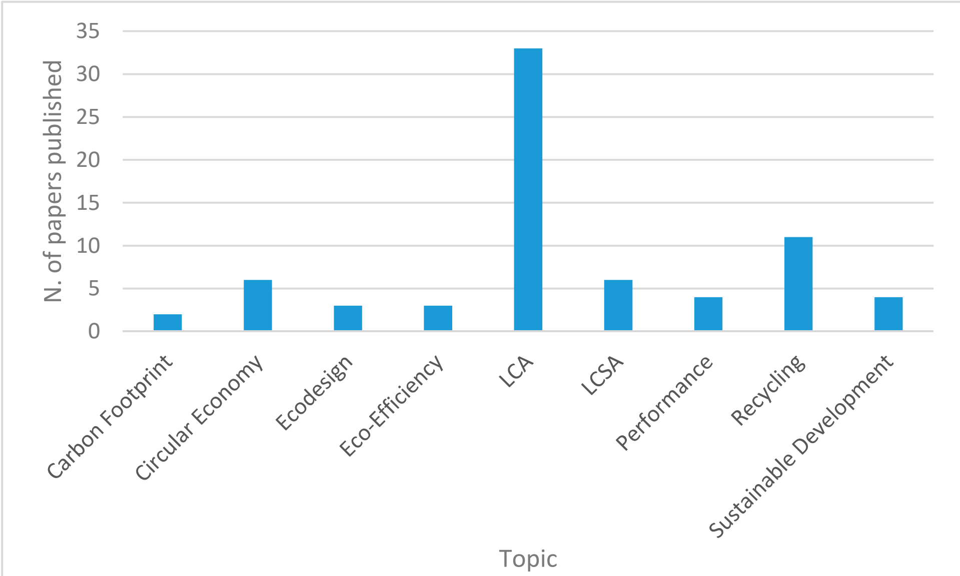

Figure 2. Number of papers published per specific topic. LCA: life cycle assessment; LCSA: life cycle sustainable assessment.

The papers were published in international peer-reviewed Journals constitute quite a recognizable stream of research, hosted on Journals engaged on topics related either to material recycling, such as Resources Conservation and Recycling and Waste Management, or assessment methods, like International Journal of Life Cycle Assessment, or clean production in general, as Journal of Cleaner Production (Figure 3).

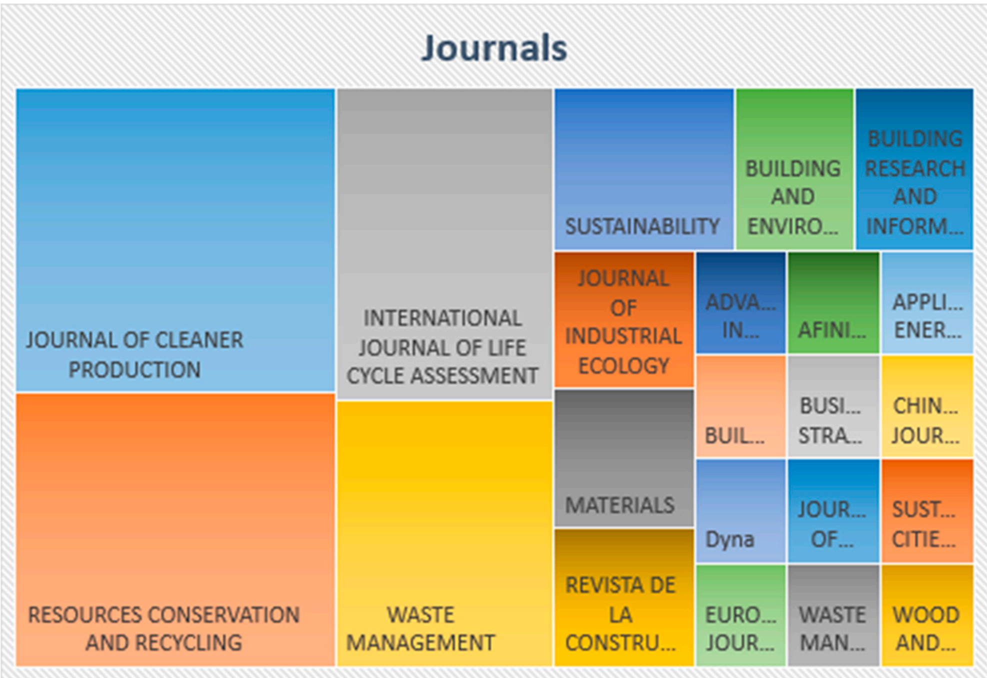

Figure 3. International peer-reviewed journals hosting papers on the topics analyzed.

3. Results and Discussion

The literature review performed highlighted the presence of two pillars underpinning the academic conversation (Figure 4). One is more oriented to the systemic view required for policy formulation, referring to the topics of sustainable development in general, circular economic systems, and recycling as a fundamental approach to waste management. The other tends to ground the researches into a more product-oriented approach, rooted in performance and efficiency evaluations and the application of an advanced tool for the impact assessment of products and processes, as well as the development of Eco-design methodologies and products. This last topic, in particular, configures as the natural bridge between the two frameworks, as it takes advantage of product-oriented tools to develop solutions integrated with more systemic views. In the following, the two frameworks are presented and supported by the analysis of case studies of particular significance.

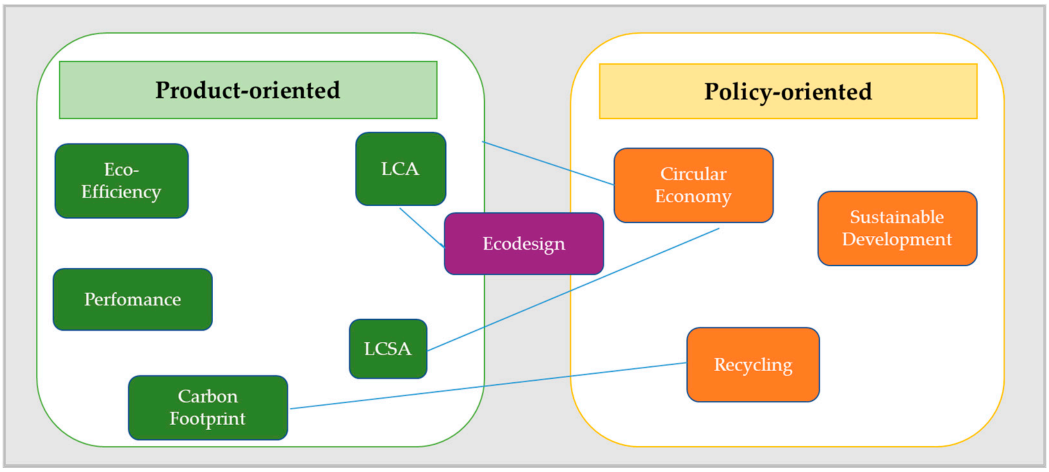

Figure 4. Summary of the frameworks identified within the review.

3.1. *Product-Oriented Framework*

A remarkable stream of research deals with product-oriented approaches, typically promoting the efficiency and performance of products in terms of environmental impacts, and the tools were supporting both assessment and product development, such as Life Cycle Assessment, Sustainability Assessment, and Carbon Footprint.

3.1.1. Life Cycle Thinking, Life Cycle Assessment and Environmental Product Declaration

Over their lifetime, products (goods and services) can contribute to various environmental impacts. Life Cycle Thinking considers the range of impacts throughout the life of a product.

The fundamental aim of Life Cycle Thinking is to reduce overall environmental impacts. This can involve trade-offs between impacts at different stages of the life cycle. However, care needs to be taken to avoid shifting problems from one stage to another. Reducing the environmental impact of a product at the production stage may lead to a greater environmental impact further down the line. An apparent benefit of a waste management option can therefore be canceled out if not thoroughly evaluated.

The European Commission has developed guidelines for LCAs that are fully compatible with international standards. These aim to ensure quality and consistency based on scientific evidence when carrying out assessments. The LCA quantifies environmental impacts by assessing emissions, consumed resources, and pressures on health and the environment.

The assessment of the life cycle of a product or of a process represents a standardized EN ISO methodology [24] that allows to carry out a complete study on the environmental impacts by considering the entire life cycle ('from the cradle to the grave', in the traditional concept of linear products, or "from the cradle to the cradle" in the CE perspective). It includes the extraction and processing of raw materials, the manufacturing phase of the products, transport, and distribution, the use and possible reuse of the product or its parts, collection, storage, recovery, and the end of life management.

LCA represents an excellent tool in the case of several alternatives or solutions comparison [25], being able as well to validate decisions. LCA is able to analyze, quantify and evaluate the causes of the environmental impact determined by a product during its life cycle, and can usefully demonstrate the products and processes sustainability from a quantitative point of view by estimating and weighting each environmental impact categories, such as Climate Change or minerals consumption.

LCA and Environmental Product Declarations (EPD) represent important sources of information in applications in B and C also in the context of Design for Environment [26].

EPDs aim to certify the environmental performance of construction products and services on the basis of consistent, accurate, and certain data and evaluations. In that way, LCA can represent the starting point for a reliable EPD, becoming the most interesting assessment tool of the environmental performance of buildings [27].

As for a product or service, LCA can be applied to buildings, taking into consideration all the phases ranging from the birth of a work to the end of its useful life, in order to calculate the relative costs and environmental impact of these activities.

In particular, it includes the phases of planning, design, construction, management of the asset and its maintenance, redevelopment, or disposal and all these phases have a robust impact on the environment.

The importance of analysis and evaluation that are as accurate as possible in terms of the environmental impact of the building life cycle has to be considered in order to understand the sustainability of the process, optimizing the available resources utilization and end of life management.

Sustainability in buildings and construction, assessed by a whole Life Cycle Assessment, begins with the extraction of natural resources and the production of energy and components; substances and energy belong to the production, transport, and use phases as well as the recovery, reuse, or disposal phase. Using the life cycle approach means balancing and defining positive environmental, economic and social impacts by defining environmental risks and opportunities, thus recognizing the damage or potential environmental risks that occur at each stage [28].

In the same way, it is possible to prevent constructive or inappropriate design choices [29] that mitigate a certain environmental impact from causing other environmental damage, producing a shift in problems from one phase of the life cycle to another or from a type of impact to another.

To date, this methodology has found numerous applications in construction. It has been used as a basic method for establishing standards for awarding eco-labels to building materials or "green buildings" certification and for supporting the definition of methods for the assessment of the ecological compatibility of construction products [30], for developing building materials life cycle database [31].

Numerous tools exist for the assessment of the environmental compatibility of buildings, based on a life cycle approach [32]. The first kind of method works by aggregating the results of LCA studies developed on building materials and components, including the evaluation of the energies, on the basis of a quantitative assessment of the environmental impact by the contributions of the different components of the building materials [33]. Other methods assess qualitatively environmental performances of buildings on the basis of checklists [34] or key performance indicators [35].

3.1.2. Eco-Design in Constructions

The design process is a very important phase for the sustainability of a building by improving environmental, social, and economic sustainability, minimizing environmental impacts by making decisions based on a holistic perspective, mainly if based on a Life Cycle Thinking approach.

According to the Eco-design Working Plan 2016–2019 [36], it is necessary to assume effective quantitative and qualitative criteria to assess material efficiency, to use upcycled materials, and an integrated design. By using this approach, the European Commission is working on the Eco-design toolbox that looks at all the products and materials from the qualitative and quantitative point of view by integrating technical and technological aspects with environmental impacts, such as energy consumption and greenhouse gases emissions. The integration of environmental criteria into design thinking is a new and challenging area, and product Eco-design activities can actually encourage step changes in Small and Medium Enterprises (SMEs) in the construction and building sector [37].

According to the common definitions, Eco-design, ecological design, or sustainable design is the incorporation of environmental aspects into the design and into product development [38] in order to avoid negative environmental impacts throughout its useful life. Appropriate tools are necessary to perform at best an Eco-design process, also by considering a strict connection with technical and economic issues and business strategy [39].

Eco-design can offer different benefits and opportunities also to B and C companies, not only environmentally but also from the economic and social point of views. The environmental performance can be improved by optimizing inputs and outputs of the construction process, reducing resource consumption (energy, raw materials, and water), emissions and waste, and increasing the efficiency of the system [39]. An effective Eco-design implementation firstly needs the appropriate tools but also an inclusion inside business models and operation. Many SMEs in the B and C sectors still face difficulties in the effective implementation of these methods because of barriers and challenges associated with Eco-design methods and to their implementation. Several barriers include specific knowledge about tools, awareness of the environmental issues, time-consuming efforts, limited financial and personnel resources [40].

Within the Eco-design approach, the Integrated Product Policy can represent a relevant guiding tool for the B and C sector towards best practices in design, suggesting instruments and solutions useful for the greening of products during their whole life cycle [41].

As the Eco-design is rooted in a more comprehensive view of the product as a system, integrated into a broader value-network, it represents the ideal bridge toward the policy-oriented framework.

3.2. Policy-Oriented Framework

A wider perspective characterizes the policy-oriented framework identified within the body of literature included in the review. This more systemic approach toward the study of sustainable management of CDW encompasses elaborations about their role within the Circular Economy, the recycling options technologically available, and its contribution to the design of new materials, twinning, in this sense, the focus on Eco-design presented above.

Circular Economy, CDW Recycling, and New Materials Design

Circular Economy is proposed as an economic system planned to reuse materials in subsequent production cycles, extending their useful life, with the aim of reducing and, if possible, eliminating any waste. According to a circularity approach, materials, resources, goods, and products have to be maintained in the economic system for as long as possible, and the production of waste is minimized, with consequent important environmental and economic advantages [42].

Western societies have increasingly encouraged the use of natural resources for the production of a considerable amount of goods and products, often with a limited lifetime duration. This means a resource is consumed faster than the natural systems regeneration capability, and, at the same time, production of waste higher than the absorption and transformation capacity of the environment. These phenomena have also affected the construction industry. Today we can say that this approach is no longer sustainable. Indeed, the demand for aggregates has generated high impacts on the territory and the significant amount of CDW that have to be properly managed, avoiding landfilling or, as a worst-case scenario, illegal dumping.

The C and D industry is responsible for about 50% of the non-renewable raw materials consumption and 40% of the total amount of solid waste production [18]. CDW has to be considered as a severe priority in waste management and recycling by European Union.

Thanks to an effective CE perspective that has to be entirely reached and applied, CDW recycling and reuse have to be implemented because also the high value and quality, and the good performance of the related secondary raw materials also by incorporating the CDW into fresh-made concrete and other construction elements.

CDW is one of the heaviest and most voluminous waste streams generated worldwide. Huge amounts of wastes, with the higher percentage still landfilled, are produced in quarries and processing plants (700 million tons every year in Europe), as well as in construction and demolition stages (870 million tons per year in Europe representing 40% of special wastes) (Figure 5) [43]. CDW consists of different materials, including concrete, bricks, gypsum, wood, glass, metals, plastic, asbestos, many of which can be recycled and can substitute natural aggregates for new constructions. The idea to improve and enlarge recycled materials coming from CDW is related to the CE perspective applied to the B and C field.

Figure 5. Examples of construction and demolition waste (CDW) management. On the left, unsorted cumulus of materials from emergency management in the event of the Emilia earthquake (2012; on the right, a mobile CDW treatment plant.

Some examples demonstrate the possibility of recovery and reuse of materials derived from the demolition of existing structures. For instance, the materials for the new Juventus Stadium construction in Turin have been recovered from the demolition of the old "Delle Alpi" Stadium, by using 40,000 m^3 of concrete, reused for the structural embankment of the new plant, and 5000 t of recycled steel, 2000 m^2 of recycled glass and 300 t of recycled aluminum. It means notable environmental and economic advantages: a reduction in waste production and in new raw materials supply, and in addition remarkable economic savings that were estimated at around 2 million euros [44].

According to several studies, it can be seen that recycled aggregates can be used for different construction purposes. CDW aggregates can be used for producing low environmental impact masonry mortars [45] or low-cost bricks [46], satisfying the international standards and providing better performances such as thermal conductivity than normal earth bricks [47]. CDW aggregates are excellent for asphalt mixture, meeting the standards of mix design criteria for heavy traffic (Figure 6). Furthermore, with a usage of a mixture with an appropriate percentage in recycled aggregates, a reduction of the thickness of the asphalt layer can be obtained, resulting in both a reduction of environmental impact and of the total costs of the road construction [48].

An interesting study shows the possibility to consider an appropriate mixture, combining fine recycled aggregates (30%) and coarse natural aggregates for paving [49]. A similar analysis [50] demonstrates the feasibility of incorporating a fine fraction of aggregates from CDW in the manufacture of cement-based masonry mortars based on recycled concrete, mixed and ceramic aggregates.

Figure 6. Examples of properly managed CDW materials, deriving from selective demolitions (from the left: concrete structural elements, mixed materials from water systems, and finally, ready-to-use ground asphalt from road pavement demolition).

The use of recycled CDW aggregates is worldwide recognized as appropriate to create asphalt mixes for the construction of urban asphalt roads and paving of urban roads [51–54].

With respect to the utilization of CDW in concrete, it is possible to recognize that the use of the fine part of crushed concrete into new mixtures of concrete present similar compressive strength to a reference concrete when the mixtures are composed of up to 30% of CDW aggregates [55]. CDW can be used for the production of building materials, replacing the natural aggregate for the production of bricks. The high performance and properties low-cost bricks can be produced by using CDW as aggregate and lime or cement as additives, as shown in a case study in Brazil [56].

Geopolymers containing concrete aggregates and fired clay from CDW showed promising properties for use in building elements even with the 50% of aggregates and more [57].

Some authors [58–61] conducted studies on recycled aggregates for the production of new concrete by analyzing and comparing standards and guidelines of various countries around the world. That approach is almost interesting in order to determine the quality criteria for the physical and mechanical properties of concrete, highlighting the feasibility and appropriateness of using recycled aggregates and in an environmental assessment perspective.

Several studies have executed on CDW management, recovery, and recycling, paying particular attention to the production of recycled aggregates, their properties, and possible utilization in a wide range of building applications by using a CE perspective [62].

Several kinds of industrial scraps and by-products are actually used as aggregate in construction to produce new concrete, at different content value, in relation to the expected properties, such as waste foundry sand [63] or fly ashes [64]. Recycled aggregates are also applied in new digital construction like 3D printing with excellent performances also in terms of reduced environmental impact and costs [65]. Besides inert material, also other CDW, such as plastics and glass, which are actually very often landfilled, can be recycled for different applications to produce aggregate and concrete [66]. With a global production of more than 5.3 billion cubic meters per year, there may be a huge potential for using recycled plastics in concrete [67]. Consequently, the significant use of waste plastics as aggregate in construction can contribute to a rise in the recycled plastic waste rate. The utilization of this type of waste in concrete can have a positive effect on the properties of the material and definitively beneficial from an environmental point of view.

It is clear that more research is required on influencing factors such as the treated plastic aggregates, shape and size aggregates, favorable mix compositions of concrete, curing conditions to grow confidence in the use of plastic aggregates in concrete.

In the same way, a life cycle analysis can quantify the environmental impacts assessing how the demolition and subsequent recycling and reuse operations can bring clear environmental benefits. Considering the potential environmental impacts related to the end of life of residential buildings, it is possible to highlight how the choice of an adequate selective demolition technique can increase the quantity and quality of recyclable materials with excellent effects in terms of environmental sustainability. An interesting study performed in a building demolition case [68] shown environmental advantages related to selective demolition by applying an attributional life cycle assessment able to highlight and quantify the contributions of each end-of-life phase (i.e., separation and collection of main components, sorting, and recycling of the waste, etc.). Steel components recycling results of the primary importance, accounting for 65% of the total avoided impacts related to respiratory inorganics, 89% of those for global warming, and 73% of those for natural resources depletion.

Several studies identify environmental performances by using LCA and specific properties and appropriate behavior in some local contexts around the world, demonstrating the favorable impact derived from CDW recycling.

The life cycle assessment methodology can be applied to compare the environmental performance, in a specific context, such as in a northern Italy region, of the CDW management by identifying critical aspects and possible improvement actions [69]. LCA and LCC can also be really useful to evaluate the economic and environmental implications of both conventional demolition and selective demolition. Some scenarios are considered, in a specific case study in Portugal, based on possible different waste management options, encouraging selective demolition over conventional type by demonstrating advantages both by economic and environmental impact assessment [70]. Another example is provided by a case study developed in the area of Bologna, Italy [71], in which the evaluation of different management options for CDW was coupled with the design of concrete mixes, implementing CDW-derived aggregates as a partial replacement for natural aggregates, traditionally cultivated in the area. LCA methodology guided the assessment of the environmental impact of the options designed in comparison with commercial concrete mixes. The model allowed to identify the breakeven point for the compensation of the trade-off between the impact generated by CDW processing and the benefit obtained by the replacement. However, findings suggest that aggregates replacement should be coupled by a parallel replacement in the cement component in order to trigger a substantial decrease of the environmental impact of the newly designed mixes.

A particular recycling process, oriented in wood polymer composite (WPC) production, was able to achieve a robust amount in CDW recovery and recycling in Finland [72]. The environmental impact of WPC production, by using specific fractions of CDW (i.e., wood, plastic, plasterboard, and mineral wool), wa demonstrated to be reduced in comparison with the baseline situation of a common CDW treatment and recycling.

Technological, economic, and environmental aspects are relevant to orient operational CDW management, usefully assessed by life cycle assessment and life cycle cost with the aim to support sustainable policymaking.

A rigorous study [73] presents integrated LCA and LCC analysis in four alternative scenarios (i.e, landfilling, downcycling, advanced recycling, and recycling after selective demolition) for CDW end-of-life in the Belgian region of Flanders. Recycling and selective demolition present environmental impact reductions of 36% and 59%, respectively, compared to landfilling. Avoided landfilling and substitution of natural resources is the main environmental benefit of CDW recycling, while, in the case of selective demolition, the most significant advantage comes from the recovery of metals and wood during dismantling. Economically, landfilling is the worse alternative with a total cost of 79 M€/y, followed by selective demolition (47.8 M€), recycling (27.9 M€), and downcycling (27.8 M€).

In the same way, an evaluation of appropriate CDW management can be considered by comparing the two common end of life possibilities, recycling or disposal, by quantifying both the eco-efficiency [74] or the ecological footprint [75] or the economic impact and the total indirect costs. CDW landfilling represents an economic and environmental impact, producing an effect on human health-related and consisting of ineffective mitigation costs, while recycling means a saving of total external cost [76].

Finally, the implementation of best practices for CDW management across the entire construction value chain could drastically improve resource efficiency and reduce environmental impact by reducing waste generation, minimizing transport impacts, maximizing reuse and recycling by improving the quality of secondary materials, and optimizing the environmental performance of treatment methods [77].

4. Conclusions

According to the literature, the attention to B and C sustainability is definitively growing. This sector represents one of the most natural resources (raw materials and energy) demanding and contributes to a huge amount of greenhouse gas emissions and solid waste production. For these reasons, the European Commission has been developing a long-term strategy to tackle the issues. All last policies and action plans, such as the New Green Deal, the Circular Economy Action Plan, and the Circular Cities and Regions Initiative, just to mention the most important, are rowing in the same direction. A coherent and integrated is required to achieve ambitious goals in a few decades, by 2050: European carbon neutrality, zero pollution, low resource consumption, zero energy buildings, whole and perfect circularity, zero-waste, and orientation to prevention.

All European countries also have to implement these processes at a national level by active and effective actions to promote sustainability in B and C.

Nowadays, a more effective CE approach is mandatory, allowing waste to be reprocessed or remanufactured, prolonging the life cycle of the material, and therefore, alleviating the rising amount of CDW disposed of. Recycling and closing the material loop are efficient strategies for reducing the environmental impacts of the building industry. Further research has to be encouraged to promote innovative methods for high-value advanced recycle, to obtain high quality secondary raw materials. To boost the opportunities in this sense, it is crucial to demonstrate both environmental and economic advantages derived from appropriate life cycle thinking and Eco-design approaches. In fact, an effective recycling process starts from the design phase of the material, when the real impact of sustainability-oriented solutions can be triggered, and the quality and quantity of recycled materials depends on proper end of life planning and management. LCA can demonstrate environmental advantages and compare different solutions in terms of materials, components, or processes, while, for example, Life Cycle Costing (LCC) can act on the economic aspects. The Environmental Product Declaration, based on an LCA and applied in B and C, could represent an effective and standardized way of quantifying and communicate the environmental impacts in future buildings. For these reasons, the enhancement of assessment tools, in terms of both reliability and widespread application is strategic, especially when applied with a systemic view.

Green Public Procurement or the Integrated Product Policy can represent effective tools Eco-design oriented supporting B and C sector, designers and policymakers towards sustainability path. Several authors highlight al-so the importance of standardization of the processes and of the methodologies to develop a design or an environmental assessment, to apply universally recognized measure units, and to account for impacts. Also, in that issue, European action plans and guidelines can provide an effective contribution.

According to several pieces of research, it can be demonstrated that recycled CDW has good physical and technical properties, effective performance and can be appropriately used as a substitution of natural aggregates and inert materials. In the same way, the importance of utilizing recycled CDW, both in terms of environmental sustainability and economic advantages, has been proved. Quality control and certification are essential to prompt and sustain stakeholder's confidence in the recycled material. When properly processed and categorized, in fact, it may be considered as excellent secondary raw material, fitting for several uses in construction activities, and this has to be supported by greater governmental intervention in the form of legislations and standardizations.

There is still strong resistance by some practitioners to the use of secondary raw materials despite numerous studies, such as those analyzed in this paper; however, if mainly oriented in concrete recycling and consolidated worldwide practices, research has demonstrated the high quality of some recycled materials and their suitability for different applications.

However, the existing Eco-design research can provide a greater understanding of the barriers and opportunities facing designers and companies wishing to develop environmentally responsible products. Many companies face difficulties in the effective implementation of these methods because of obstacles and challenges which are associated with Eco-design tools and methods. Practitioners and companies have to be supported by simplifications and, at the same, by an effective recognition of the sustainability approach's complexity and importance.

Finally, construction materials eco-labels and green buildings certification can contribute to support and promote B and C sustainability.

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Annex 2

Paper 2

Applicability of life cycle assessment methodology to conservation works in historical building: The case of cleaning

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Applicability of life cycle assessment methodology to conservation works in historical building: The case of cleaning

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ABSTRACT

The Life Cycle Assessment (LCA) represents a suitable methodology to evaluate quantitatively the environmental impact related to a product or a process and it can be used as a guiding tool to make effective environmental sustainability choices. While the LCA-based methods are more and more diffused in the assessment and selection of materials for new constructions, they are still scarcely applied in the field of conservation and repair of historical buildings, although these buildings, especially in Europe, represent a high percentage of the building stock. In the present paper, the LCA method was applied to the field of the restoration, with particular reference to cleaning technologies and materials, in order to investigate if LCA can be applied in this field. The analysis of results pointed out the different environmental impact of the cleaning methods investigated (ascribed to different impact categories), but also the shortcomings and proxies arising from the lack of specific database. The impact of the waste treatment stage was also analysed, in order to highlight the main impact spots related with the end of life of materials and equipment. Results showed that, for some cleaning methods, the impacts related to manufacturing and disposal are very similar, which emphasizes the importance of performing LCA including the end of life scenarios. Finally, an evaluation of externalities was performed, to provide a monetary value of the environmental damage.

1. Introduction and research aim

"Sustainable cities and communities" is one of the seventeen Sustainable Development Goals that United Nations adopted within the "Agenda 2030 plan of action, in order to promote a global sustainable development by the integration of its three dimensions: environmental, social and economic [1]. Cities play a key role in achieving this goal, also because more than 60% of humanity presently lives in cities and this number is expected to grow, so it is crucial to make them prosperous, safe and inclusive [2]. Furthermore, the cities, especially through their architecture and buildings, maintain the historical and cultural value of society and keep the heritage of the past. As opposed to demolition of existing buildings and construction of new ones, restoration and rehabilitation can represent a viable alternative to reduce the environmental impacts of the building industry. For instance in terms of consumption of raw materials for new constructions and treatment of the waste derived from demolition; moreover, architectural rehabilitation preserves and valorises architectural heritage that otherwise would be irreversibly lost [3]. In addition, the integration of these preservation issues into public policies and strategic plans can transform cultural heritage from a "static object" to be purely safeguarded and preserved into an active driver for the development of sites or clusters [4].

However, it is undeniable that historical buildings are responsible for a high energy consumption during their operational phase, due to low thermal insulation of the envelope, low efficiency of existing Heating, Ventilation and Air Conditioning (HVAC) systems, etc. [5], and they also require maintenance and repair interventions. This impact cannot be neglected, especially in Europe, where historical buildings represent a high percentage of the building stock; a better understanding of this impact is of paramount importance towards the improvement of the overall sustainability of existing buildings.

The evaluation of the environmental impact of conservation practices have been carried out in some literature papers [6], while the assessment of the impact of conservation works carried out in heritage buildings is still quite limited.

A first attempt towards such evaluation was made by the Green Building Council (GBC) Italy, a no profit organization founded in 2008 with the aim of implementing sustainable practices into the Italian building sector. In addition to the promotion of the LEED certification system (where LEED is the acronym of "Leadership

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Abbreviation list

Aq. acid.	Aquatic acidification
Aq. ec.	Aquatic ecotoxicity
Aq. eutr.	Aquatic eutrophication
Carc.	Carcinogens
ELU	Environmental Load Unit
EoL	End of Life
FU	Functional Unit
Glo. war.	Global warming
GWP	Global Warming Potential
Ion. rad.	Ionizing radiation
IPCC	International Panel on Climate Change
Land oc.	Land occupation
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
Min. ext.	Mineral extraction
mPt	milli-Points
Non-carc.	Non carcinogens
Non-ren. en.	Non-renewable energy
Oz. lay. dep.	Ozone layer depletion
Resp. in.	Respiratory inorganics
Resp. or.	Respiratory organics
Terr. a/n	Terrestrial acid/nutri
Terr. ec.	Terrestrial ecotoxicity

in Energy and Environmental Design") and the development of a certification specific for the Italian context, the GBC Italy has established a new rating system for historical buildings, named 'GBC Historic Buildings' [7]. This protocol can be applied to those buildings that were built before 1945, that is considered the beginning of the building industrialization in Europe, or even later for those that exhibit historical or cultural value. It is a voluntary scheme for the evaluation of the sustainability related to significant activities in the field of restoration, rehabilitation and recovery of buildings. It is noteworthy that 'restoration' (or 'conservation') interventions are generally carried in heritage buildings, in compliance to well established conservation principles such as minimum intervention and authenticity, while the terms 'rehabilitation' and 'recovery' are generally used to describe retrofitting and major renovations of historic buildings that are not necessarily heritage buildings.

This 'GBC Historic Buildings' protocol is based on six categories: historic significance, sustainability of the site, water management, energy and atmosphere, materials and resources, indoor quality, design innovation and regional priorities. Each category is divided into different subcategories called "credits", in order to assign them different scores, depending on the environmental impact of the specific activities. The results obtained by adding the scores corresponds to four levels of certification: Base (40–49 points), Silver (50–59 points), Gold (60–79) and Platinum (>80 points) [7], as in the LEED system.

The GBC Historic Building represents an innovative tool that allows to link sustainability issues to cultural and historical aspects of restoration, based on the common goal of promoting and preserving cultural heritage for the future generations. However, this protocol is a qualitative rating system and it does not provide any quantitative information about the environmental impacts associated to the human activities. Conversely, the Life Cycle Assessment (LCA) represents a suitable methodology to evaluate quantitatively the environmental impact related to a product or a process and it can be used as a guiding tool to make effective sustainability choices.

The impact of historic buildings in terms of energy consumption and saving [4] and environmental loads [8–9] and the strategies aimed at reducing such impact [9–10] were investigated in several papers, considering the entire life cycle of buildings from the LCA perspective. Also several studies in building refurbishment [11] and restoration [12], repair mortar and concrete [13–14] and recycled material use [15–16], or generally in sustainable maintenance for heritage buildings [17] have been performed. Approximately in the last two years, a number of papers started to investigate the environmental impact of conservation interventions and materials [18–22], highlighting the great significance of extending the LCA approach also to this field.

However, it should be pointed out that there are many obstacles in applying the LCA methodology in the field of conservation works, which derive from the specificity of the subject of the study. First of all, each restoration operation is completely case-specific and it depends on the physical, chemical and mechanical properties of the substrate, the history of the building, any previous conservation interventions, etc. It may involve the use of a wide variety of materials and technologies and sometimes, due to a lack of specific inventory data on them, it is difficult to precisely represent each particular operation. In addition, it is important to highlight that many restoration activities are craftsmanship activities and therefore there are many variables that are difficult to control, if compared to standard industrial activities.

It is noteworthy that these methodological issues should not represent an obstacle for a correct and wide LCA implementation. On the contrary, they can represent a challenging starting point for the setting up of ad hoc databases in order to make the LCA totally applicable in this sector. The LCA approach in restoration works should be increasingly developed in the future to support design, buildings' environmental certification and all kind of construction-related activities evaluation, such as public procurements.

As a contribution towards the LCA implementation in the conservation field, a first study was carried out by the authors to evaluate the environmental impact of cleaning procedures, which are commonly performed in any repair work and hence represent an important step in the repair process [23]. In the previous analysis, the research was focused on the evaluation of a high number of different cleaning technologies, investigating how the different types materials and equipment that can be used by the professionals (supporting mixtures, solvents, mechanical equipment, hand tools, etc.) contribute to the environmental impact. Starting from that previous analysis, the present work is aimed at investigating the applicability and reliability of the Life Cycle Assessment to the field of the restoration, with particular reference to cleaning. In this paper, only a limited number of cleaning techniques was selected, and the research was focussed on the possible shortcomings and proxies arising from the lack of a specific database, on a sensitivity analysis concerning LCA application and on the influence of the waste treatment stage. Including the waste treatment stage allowed to highlight the main impact spots related with end of life of materials and equipment, and the relative weight of the end of life stage with respect to the manufacturing and operational stages. Furthermore, an evaluation of externalities was performed by using the EPS 2015dx (Environmental Priority Strategies) assessment method, to provide a monetary value of the environmental damage.

2. The methodology applied

2.1. The object of the analysis: cleaning methods selected

In the previous study [23], the most diffused cleaning procedures in current practice of restoration works were identified based on the experience of the authors in this field and on the suggestions of some professionals involved in this study. These procedures were sorted into six groups: water-based methods (1

Table 1
Cleaning methods selected for the analysis.

Cleaning method	Label	Short description
Water-based methods	WATER	Nebula spray with deionised water
Solvent-based methods	SOLVENT-ASOLVENT-B	Acetone (free)Solvent gel (supported)
Poultices	POULTICE	Cellulose + water + EDTA
Ion-exchange resins	RESIN	Ion-exchange resins
Mechanical methods	MECHANICAL	Micro-sandblasting
Laser cleaning	LASER	Laser cleaning

free, with nebula spray, and 3 supported methods), solvent-based methods (4 free, with different solvents, and 2 supported methods), poultices (36 different combinations of poultice materials and active ingredients), ion-exchange resins, mechanical methods (4 methods, with different hand tools or mechanical equipment) and laser cleaning. A total of 52 cleaning methods was analysed. Within each group, no significant differences were found, except for the solvent-based methods [23]. Based on those results, the present study takes into account one type of cleaning method for each group and two for the solvent-based methods, as shown in Table 1. These cleaning methods were used to investigate more in depth the applicability and sensitivity of the LCA analysis.

The cleaning with deionised water consists of a mild wash with droplets (nebula spray) to remove especially gypsum deposits, thanks to the physical action owing to water run-off. Solvents are more appropriate for dissolving dark layers containing organic substances with similar polarity and can be used both free and supported (solvent gel). Regarding the first ones, the liquid solvent is directly applied to the surface by cotton balls, while regarding the second ones, the solvent is jelled and then applied to the surface. Another cleaning technique, frequently used for the removal of crusts and extraction of salts, is poultice, in which an absorbent support (mostly cellulose, but also clay) soaked with water and cleaning agents, is applied and left on the surface to soften and detach the deposits/crusts. Ion-exchange resins are used for the removal of black crust and limescale formations through an ion-exchange mechanism activated by water. Mechanical methods include different techniques based on an abrasive action, ranging from micro- and hydro-sandblasting to scalpel and engraving pen; the effectiveness of these methods strongly depends on the worker's ability. Laser cleaning exploits a laser ray which allows to vaporize black crusts and layers, after a preliminary wetting aimed at increasing their darkness.

2.2. Life cycle assessment

According to the original definition provided by Setac [24] the Life Cycle Assessment of a product can be defined as a methodology to evaluate the environmental burdens by identifying and quantifying energy and materials used and wastes released to the environment, including the entire life cycle of the product. LCA can be conveniently used in several applications in order to identify specific environmental hotspots or to compare different scenarios. All inputs and outputs have to be considered during all the processes' phases. Fig. 1 schematically summarizes the LCA approach.

2.2.1. Goal and scope definition

The main purpose of LCA results is considered since the beginning during definitions of the goal and scope.

The goal of an LCA states the intended application and the reasons for carrying out the study, the intended users and whether the results are to be used for internal purpose or for disclosure to any stakeholders, while the scope includes several items related with the correctness of the study and of all assumed procedures. Allocation method and data requirements and quality apart, the

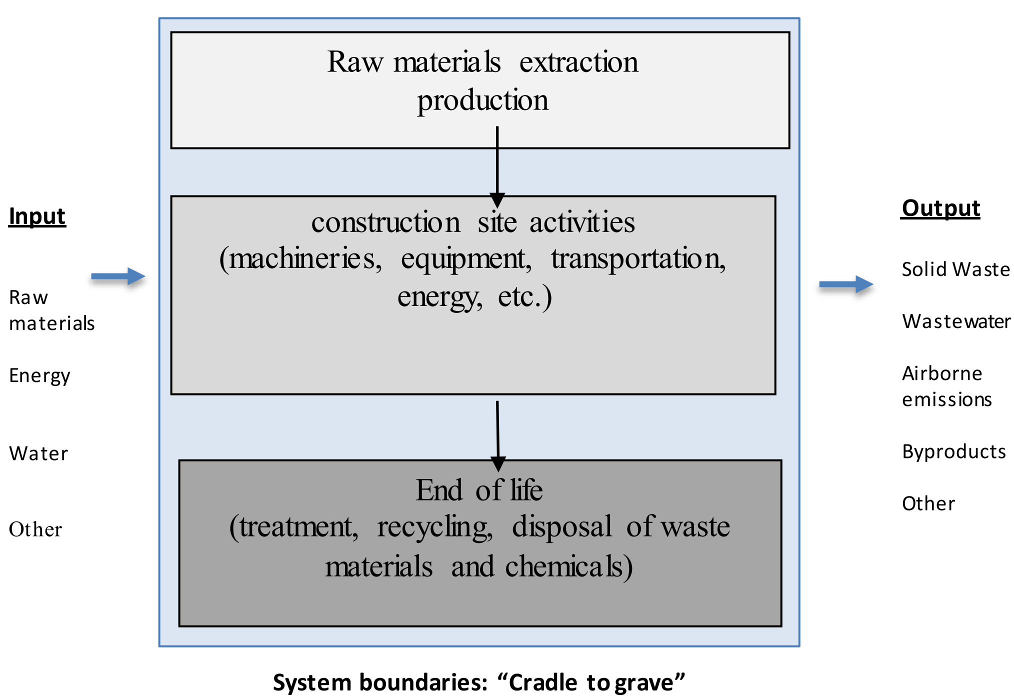


Fig. 1. LCA scheme.

Table 2
Some significant data collected during the inventory analysis.

Cleaning method	Material	Amount [kg]	Machinery	Power [kW]	Time [min]	PPE
WATER	Deionised water	5	Nebula sprayer Compressor Demineralizer	-2,2 0.37	 10 10	Gloves
SOLVENT-A	Acetone Cotton	30.5	–	–		Gloves Glasses Mask
SOLVENT-B	Deionised water	0.15	Demineralizer Blender Brush Sponge	0.37 0.7–	20 10	Gloves Glasses Mask
	Carbopol® Ethomeen® (oxyethylene) Solvent (ethanol) Deionised water (washing)	0.02 0.2 1 25				
POULTICE	Deionised water Cellulose pulp EDTA Deionised water (washing)	7 0.6 0.21 25	Demineralizer Brush Sponge Nylon film	0.37—	40	Gloves Glasses Mask
RESIN	Deionised water Resin Deionised water (washing)	0.5 1.5 20	Demineralizer Brush Sponge	0.37–	60	Gloves Glasses Coverall
MECHANICAL	Sand	5	Micro sandblaster with compressor Extractor fan	2.2 1.29	10 10	Gloves Glasses Mask Earmuffs Coverall
LASER	Deionised water	10	Demineralizer Laser equipment	0.37 3.7	10 180	Gloves Glasses Coverall

main items that have to be defined for a correct LCA are functional unit and system boundary.

The present study is intended to provide an insight on the applicability of the LCA approach to the field of conservation work, with particular refence to cleaning, so the goals are twofold: i) to investigate if the LCA analysis can be applied to the selected materials and technologies and if problems arise in this analysis; ii) to evaluate the reliability of the results obtained and to compare the different cleaning methods selected. Concerning the goal i), the analysis was carried out from the point of view of professionals involved in the conservation process (architects, engineers and conservation companies), so considering the input data that they can have access to in real practice.

2.2.1.1. Functional unit. The functional unit (FU) is a fundamental element for the LCA analysis [25,26]. It defines the quantification of the identified function of the product and represents the reference unit to which all input and output flows are referred to, providing a quantitative description of the performance of the product systems [27]. The definition of the functional unit is a critical point of the study, because the reliability of the comparison between different product or processes strongly depends on its choice. This issue is particularly challenging in the conservation field, due to the considerable difficulty in comparing different cleaning technologies; in fact, there are several variables to take into account, starting from the nature of the deposit that has to be removed, its thickness and hardness, which may require different cleaning durations and/or materials' amounts. Moreover, also the nature of the substrate affected by the deposit (cracked, powdering, etc.) and the possible presence of previous conservation materials (consolidants, protectives, etc.) must be considered in repair works, as well the boundary conditions on site, therefore sometimes a cleaning technology is more appropriate than another one, and the selection of the method is based on this. However, the evaluation of the environmental impact of cleaning requires the definition of a functional unit, so in this study the FU corresponding to the cleaning of one square meter of a plain vertical surface affected by a 'normal black crust' has been selected, based on the experience of a company working in the conservation field since many years [23]. In fact, the same level of cleaning effectiveness shall be provided in order to ensure the comparability of the cleaning methods. This involves different types and amounts of materials, equipment, energy consumption and duration, which are specific of each method and lead to an equal result in term of cleaning.

2.2.1.2. System boundaries. In this study, an approach "from cradle to grave", according with the ISO definitions [25,26] has been assumed. All inputs were considered from raw material extraction to their back to environment as waste or emissions, evaluated in terms of their end of life. In fact, the system boundaries cover the construction site activities with regard to materials, machineries, equipment, all transportation activities to the site and energy consumption. Several assumptions and results of the processes were made, according to the previous study [23]. In particular, in this issue a robust additional analysis has been carried out, including the waste processes, in order to evaluate the incidence of end of life treatment phase. Including the final waste treatment is usually quite challenging in LCA analysis applied to building works, owing to the lack of specific information and the complexity in the collection of data regarding the transport and the disposal scenario of waste materials, packaging and equipment. For this reason, waste treatment is often not included in LCA analysis. In this paper, the LCA analysis was carried out both with and without the end of life stage, to investigate whether it has a significant impact in the results.

2.2.2. Life cycle inventory

In this study, data quality has been considered as a priority, both for primary and secondary data collection. The primary data have been gathered directly from an Italian company operating in the restoration field (Leonardo srl); these data concern the amount of materials used in each cleaning operation, the electricity consumption and the duration of the operations. Secondary data have

Table 3
Waste treatment of materials and chemicals used for the cleaning operations.

Cleaning method	Material	Waste treatment
WATER	Deionised water	Wastewater treatment (95%)
SOLVENT-A	Acetone + cotton	Hazardous waste incineration
SOLVENT-B	Solvent gelDeionised water (final surface washing)	Hazardous waste incinerationWastewater treatment
POULTICE	PoulticeDeionised water (final surface washing)	Hazardous waste incinerationWastewater treatment
RESIN	Resin + deionised waterDeionised water (final surface washing)	Hazardous waste incinerationWastewater treatment
MECHANICAL	Sand	Recycling of inert material

been obtained from the Ecoinvent 3.4 database [28], especially for materials, chemicals and background processes, such as transport, electricity production and waste treatment. When the specific materials and chemicals used in cleaning were not included in the database, similar products were selected and a sensitivity analysis was carried out to evaluate the impact of this change of materials. This evaluation was carried out at the LCIA level, as its purpose was the investigation of the shortcoming arising from the lack of specific database and not the assessment of the cleaning technology having the lowest environmental impact in absolute terms. The GWP was chosen for the sensitivity analysis, because global warming is one of the most critical and challenging environmental problems today, so the evaluation was addressed to understand how the results of the environmental impact change with the method selected and what relevance the various methods give to this category.

A working site located in the city of Bologna was considered in this study. In order to take into account the geographical location, an energy mix referred to the Italian context was selected, while for the other processes a reference European context was considered. The processes related to machineries, tools and personal protective equipment (PPE) used in each activity were modelled *ad hoc*, according to the available technical datasheets of the market products, including also the information about their packaging.

The inventory analysis has been modelled using SimaPro 8.5.2.2 software [29], following the “Allocation at the point of Substitution” (APOS) approach, which is an attributional approach where the burdens are attributed proportionally to the processes [30]. The attributional approach was chosen because it considers all the materials and physical flows related to the life cycle of the specific product or process under study and it provides the environmental impact directly associated with that system in a status quo condition.

Table 2 reports some of the most significant inventory analysis data.

Waste management represents a critical point in the end of life phase. In the previous study [23], this parameter was not considered, while in the present paper two scenarios, with and without waste treatment, were analysed. About the first scenario assumptions, regarding the end of life of tools, machineries and packaging, a complete treatment process has been considered, including the transportation to the recycling plant.

Also the treatment of waste materials and chemicals used for the cleaning operations, was considered, as shown in Table 3. Wastewater apart, further output such as emissions into the atmosphere specifically produced by cleaning operations were not included because they were considered negligible. The wastewater treatments were chosen in agreement with the company operating in the restoration field, that provided also other inventory data, according to their usual disposal practices.

2.2.3. Impact assessment methods

The calculation method IMPACT 2002+ [31] was used to compare the different cleaning methods both in terms of midpoint and endpoint analysis. Both midpoint and endpoint analysis were considered in order to provide a twofold level of interpretation of the results. The endpoint analysis is more understandable and particularly useful for decision-making, due to the fact that it considers the environmental impacts at the end of the cause-effect chain. The midpoint approach has been used too, to give more detailed results with a focus on specific impact categories. Then, a comparison with further three methods, namely CML-IA baseline [32], IPCC GWP 100a [33] and TRACI 2.1 [34], was carried out in terms of the Global Warming impact category. In addition, in order to evaluate the external costs related to the different techniques, a further assessment with EPS 2015dx [35] method was performed.

3. Results and discussion

A critical point in performing Life Cycle Assessments is the availability of precise information and the consistency between inventory data and databases. This fact is relevant especially for those activities that involve specific products and materials, such as in this study. Whereas the LCA provides a representation of reality as detailed as possible, it is still a model and involves simplifications and choices by practitioners. For these reasons, it was necessary to make some approximations, due to a lack of specific data for conservation works within the Ecoinvent database.

In particular, some of the chemicals and materials used in the cleaning procedures were not present, which was critical especially for the supported solvent-based methods. The Carbopol® gelling agent, a polymer obtained from polyacrylic acid, was not present in the database and a generic acrylic acid was selected. Similarly, the Ethomeen® surfactant, a polyethoxilated amine that acts as a neutralizing base for Carbopol, was modelled by using the data available for diethanolamine. Moreover, ethanol was chosen as representative of the solvents used.

Concerning the poultice cleaning, the most critical issue is that cellulose pulp (one of the most used material for poulticing) is not included in the database, thus a comparison was carried out among the cleaning with different types of pulp available in the Ecoinvent database, namely thermomechanical, chemo-thermomechanical, mechanical and sulfate pulps, assuming the same amount of pulp. The results of the sensitivity analysis, carried out with IMPACT 2002+ assessment method and shown in Fig. 2, highlight that there are no significant differences, so the use of different pulps does not affect considerably the outcomes of the cleaning procedure. Consequently, a generic and common thermo-mechanical pulping device was considered in the following analyses.

Concerning the techniques based on resins, both cationic and anionic resins can be used, their effectiveness depending on the specific nature of the black crust to remove. Then, as for the poultices, throughout a sensitivity analysis, a comparison between the cleaning with a cationic and anionic resin has been performed. Fig. 3 shows an increase of about 46% of the damage in terms of score for the anionic resin compared to the cationic one. As anionic resins are more used for the cleaning of black crusts, an anionic resin was considered for the following LCA analysis.

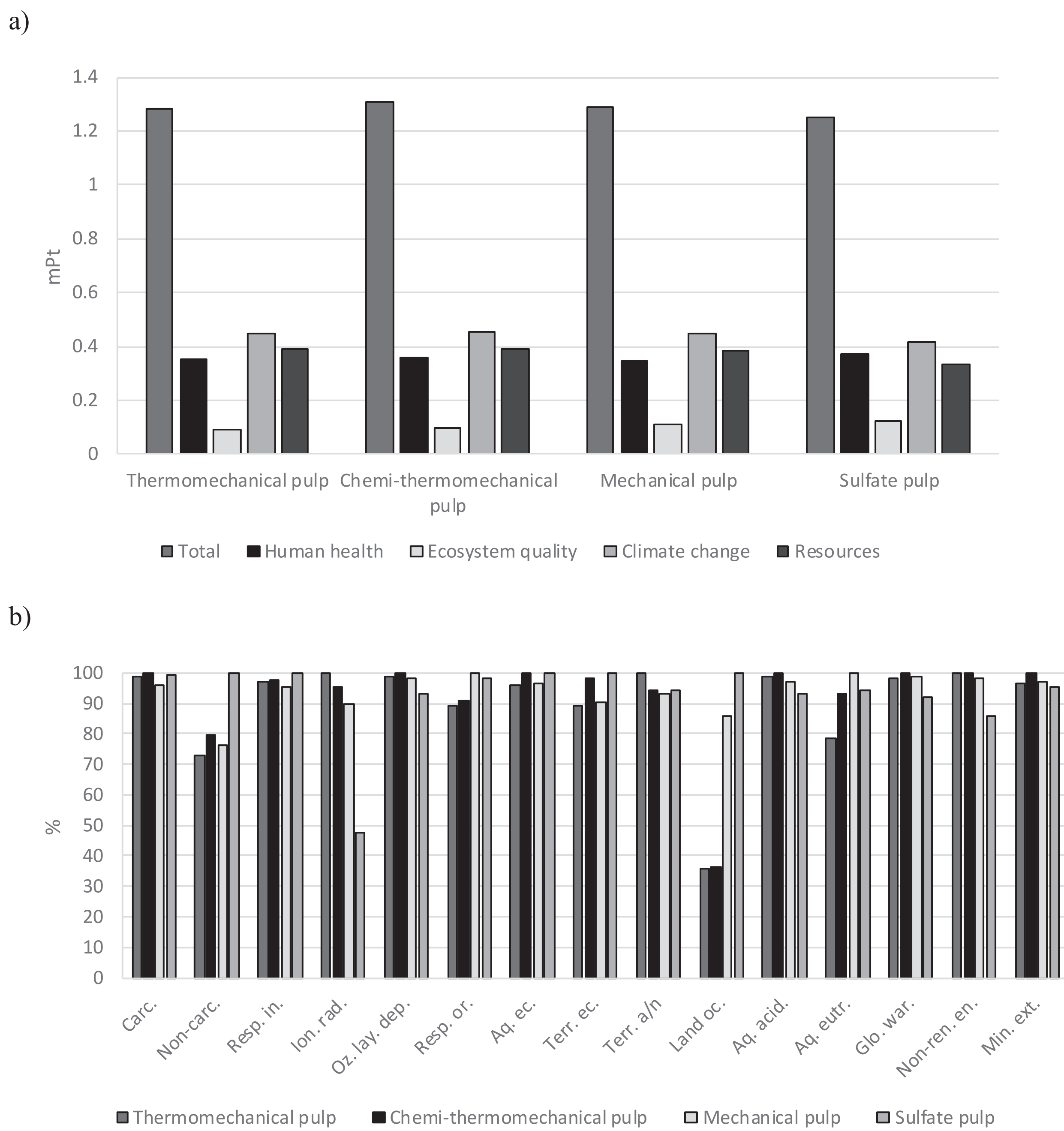


Fig. 2. The results of the comparison between the cleaning of 1 sqm of surface with different type of pulp, with IMPACT 2002+ assessment method in terms of a) damage categories and b) impact categories.

Concerning the tools and machineries used for the activities, the previous study [23] showed that the main impacts are basically due to the energy consumption during the use phase rather than to their manufacturing and transport. Thus it is essential to consider both the technical information provided by the datasheets and the actual duration of the activity, in order to accurately calculate the electricity consumption, especially for energy-intensive technologies.

Taking into account the considerations above reported, the LCA analysis carried out for the 7 selected cleaning methods and the results are reported in Fig. 4, where the most significant results are collected. In particular, the most significant impact categories were considered, i.e., those giving the highest impact as Carcinogens, Ozone Layer Depletion and Global Warming, and the water use (in all the cleaning methods, the end of life – EoL – was included in the analysis). The analysis highlights that for Carcinogens impact category the most harmful method is the free-solvent cleaning (0.408 kg C_2H_3Cl eq), especially due to atmospheric emissions of aromatic hydrocarbons during the production of the acetone. This is followed by the cleaning with resins (0.180 kg C_2H_3Cl eq) and solvent gels (0.160 kg C_2H_3Cl eq), due to atmospheric emissions of aromatic hydrocarbons respectively arising from the production of natural gas used for the production of the methanol present in the anionic resin and from the production of ethylene needed for the ethanol. For Ozone Layer Depletion impact category, the resins show a much higher value (2.577E-4 kg CFC-11 eq) than all other cleaning methods, especially due to atmospheric emissions of tetrachlolomethane from the production of the trichloromethane for the anion resin. The free-solvent methods are responsible for the major impacts in the Global Warming im-

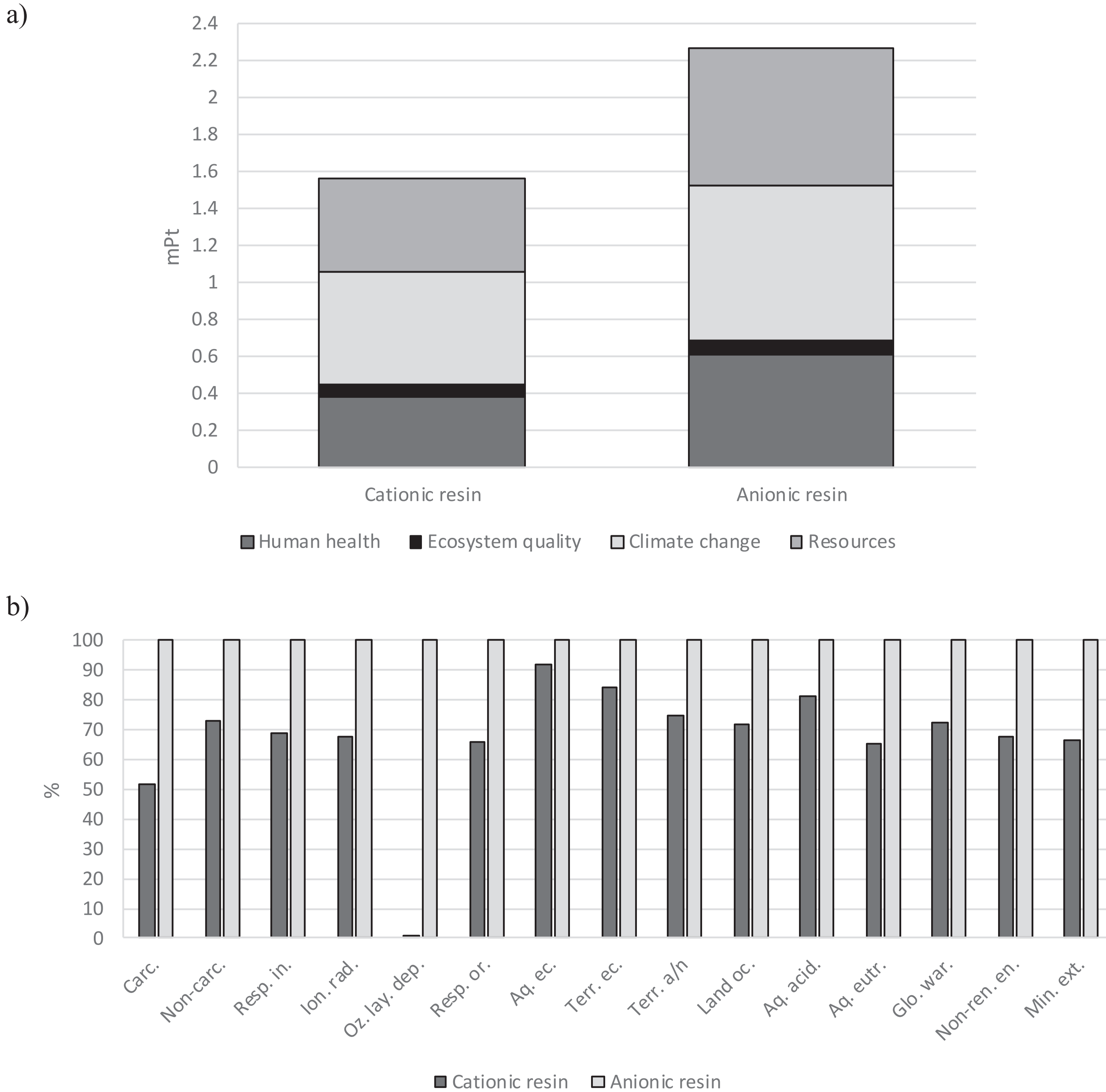


Fig. 3. The results of the comparison between the cleaning of 1 sqm of surface with a cation and anionic resin, with IMPACT 2002+ assessment method in terms of a) damage categories and b) impact categories.

pact category (17.0 kg CO_2 eq), owing to the atmospheric emissions of carbon dioxide from fossil sources during the production of acetone. The resins and laser methods rank second and third (8.4 kg CO_2 eq and 5.4 kg CO_2 eq), due to atmospheric emissions of carbon dioxide from fossil sources respectively arising from the incineration of the resin and from the production of electricity used during the laser cleaning. Regarding the water use, contrary to what can be expected, the cleaning with deionised water exhibits the lowest water consumption (2.6 m^3), while the most water-consuming technique is the laser (63.7 m^3). This is especially due to the fact that this indicator takes into account the water use at each stage of the life cycle and for each type of utilization, for example also for the electricity production needed in this case for the laser operation.

Some further interesting results were found when comparing the same cleaning methods in the two scenarios: with and without waste treatments, as shown in Fig. 5 in terms of Single Score.

As expected, the scenario including the end of life processes involves a higher impact for all the techniques, due to the environmental burdens related to the waste treatment. However, the difference varies depending on the specific cleaning method; the major difference is related to the solvent gels (+62.2%) followed by poultices (+46.7%), resins (+45.4%) and acetone (+44.5%). Lower differences can be noticed in the other techniques (+5.3% for deionised water, +3.5% for micro-sandblasting and basically no difference for laser). The increase of the impact for the first four methods is due to the incineration of hazardous wastes, i.e. the consumables used for the cleaning. In particular, for the cleaning with resins and solvent gels, an in-depth analysis highlighted that the environmental damage related to their production is similar to that of their disposal.

Moreover, as shown in Fig. 5, the impact of the waste treatment affects partially the ranking of the different cleaning methods in terms of impact; free solvent-based methods remain responsible

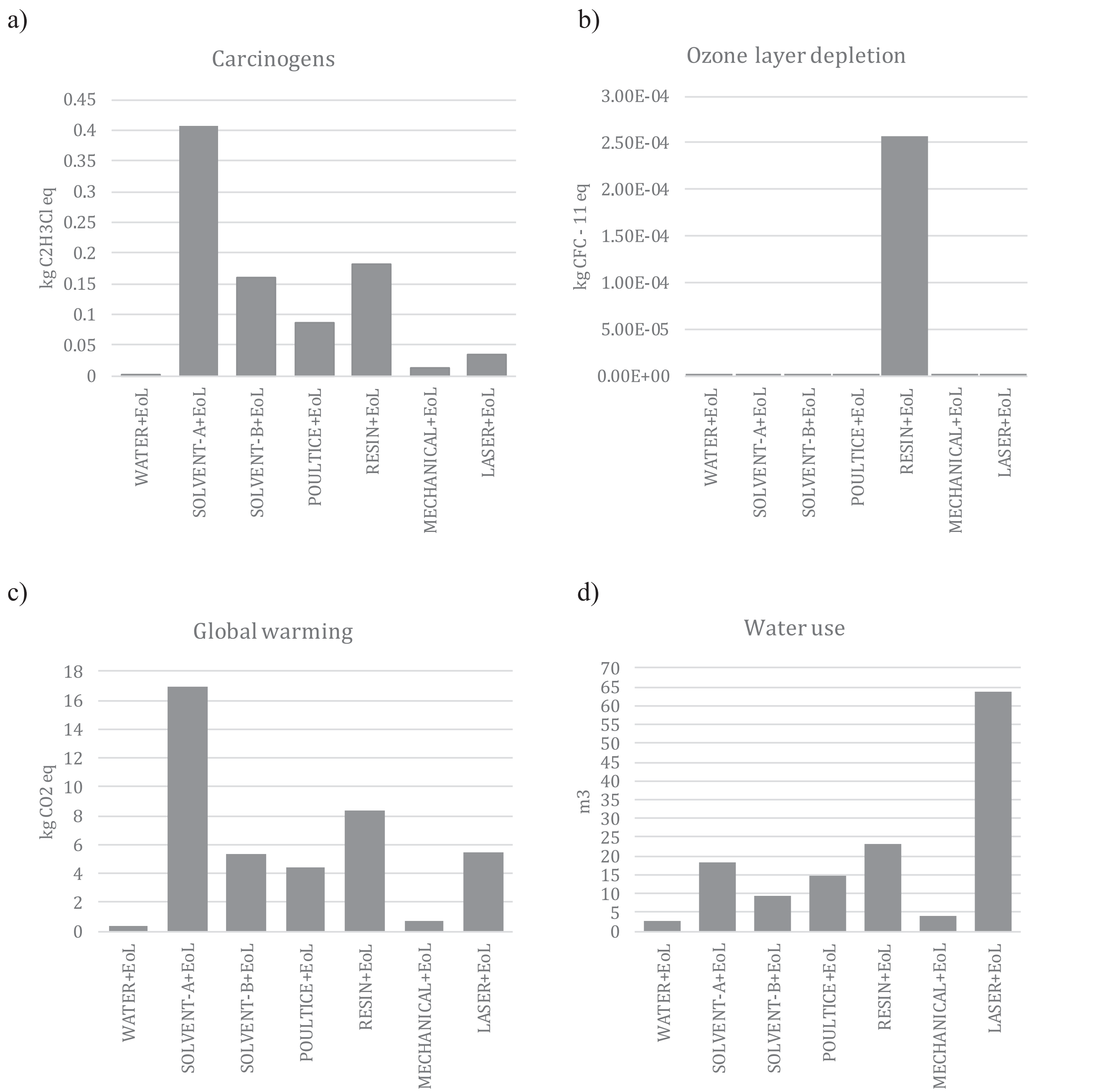
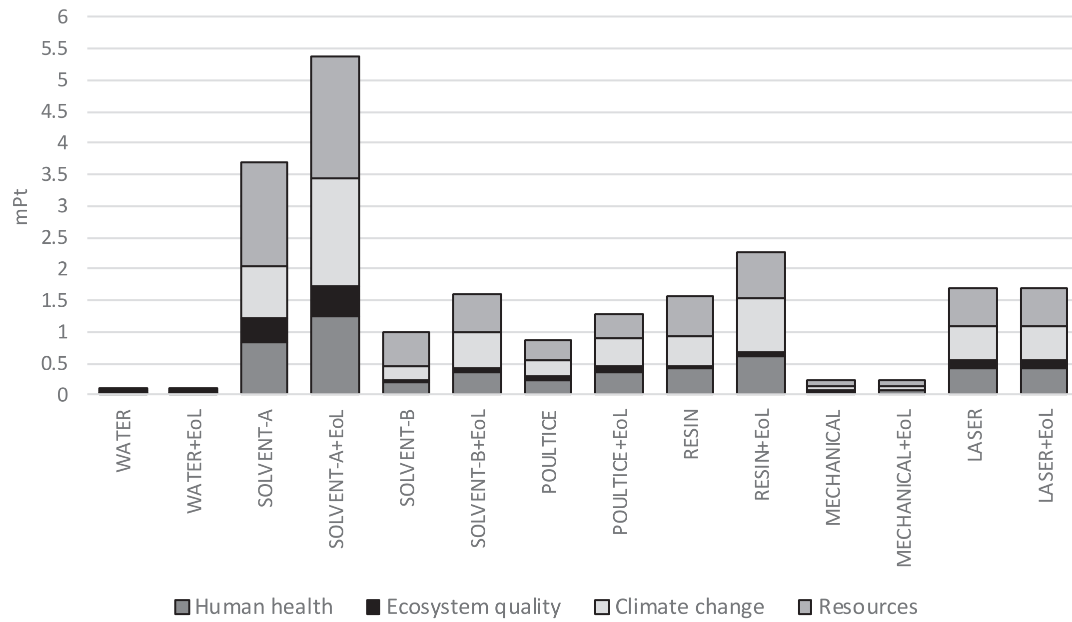


Fig. 4. Results of the midpoint analysis with IMPACT 2002+ assessment method for the impact categories: a) Carcinogens; b) Ozone Layer Depletion; c) Global Warming Potential. The analysis of the Water use, related to the cleaning of 1 sqm of surface, is reported in d).

for the main impact in both cases but they are followed respectively by the laser cleaning and the resins, in the scenario with end of life treatments, and inversely by the resins and the laser cleaning in the other scenario. The following lowest part of the ranking remains unchanged for both scenarios.

An element of subjectivity in the LCA analysis is the selection of the assessment method. Several methods are implemented in LCA software and viable for the analysis, but it is not straightforward to compare the results obtained with different methods. In fact, some methods provide a "midpoint" evaluation, i.e. impact categories, focussing on those environmental mechanisms that occur early in the cause–effect chain such as emissions or extractions that lead to the so-called primary changes in the environment. Primary changes could result in secondary and then tertiary changes later in the cause-effect chain, for example human health and ecosystem quality in terms of damage categories as highlighted by endpoint perspective [30,36]. Moreover, within both midpoint and endpoint methods, different categories and subcategories can be considered, with different units of measure, different substances may be included or not, with different characterization factors [37]. Therefore, the results of the comparison between methods is not easy to be understood and require close attention; however, it can be interesting to note if there are some common trends between methods, considering the same impact categories with the same units. In the present work, a further analysis has been performed, considering three assessment methods (IMPACT 2002+, CML-IA baseline, IPCC GWP 100a, TRACI 2.1) and focussing on the common impact category of Global Warming. In this analysis, also the waste treatments have been included. Fig. 6 highlights that, for all the techniques, the different assessment meth-



Cleaning operation	Damage without EoL processes (mPt)	Damage with EoL processes (mPt)	Difference [%]
WATER	0.98E-01	1.03E-01	5.3
SOLVENT-A	37.11E-01	53.63E-01	44.5
SOLVENT-B	9.86E-01	15.99E-01	62.2
POULTICE	8.75E-01	12.84E-01	46.7
RESIN	15.62E-01	22,72E-01	45.4
MECHANICAL	2.32E-01	2.40E-01	3.5
LASER	16.90E-01	16.91E-01	0.0

Fig. 5. Comparison between processes including and not including the end of life processes (suffix +EoL), with IMPACT 2002+ assessment method, related to the cleaning of 1 sqm of surface.

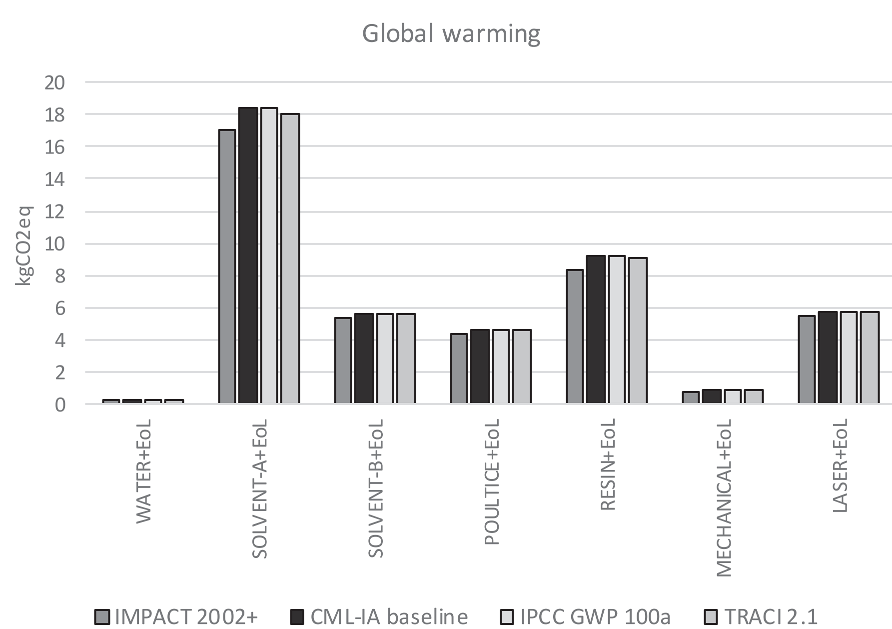


Fig. 6. Results of Global Warming impact category respectively with IMPACT2002+, CML-IA baseline, IPCC GWP 100a and TRACI 2.1 assessment methods, related to the cleaning of 1 sqm of surface.

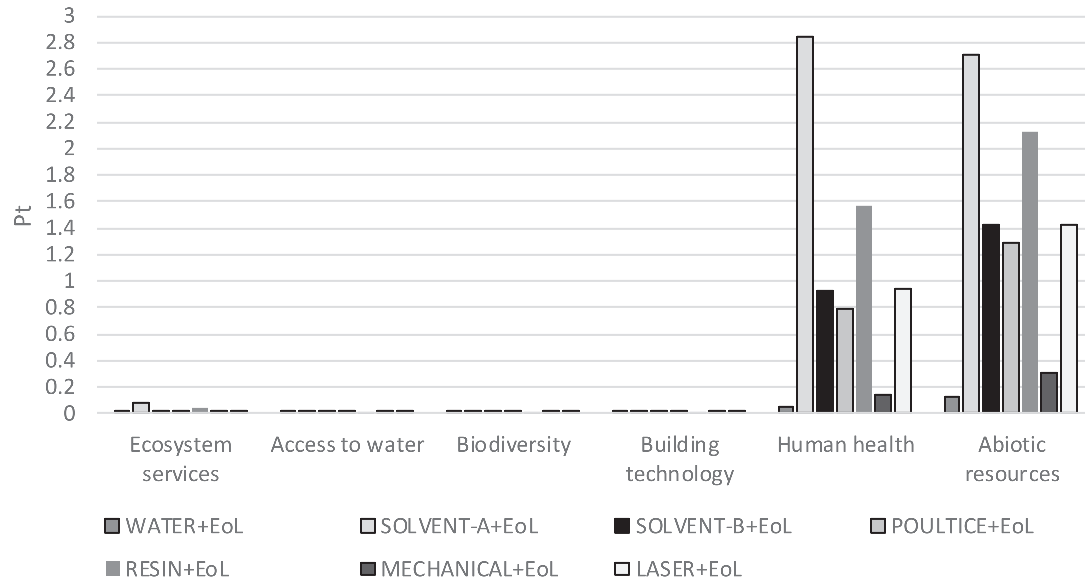


Fig. 7. Weighting results of the evaluation of the externalities with EPS 2015dx related to the cleaning of 1 sqm of surface.

ods give comparable results, but the analysis with IMPACT 2002+ gives lower values that the others for all the considered cleaning operation.

In addition to the assessment of the environmental impacts, the evaluation of the externalities related to the process under study can be useful to obtain a more detailed analysis that takes into account also the external costs. In fact, considering the externalities, i.e. the indirect costs and economic impacts related to the environmental issues and not directly quantifiable, gives an added value to an LCA study that has the ambition to consider the entire cycle of a process. In this study, the analysis of the externalities has been performed with EPS 2015dx (Environmental Priority Strategies) assessment method which provides a monetarisation of the impacts. The external costs are assessed based on the willingness to pay to restore environmental changes and the monetary measurement is the ELU which corresponds to one Euro (= 1Pt). The results of the calculation show that free solvent methods are responsible for the main impact (5.62 Pt), followed by resins (3.73 Pt), laser (2.38 Pt), solvent gels (2.36 Pt), poultices (2.09 Pt), micro-sandblasting (0.45Pt) and deionised water (0.18Pt). Moreover, Fig. 7 highlights that Abiotic resources and Human health are the most affected damage categories (68.9% and 30.35% respectively). In particular, the cleaning with free solvents is the largest contributor to the impacts in both damage categories, for Abiotic Resources due to the crude oil needed for the production of acetone while for Human Health due to the emissions of carbon dioxide from fossil sources in air again during the production of acetone.

4. Conclusions

Seven cleaning methods, different from the point of view of both cleaning principle and materials/equipment employed, were analysed by the LCA approach. These methods represent the most diffused ones in the conservation of historic buildings and hence they can be considered representative for this field. The results of the LCA analysis allow to derive the following remarks.

- The environmental impact of cleaning has never been investigated so far, to the authors' best knowledge, hence some of the specific products and materials employed are not present in the Ecoinvent database and it was necessary to make some approximations. For some of the materials not present in the database (Carbopol® gelling agent and Ethomeen® surfactant), the most similar chemicals were selected, but a sensitivity analysis was not possible. In the case of the cellulose pulp used for the poultice and not reported in the database, it was shown that the selection of different pulps has basically no influence and the final impact does not change. Conversely, in the case of the ion-exchange resin, the impact of cleaning with an anionic resin is much higher (+46%) with respect to cationic resin, although the kind of resin must be selected on the basis of the nature of the black crust to remove and not only of the environmental impact of the method.
- The impact of the different cleaning methods is strongly different, being maximum for free solvent methods (SOLVENT-A), followed by laser, and minimum for the water-based method (nebula spray) and micro-sandblasting, if the end-of-life treatments are not included. However, the contribution of the cleaning methods to the different impact categories are different, as displayed in Fig. 4. In fact, for Carcinogens and Global Warming impact categories, the free solvent methods involve the highest impacts, while the resins are dominant in term of impact regarding Ozone Layer Depletion category. Conversely, the analysis of the water use shows that laser is in the first place, especially due to the water consumption for the production the electricity, which is needed during all the cleaning operation.
- The impact of the cleaning methods is very different if waste treatment (end of life scenario) is included in the analysis, as expected. However, it is noteworthy that difference varies depending on method, being maximum for cleaning based on solvent gels (+62.2%) followed by poultices, resins and acetone (+46.7%, +45.4% and +44.5% respectively) which is mainly due to the incineration of hazardous waste, i.e. the consumables used for the cleaning. For the techniques that do not involve hazardous wastes, the difference is negligible. A more in-depth analysis showed that for the cleaning with resins and solvent gels, the environmental damage related to their manufacturing is comparable to that of their disposal. Moreover, including the impact of the waste treatment partially affects the ranking of the different cleaning methods.
- The comparison of the results of the Global Warming obtained by different assessment methods (IMPACT 2002+, CML-IA baseline, IPCC GWP 100a and TRACI 2.1) highlights that the results are quite similar and the ranking among the cleaning technolo-

gies is basically the same. This emphasizes the usefulness of the LCA as a support tool for the selection of materials and technologies for cleaning.

The results show that the LCA is actually applicable to conservation works, with particular reference to cleaning, although some limitations still exist, such as the limited data availability in the databases. This research also showed how critical is the selection of the FU is in the conservation field, as the working operations are dependent on the skilfulness and experience of the conservators involved. The FU used in this study, namely the cleaning of one square meter of a plain vertical surface affected by a 'normal black crust', was selected on the basis of the experience of the authors and some professionals working in the conservation field since many years, but this aspect should be improved in the future. The extension of the LCA analysis to other stage of the conservation work, such as repointing with repair mortars and renders, consolidation and protection are presently under investigation.

The diffusion of the environmental impact assessment may largely contribute to a more sensible selection of materials and technologies in the conservation and repair of historic buildings, but also to the set-up of improving measures to reduce the environmental impact, thus promoting the sustainability awareness also in this important field.

Declaration of Competing Interest

The authors declare to have no conflict of interest.

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Annex 3

Paper 3

Organic Waste Management and Circular Bioeconomy: A Literature Review Comparison between Latin America and the European Union

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MDPI

Review

Organic Waste Management and Circular Bioeconomy: A Literature Review Comparison between Latin America and the European Union

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Abstract: Worldwide, organic waste represents one of the most significant shares in the waste management system. Within the framework of circular bioeconomy, new and cutting-edge infrastructure has been developed at the European level to turn organic waste into valuable resources. The present paper aims to provide an exhaustive comparison between the European Union and Latin America regarding organic waste valorization. To this end, an introductive analysis about the state of the art circular bioeconomy in Latin America and Caribbean countries was developed. Subsequently, a systematic literature review in the context of South and Central America was conducted to detect differences and similarities in technologies and best practices for treating biowaste. The results show that the Latin American region is home to numerous bio-based infrastructures: biogas recovery, composting facilities and bioremediation strategies. Nevertheless, a conclusive remark underlines that some social, economic and political barriers are still encountered in the region, and therefore, new and locally-based studies are of paramount importance.

Keywords: biowaste; bioresources; composting; organic waste to energy; circular bioeconomy

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1. Introduction

The birth of the bioeconomy, conceived as "the process of transforming life-science knowledge into new, sustainable, eco-efficient and competitive products" [1], has been the result of chance, necessity and evolution of several societies [2]. This evolution and concern for sustainability also involves anthropological issues as ethics, an increasing delimiting factor in the modern context, as already mentioned by the Romanian economist and mathematician Nicholas Georgescu-Roegen on his treatise on bioeconomic and degrowth in 1975. For Georgescu-Roegen, it was clear that an unequal appropriation of natural resources (even for economic development) could trigger a social fracture and eventual economic degrowth [3].

In the same line, there is consensus that the transition towards a bioeconomy is often associated with a number of economic, environmental and social benefits; however, the bioeconomy is not sustainable per se. Various environmental and socio-economic risks could undermine the sustainability of the bioeconomy, such as increased competition for land between food crops and fuel crops, direct and indirect changes in land use, marginal land use with negative effects on the biodiversity and greenhouse gas emissions, among others [4]. At the Latin American level, in 2014, around 4.6 giga tons of CO_2 were registered, of which 50% were associated with agricultural activities and land use. On the other hand, only in Central America between 1990 and 2017, about 20 million hectares of forests have been lost due to changes in land use [1].

For full bioeconomy application, ethics and other social rules have to be set in order to achieve sustainability. This is especially true in developing countries, where bioeconomy can enhance the dichotomy between food safety and industrial development, considering that there is consensus in the global scientific community that conventional technology will not, on its own, increase or diversify food production in sufficient quantity and quality to feed a population that will almost double in 50 years. This will directly influence the food security of several countries, especially those developing countries, where demands will be higher [5].

In terms of global bioeconomy development, while it is true that the European Union is one of the pioneers in the world in terms of application of the bioeconomy [6], the bioeconomy has found a niche of opportunities in other parts of the world including Latin American and the Caribbean (LAC).

In terms of a literature review, the state of maturity and development level of the bioeconomy in Europe is well documented, mainly by institutional organisms, while in LAC and especially in Central America (CA), the number of specialized publications is currently limited and rarely diffused. Additionally, the mentioned publications are mainly performed by international organisms that respond to its own necessities and agendas.

However, some actors have analyzed the current state of the technological context in LAC and CA also based on the number of scientific publications, where Brazil rose to first place with the highest number of scientific publications, accounting for 37% of the analyzed available documents [7]. The number of scientific publications—especially for Central American countries—regarding bioeconomy issues, including biofuels and enhancement of crops, is very limited; thus, one of the main objectives of the present paper is to contribute to the systematization of state of the art biowaste valorization.

The following lines are intended to show a qualitative overview between the development level of bioeconomy at the European Union (EU) and the Latin America and Caribbean region (LAC).

1.1. Legal Framework for the Bioeconomy in EU and Latin America

As far as public policies are concerned, one of the biggest differences between the EU, LAC and CA is the common legal structure and framework. While at the EU levels, it counts with a formal bioeconomy strategy that groups many sectors of the economy as agriculture, fishing and forestry [8], the LAC and CA structures are rarely united. In the specific case of the Central America region, through the so-called Central America Integration System (SICA), the system counts with some regional mechanism that enforce bioeconomy application as a "Agricultural Policy," a "Common energy strategy" and other regional instrument, but there is still no cohesion between them and binding force in all the state members [9].

It can be seen that, although there are triggering elements, the state of public policies in terms of circular economy, biotechnology and bioeconomy are still incipient [10]. In particular, limitations are observed in the absence of harmonization in the classification criteria for new products related to the bioeconomy, including by-products that, due to their lack of analytical classification, cannot be used in a timely manner as inputs for recovery and recovery processes [11].

1.2. Main Drivers of Bioeconomy Development in EU and Latin America

In terms of biodiversity, conceived as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" [12], the LAC region presents 20% of the key biodiversity areas identified worldwide [13]. The specific case of Central America is classified as a hotspot of biodiversity, with about 7% of the world biological patrimony [14]. Moreover, the United Nations points to Latin America as one of the most forest-covered areas in the world; in particular, Central America enjoys a land cover of about 19.499.000 ha, 38% of its total surface [15]. Moreover, 42.7% of LAC land is dedicated to biotech, consisting of a total of 191.7 million hectares in 2018 [5].

The region of Central America possesses structural factors linked to the agricultural vocation that may favor the successful application of bio-based economical models, especially for the generation of subproducts in high quantities as rice husks, postmortem waste from a bovine, mucilage, pulp and lees from coffee and cocoa, sugar cane residues, citrus peel, potato waste and pineapple waste, [11]. This last factor, considered a problem from the traditional and linear economy standpoint, can be of great importance in the creation of new value chains [15].

On the other hand, there is significant potential for water resources in all countries in the region. In measurable terms of water stress (relationship between quantity, quality and access to water)—with the exception of Guatemala and El Salvador, which present "medium-high" and "medium-low" stress levels, respectively—the rest of the CA countries experience levels of water stress considered "low," indicating average good "water health" [1].

Additionally, a social factor of opportunity to be considered is the native indigenous population present in the Central American Region. Indigenous communities, according to various studies, amount to almost 8 million people [1] who can contribute, through their historical richness, to understanding the potential of existing crops in the region and their potential use in the value chains of the bioeconomy [11].

1.3. Limitation of Bioeconomy Development in Latin America

Other remarked difference in the application of the bioeconomy in Latin America and the European Union is the level of maturity of governance, which can be understood as the process by which societies adapt their rules to new challenges [5]. This rule, as mentioned before, constitutes the framework through which bioeconomy or any other economic model can be set and runed. It is valid to mention that there are also significant limitations by the absence of harmonization in the classification criteria for new products related to the bioeconomy, including by-products that, due to their lack of analytical classification, cannot be used in a timely manner as inputs for recovery and recovery processes [11].

In terms of funding, the main difference between the UE, LAC and CA is the origin of funding. Midence Diaz and García Gómez [16] stated the main sources of funding in the LAC and CA come from international cooperation agencies as the Green Climate Fund, the United Nations Development Program and the World Bank [16], in contrast with the public funding provided by the EU as the well-known European Green Deal.

Regarding bioenergy development, the main difference between LAC, but especially CA, and the European Union is that ono one hand, the European Union predicts the direct diminution of the significance of bioenergy and the increase of the relevance of biomaterials by 2050 [17], while on the other hand, in the case of Central America, sugarcane bagasse and straw are currently agricultural residues that produce energy on a large scale with a positive trend, especially in Nicaragua, Guatemala and Honduras. At the LAC scale, Brazil counts with different sources of bioenergy coming from agricultural waste with significant level of power; for example, black liquor (1.7 GW), wood residues (371 MW), rice husk (36 MW), charcoal (35 MW), elephant grass (32 MW) and palm oil (4 MW) [7]. On the other hand, bioeconomy applied for environmental remediation can have a place in LAC and CA. In the particular case of Nicaragua, there is experience with the use of autochthonous microorganisms, in particular fungi, to propitiate bioleaching to extract heavy metals from tailings derived from mining activities [16].

Within the aforementioned framework of bioeconomy, the present study aims to draw a comparison analysis about biowaste recovery and treatment between the European and the Latin American contexts. To this end, the paper proposes a structural literature review of the current trends to turn organic waste into bioresources in the Latin American region.

The presentation of the work is divided into two main sections: the materials and methods that will describe the methodology performed to collect valid material and the results and discussion part will show the outcoming information grouped in three approaches. The groups cover composting technologies, biogas generation and other biowaste valorization solutions.

2. Materials and Methods

A literature-based review was conducted in order to frame a comprehensive picture of biowaste remediation in Latin American.

The methodology follows the structure adopted by [18]. The research was developed using the Scopus database and facilitated by the filter TITLE-ABS-KEY. The keywords assumed for the review were: "Latin America" AND "organic waste" OR "bioeconomy" OR "composting" OR "biogas". A total number of 66 entries were initially obtained. Afterwards, the field was restricted to only English and Spanish languages and within a time window between 1990 and 2002, which led to a total of 61 potential papers. Given the specific topic of choice, the remaining articles could potentially all be suitable for the research; however, to collect only highly relevant contributions, a further screening was also conducted and a final sample of 17 relevant manuscripts was obtained. The selection process is summarized and shown in Figure 1.

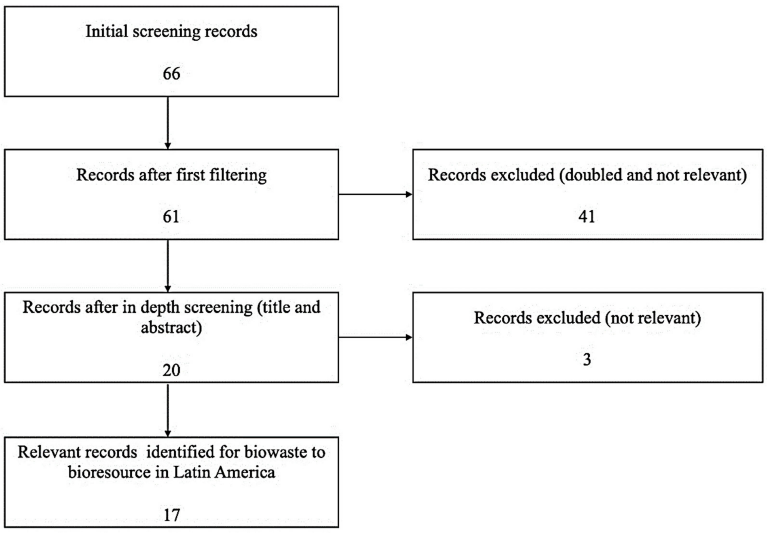

Figure 1. Overview of the selection process (own representation).

Regarding the geographical representation of the selected papers, Spain was the most popular country (5) followed by Italy, Colombia and Germany (3) (Figure 2).

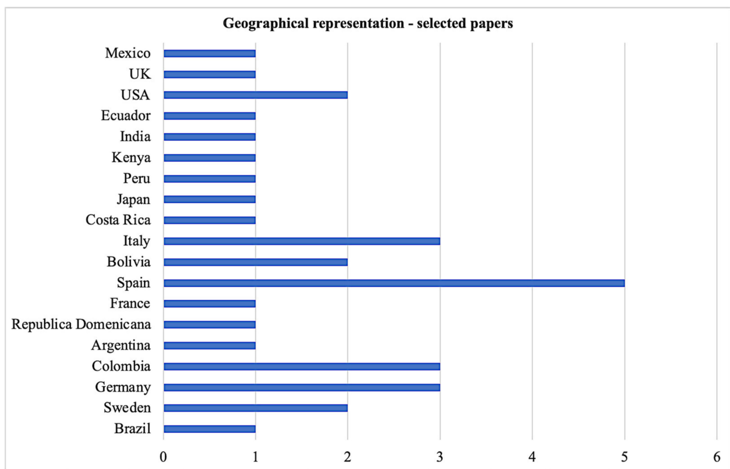

Figure 2. Geographical coverage. Source: own representation.

As far as the research method is concerned, 29% of articles analyzed were specific case studies, followed by theoretical model applications and literature reviews (Figure 3).

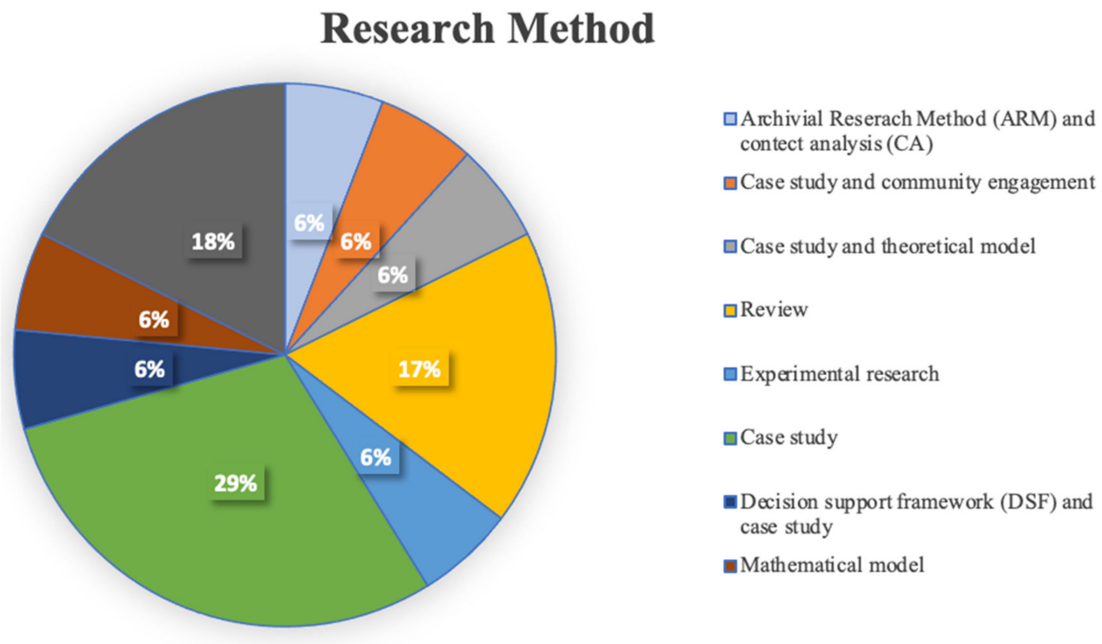

Figure 3. Research methodology (own representation).

Concerning the temporal representation, a peak of publication was encountered in 2020 (Figure 4).

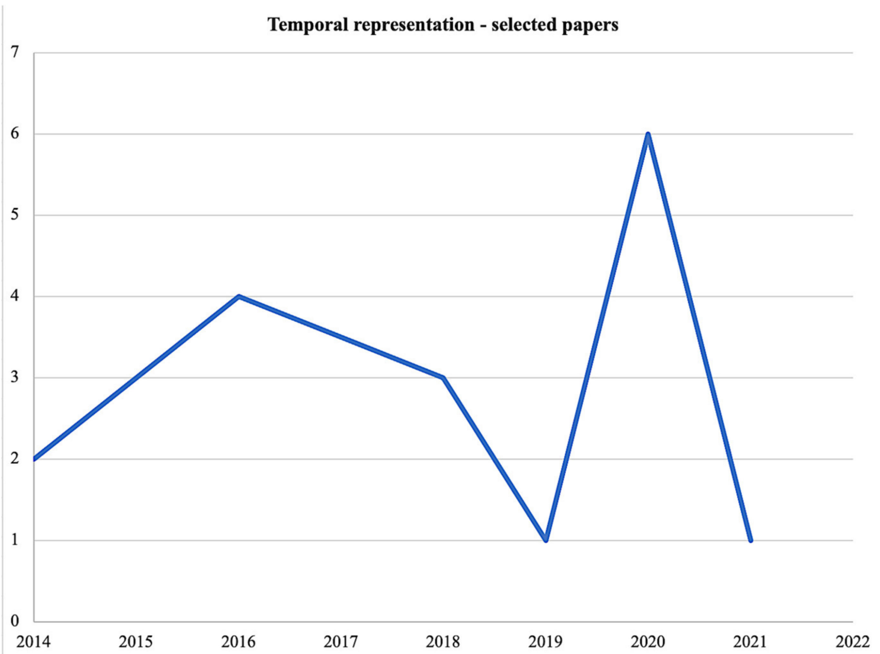

Figure 4. Temporal coverage (own representation).

3. Results

From the literature analysis described, it was possible to divide the obtaining sample in three main groups due to consistent analogies among the information gathered. The papers, indeed, tackle the topic considering three main different bio technologies recovery solutions. Some focused on diverse composting technologies, others on biogas generation and a small percentage on different biowaste valorization alternatives. This section divides the papers into three main recovery groups and aims to systematically describe current practices in the Latin American region for turning biowaste into bioresources. The manuscript grouping is summarized in Table 1.

Table 1. Literature review group analysis.

Composting Alternative	Biogas Generation	Other Biowaste Valorisation Solutions
(Sandoval Duarte, Osuna, Jenny, Rodríguez, & Juan, 2020) [19]	(Silva-Martínez, Sanches-Pereira, Ortiz, Gomez Galindo, & Teixeira Coelho, 2020) [7]	(Sasson & Malpica, Bioeconomy in Latin America, 2017) [20]
(Ferronato, Pineto, & Torretta, Assessment of Used Baby Diapers Composting in Bolivia, 2020) [21]	(Colombo & Rodriguez Cuevas, 2020) [22]	(Acevedo, Díaz Carrillo, Flórez-López, & Grande-Tovar, 2021) [23]
(Brenes-Peralta, Jiménez-Morales, Campos-Rodríguez, De Menna, & Vittuari, 2020) [24]	(Ferrer-Martí, Ferrer, Sánchez, & Garfí) [25]	(Ziegler-Rodriguez, Margallo, Aldaco, Ian, & Kahhat, 2019) [26]
(Ferrans, et al., 2018) [27]	(Garfí, Martí-Herrero, Garwood, & Ferrer) [28]	(Sharma, et al., 2016) [29]
(Ferronato, et al., 2018) [30]	(Kinyua, Rowse, & Ergas, 2014) [31]	
(Diaz & Otoma, 2013) [32]	(Meneses-Jácome, et al., 2015) [33]	
	(Pérez, Garfí, Cadena, & Ferrer, 2013) [34]	

3.1. Composting Alternative

The Latin America and the Caribbean (LAC) region still relies on open dumpsters for the disposal of more than 30% of municipal solid waste (MSW), and only in better circumstances is the landfill solution adopted [26]. When it comes to organic waste recovery, one of the main alternatives to open dumpsite or landfill is undoubtedly compost production, especially in regions in which the amount of biowaste is intensely generated both at domestic and industrial levels.

In the context of Latin America and, in general, of low-and middle-income countries, besides the commitment of developing bigger waste treatment infrastructures, the presence and the importance of small-scale technologies is predominant [20]. Ferrans et al. [27], for instance, considered composting process as a complementary stabilizer solution for sewage sludge treatment. Through composting it is indeed possible to eliminate pathogens and obtain good quality organic fertilizers when the sludge is mixed with organic waste.

However, when it comes to developing regions, composting solutions are not only identified in literature to solve organic waste generation problems but also to actively involve local communities. For instance, two interesting Latin American examples were given by Ferronato et al. [21] and Duarte et al. [19].

Ferronato et al. [21] explored the context of Bolivia, considering the specific issue of recycling used baby diapers (UBDs) waste fraction. Because of the wide generation in the territory of UBDs and the common discharge in open dumps, this specific waste fraction represents an issue in the country, and proper management should be addressed. The novelty of the case study was to attempt to treat disposable used baby diapers (UBDs) through a vermicomposting process. Scouting for innovative recycling solutions can support the low-income context to reduce uncontrolled waste disposal and achieve a more recycling and circular bioeconomy [21].

The experimental work proposed by [21] sought to evaluate the degradation of the biomass with a combination of different composting agents as cow dung, earthworms and activated bacteria. The UBDs samples were collected from different areas; they were then opened and last the plastic part was removed. At the end of those stages, composting experimental trials were performed following correct and specific timings and locations. To finally compare the process, [21] identified four main parameters: acidity (pH), decomposition time, earthworm growth and compost production. The research demonstrated that vermicomposting can be implemented to treat UBDs waste mixed with cow dung over a period of 60 days. The main finding was that without the presence of cow dung the waste substrate could not decompose because of the generation of algae and fungi. On the other hand, if cow dung is combined with earthworms as well, good final compost can be obtained.

The described case study is an example of a contribution to boost circularity in low-income territories by proposing low-cost and appropriate alternatives to specific waste that otherwise would end up in open dumpsites. This is a particular need, especially when proper selective collections and good pre-treatment solutions are not developed and applied in the study area.

A complementary contribution in the Bolivian context was proposed by Ferronato et al. in [30]. The mentioned paper analyses the main strengths and difficulties for implementing a sustainable MSWM. Within this framework, it also describes the commonly used vermicomposting process to treat organic fractions in developing economies. The study considers a specific composting plant located at an old open dumb situated in the south of La Paz. The small but functioning composting facility is used for producing compost that will consequently be utilized to reclaim the old open dump and create a new green area. Additionally, the final compost is used as fertilizer and as a new soil to plant trees.

Duarte et al. [19], on the other hand, considers an even more societal-based aspect by involving recycling picker organizations. The informal recycling waste sector is a real and deep issue in developing countries, and many studies have explored potential solutions to turn informal activities into legal recycling organizations [35–37]. Duarte et al. [19] explain that in the city of Bogotà, according to [38], 55.22% of the waste generated in a year are organic fractions which generally end up in open dumpsites or—in the best cases—sanitary landfills. However, in developing countries, besides environmental damages and economic losses, an ever more touchable issue is the informal recycling sector. Based on [39], it was found that in the city of Bogotà, there are approximately 13,700 informal waste recyclers who make their livelihood through the collection and the sale of recyclable materials and therefore, integrating these informal organizations into a formal organic waste management system might represent a win–win opportunity [19]. The case study considers a specific landfill named Donña Juana. In particular, [19] aims to propose a theoretical model based on a series of strategies. It consists of developing a structural management plan for organic waste that could involve: separation at the source, collection, transport and final use with a vermiculture composting system. Duarte et al. [19] concluded that with the development of this kind of integration system, the city of Bogotà can reduce up to 50% of the waste weight discharged in the Doña Juana landfill. Moreover, composting and vermiculture technologies have shown to be a valuable choice due to their economic accessibility, easy applicability and feasible administrative duties. Another key aspect that the experiment addresses is that including waste picker organizations promotes the generation of employment and consequently, the generation of higher and legal economical incomes to vulnerable families.

In addition to the previous study, another supporting case study is the one proposed by [24], who also compared the business-as-usual scenario of adopting landfilling with two food waste (FW) valorization alternatives: anaerobic digestion (AD) and composting (CP). The case study, specifically, focuses on the FW generated from a consortium of five different universities in Costa Rica. It was calculated that the universities generated a total amount of 2.607 tons of FW per week, with an operating service of 45 weeks of the academic year. The project was facilitated by a combination of Life Cycle Thinking (in which both life cycle assessment and life cycle cost were performed), linear programming and a multicriteria decision analysis method such as the Analytic Hierarchy Process. Regarding the environmental dimension, the main findings show that FW valorization alternatives would reduce both Global Warming Potential and Freshwater Eutrophication but, clearly, the anaerobic digestion would cause lower land use than composting. On the other hand, from the economic and social standpoints, the results show that alternative scenarios as AD and CP would have higher costs than landfills that, however, in the long term will probably be reversed. In addition, the paper aims to frame a complete circular economy-oriented scenario in the decision-making process and, within this prospective, it must be noted that initial investments will likely prevent future expenses. Furthermore, the valorization of FW would require more labor, which means higher costs but also new job opportunities.

A more economical prospective was explored by [32]. Diaz and Otomo address the Peruvian context by adding a further contribution aimed towards involving and systematizing informal recycling activities. To this end, the paper investigates a mathematical model able to calculate yields and costs of separate waste collection and of recycling alternative improvements. In Peru, current recycling and composting programs barely represent the 0.5% of national waste generation, but informal recycling, on the other hand, contributes to a reduction of almost 13% of waste and of 2.6% of food waste for pig feeding. As a consequence, in this case study, improving and formalizing the current informal recycling sector set the basis for a structural waste reduction system. To confirm this, the paper was developed in two sections: on one hand, it proposes a methodology to simulate separate collection, and on the other hand, it presents a more integrated analysis of the recycling and composting business by addressing cooperation risks that influence the collection. When it comes to recycling solutions, given good community cooperation, it was demonstrated that inorganic waste recycling has a wider margin of acceptance than composting. Recycling may indeed lead to attractive incomes that can potentially reach minimum wage. On the other hand, the case of composting is a bit more difficult and is even more dependent on good cooperation. Diaz and Otomo [32] demonstrated that with good cooperation only, the net cost of composting is lower than the usual landfill business scenario. The author also suggests that an interesting strategy to reduce the risks of a bad cooperation with waste pickers and the community is to locate composting facilities close to city markets, parks, clusters of restaurants and hotels and occasionally provide the service to the nearby residential area as well. Moreover, another key measure may be to give compost equivalents for tax incentives and grants.

3.2. Waste-To-Energy Alternative: Biogas Production

Besides compost production, first-generation biofuels are another growing industry in tropical and subtropical climates in LAC [22,33]. Although organic waste to energy (OWtE) technologies have been implemented in Latin America, they are insufficient, not only for the amount of waste volume but also to significantly supply the regional energy demand and meet national sustainability goals [7]. This phenomenon is due to a series of factors: the technological difficulties that this kind of infrastructure requires, along with a lack of research and education, unaffordable economic investment and weak political legislation. Silva-Martínez et al. [7], based on the Archival Research Method, presents research of state-of-the-art OWtE technologies in the context of Latin America and also addresses challenges and opportunities for improving adequate infrastructures. Silva-Martínez et al. [7] underlines that every year, millions of tons of agricultural, forest and urban waste are generated in LAC. The paper aims to provide a full and comprehensive understanding of the OWtE situation in LAC and divides the study in two main technological classification: thermochemical and biochemical processes.

As far as thermochemical processes are concerned, the main findings demonstrated that incineration is the most commonly used treatment in LAC. Because of low costs, combustion technologies are largely applied for agricultural and forest residues to produce electricity and, in particular, sugar cane bagasse and straw are the main combusted residues [7]. Countries such as Argentina, Brazil, Chile, Costa Rica, Honduras, Mexico and Uruguay also explored some densification techniques as pelletizing and torrefaction. On the other hand, gasification systems have been implemented in Cuba and Brazil, proving valuable experiences. Lastly, pyrolysis remains one of the least favorable practices especially in the Central America region.

Regarding biochemical solutions, recent years of studies have been focused on small-scale anaerobic digesters and landfilling in the Latin American context. Large-scale anaerobic digesters (AD) are not widely applied, primarily due to their high investment costs. On the other hand, important studies have been accomplished in LAC to explore the benefit of a combination of technologies, between co-digestion and biochemical methane potential. Fermentation industries aiming to produce first-generation (1G) biofuel are growing in the region, especially in Argentina, Brazil and Colombia. On the contrary, second-generation (2G) biofuels are not yet widely implemented but are getting more attention, especially from specific crops as sugarcane, coffee, corn, banana and palm oil. Likewise, biohydrogen production from dark fermentation is gaining ground in the region.

Above all, in LAC, low-cost household biodigesters are one of the most adopted technologies in rural areas to produce fertilizers and energy from agricultural residuals. Nevertheless, there are still some difficulties better identified in Garfi et al. [28], who provided an overview of household biogas digester developed in rural areas in Latin America. The authors stated that significant improvements have been achieved in the regions, including also the creation of a Network for Biodigesters in Latin America and the Caribbean (RedBioLAC), which aims to coordinate research programs throughout the continent.

The urgent need of turning organic waste into a valuable energy resource is also demonstrated by the fact that 31 million people in Latin America lack access to electricity, of which 87% in rural areas and 13% in urban areas. The authors explain that the design of household digesters mainly depend on climate conditions and available organic waste, skills and local materials. Commonly, the most used types are fixed dome, floating drum and tubular digesters. The fixed-dome digester is one of the most used in developing countries and it consists of a cylindrical chamber, a feedstock inlet and an outlet also used as a tank. Biogas is accumulated in the upper part of the chamber, as described in Figure 5a. The size of household digesters depends generally on local conditions such as biogas needs, organic waste and water availability. As far as the operation and maintenance aspect is concerned, Garfi et al. remind that the digester should be fed semi-continuously with organic waste that generally consists of manure diluted with water. The removing of the sludge is a challenging step, and it happens no more than once a year. Another example is the floating drum digester, which also consists of a cylindrical shape digester and a floating drum, generally made of steel or polyvinyl chloride (PVC), where the gas is accumulated. The drum also acts as a storage tank. It is built underground from concrete and steel. Through a pipeline, biogas is transported to a specific reservoir and used for cooking, heating and also lighting (Figure 5b). This case requires higher skilled labor for installation and also higher investment costs because of expensive construction materials such as concrete and steel, and sometimes, construction materials are not even available in rural areas. This system is fed daily with organic waste diluted with water. Its lifespan is shorter than the fixed-dome digester due to potential drum corrosion. The last most used digesters in LAC are tubular digesters (Figure 5c), which consist of a tubular plastic bag, generally made from polyethylene or PVC, though which the diluted feedstock flows from the inlet to the outlet. The biogas in this case is also transported from the digester to the reservoir by means of a proper pipeline. As mentioned above, the size depends on a number of different factors, but in poor rural areas of LAC—where families rely on agriculture and farming—a tubular digester volume is about 6–10 m^3.

The main findings of the paper illustrate that digester design vary according to a series of conditions such as water and waste availability, biogas and fertilizers needs, climatic conditions, local skills, raw materials availability, transportation feasibility and economic affordability. Moreover, it was demonstrated that in rural communities in LAC, biogas produces sufficient fuels for cooking and in the best cases, for electricity generation as well. From an environmental standpoint, biogas production is an environmentally sustainable system in rural areas of LCA; however, further improvements can be accomplished by researching and investing in more durable and sustainable materials to reduce the environmental impact but at the same time, maintain low costs. Nevertheless, the most significant barrier is initial investment costs for rural communities. From a social perspective, the authors stated that household can obviously improve health and quality of life, but trainings are nonetheless recommended for better community acceptance.

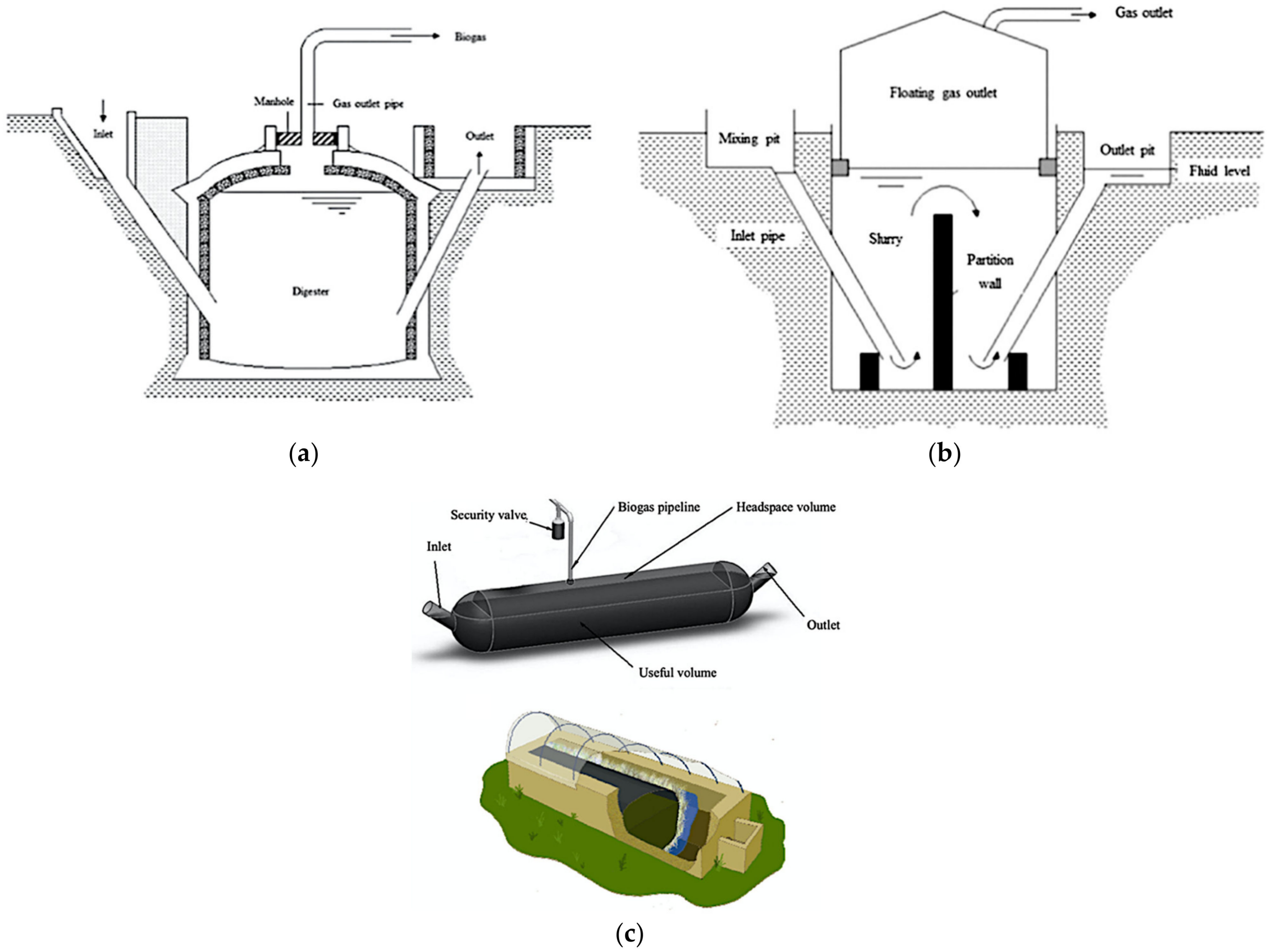

Figure 5. Schematic diagram of type of digesters. (**a**) fixed-dome digesters; (**b**) Floating digesters model. (**c**) Tubular digester model [28]. ©Elsevier, 2016.

This research was further complemented by the study of [25], whose aim was to validate and develop a multi-criteria decision support tools for the assessment of household digester programs in rural areas in LA. To this end, the methods consisted of three levels of decision: the local community, the digester model and the digester design selection. A set of evaluation criteria was established and weighted. The most significant criteria were those related to socio-economic aspects and digester reliability and durability. The methodology was then validated considering three case studies from rural Peruvian areas. To conclude, the multi-criteria decision analysis was suitable in a decision-making process for designing sustainable and reliable biogas programs, but the authors suggest that it should be introduced by specific training to help stakeholders become familiar with the applicability of new methodologies.

More specifically, [34] developed a life cycle comparison between a fixed-dome and a plastic tubular digester in the rural Andean communities. Over a span of 20 years, the plastic tubular digester were shown to be the more affordable alternative. For instance, capital costs for the plastic tubular digester were 12% lower than the fixed-dome digester, and also initial investment costs for a plastic tubular digester were also 1/3 of the fixed-dome digester. However, some maintenance costs were higher due to the plastic materials that require a replacement approximately every five years. From the environmental life cycle prospective, on the other hand, tubular digester generates the highest impacts because of the short life of plastic materials. In the fixed-dome model, high impacts are imputable to the use of concrete and bricks.

The specific case of tubular digester was also explored by [31] as it is widely used in developing countries for the treatment of livestock waste. Kinyua et al. [31], through a systematic review, list a series of potential benefits from the use of tubular digesters. First, anaerobic digestion produces net energy. Second, as far as the agricultural aspect is concerned, the digester effluent contains a large number of nutrients to be used such as soil enriching. Moreover, it contributes to decreasing deforestation, mitigating water contamination from the livestock sector and lowering air emissions if compared with combustion of firewood and other organic waste. It is also a social-oriented solution, due to important benefits for human health and gender inequality issues. Gender inequality-related concerns are not yet well tackled in poor contexts, but have been present since former generations. Due to traditional rules, women are assigned to intense and exhausting activities such as the collection of firewood and water as well as the food preparation. This means that women spend about nine hours per day in survival activities, in harsh and complicated conditions. If anaerobic digestion systems are installed, women would also be able to save energy and time.

3.3. Other Biowaste Valorizations

Besides composting and biogas production, other interesting examples are given by [29]. The paper describes the multiple benefits a correct bioeconomy system might have. For instance, it focuses on smart agroforestry systems, considering its contribution to sustainable rural development. They provide, indeed, clear energy from bioenergy (as biodiesel, bioethanol and biogas) but also a reliable level of food security due to a simultaneous system production. They also have important social advantages thanks to the creation of new jobs and therefore to additional incomes. Another significant aspect is the mitigation of climate change because of a strong reduction in GHG emissions, the absence of land-use change phenomena, a structural water protection and biodiversity conservation programs due to the application of multi-culture plantations.

Nevertheless, in developing contexts, if not properly well-design, bioenergy programs and solution still have some negative repercussions on forest degradation, indoor pollution and food insecurity; therefore, innovative system and project need to be correctly addressed in order to gain all the potential benefits that bioenergy can embrace.

A touchable example of food waste valorization is the numerous strategies to fight banana waste loss. Acevedo et al. [23], for instance, states that in 2019, 51.227 hectares of bananas were planted in Colombia and often, after harvesting, almost 60% of banana biomass was wasted. Consequently, almost 115 million metric tons of banana waste loss are generated in the world. Acevedo et al. [23] delineated a comprehensive review to demonstrate the potential of banana waste loss valorization towards a stronger circular economy in Latin America. Among others, the paper argues that thanks to the high content of carbon, compound banana peels are used in diverse applications: mainly to obtain bioplastic materials, but also to produce biofuels as diesel and ethanol. Moreover, banana leaves are used to produce biodegradable packaging, utensils and organic fertilizers. Cellulose and hemicellulose from banana waste content can also be useful for nanotechnologies.

To conclude, [20] through a series of practical examples, we dove into a more general understanding of the essence of bioeconomy in Latin America.

4. Conclusions

The study stresses the difficulties that the LAC region still encounters in its transition towards a new bioeconomy, which is particularly clear in biofuels and bioproducts sectors. In the region, local specific and small-scale solutions were shown to be more appropriate for the geographical area (widely rich in biodiversity and natural ecosystems) and also better welcomed by the community.

From the present review, it appeared clear that organic waste management and circular bioeconomy are sectors in which new technologies still need to be consolidated, in opposition to the European context. This highlights the importance of developing public and business policies that prioritize waste reduction in production and organic waste recovery and valorization.

Additionally, it is important to heed the great potential LAC region has in boosting circular economy strategies and policies. The case examples described emphasize this strong potential but also shed light on the difficulties the region is still encountering. In most of the cases, economic dependence should be reduced; this is likely, especially with the help of international cooperation. Therefore, it is necessary to advance in experimental studies to better develop more circular solutions for organic waste management to reduce huge organic fraction volumes and reduce potential environmental burdens.

As a final recommendation, the authors stated that future research should address tailored training and participatory programs to maximize social acceptance and economic revenues from innovative bio-based alternative solutions.

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Annex 4

Paper 4

Organic waste composting and sustainability in low-income communities in Palestine: lessons from a pilot project in the village of Al Jalameh, Jenin

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ORIGINAL RESEARCH

Organic waste composting and sustainability in low-income communities in Palestine: lessons from a pilot project in the village of Al Jalameh, Jenin

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Abstract

Purpose A pilot composting project was initiated as part of a 200 tons/day solid waste recycling plant with active involvement of several local stakeholders. The project aimed at introducing compost production and use in the village of Al Jalameh, Palestine. This paper describes the successes and lessons from the pilot project.

Methods Based on the data collected on the population, waste production and economic activities, the best production methodology and composting units were designed and piloted. The compost was produced from animal manure, farm waste and organic fraction of domestic solid waste. Approaches to increase profit and sustain the initiative was implemented.

Results The facility managed by Al Jalameh Agricultural Cooperative Society, recycles 60% organic fraction of domestic waste reducing the quantity of waste to the landfill. An estimated 1425 m^3/year of compost are required for local agriculture while 800 tons/year is produced. With most of their compost coming from Israeli sources, the composting facility is at a competitive advantage. To increase the profit, around 28,125 kg of waste plastic sheets from greenhouses are collected for recycling each year generating a stable income of 5625.00 JOD/year.

Conclusions The compost produced in the village is purchased by the local farmers increasing access to compost at competitive price. Farmers are economically encouraged by compost production that could solve the organic waste management issue and at the same time guarantee a sort of "self-production" of fertiliser useful for local agriculture. This initiative could be extended to other villages in Jenin and other developing countries where agriculture is their major occupation.

Keywords Composting · Jenin · Organic waste · Palestine · Waste management

Introduction

The Middle East is marked by increasing environmental problems. The Occupied Palestinian Territories is no exception. In Occupied Palestinian Territories, the increasing environmental degradation is worsened by years of conflicts. The area is characterized by dense and rapidly increasing population coupled with scarce water resources, climate change and land degradation. Their environmental situation is regarded as alarming (Zurbrugg and Drescher 2002) and strictly intertwined with political background (ARIJ 1997). The decades of conflict have affected Palestinian authorities' efforts to safely and sustainably manage their environment and natural resources.

Open dumping and burning of solid wastes, which is considered a primitive form of landfilling (Rushbrook and WHO 2001) is practiced in most areas of Palestine (ARIJ 2005). This practice poses several threats both to humans and the environment. For instance, open dumpsites are susceptible to open burning and exposed to scavengers and disease vectors (Karthikeyan et al. 2007; Kurian and Visvanathan 2007; Mannapperuma and Basnayake 2004). Population living in the proximity of dumpsites are reported to suffer from various diseases (cholera, diarrhoea and malaria, where present), resulting from direct and indirect exposure to open dumping

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(Sankoh et al. 2013). Leachate generated from decomposing organic matter in waste can contaminate surface and groundwater. Additional public health risks associated with open burning of wastes are air pollution and explosions. Methane and carbon dioxide which are major greenhouse gases are associated with anaerobic decomposition of waste (Hegde et al. 2003). The scattering of wastes by wind and scavenging by animals create aesthetic nuisance (Abah and Ohimain 2010). Not the least is the odour emanating from the degradation of the waste which could become a disturbing issue for the surroundings. Moreover, scavengers working on the dumpsites are constantly exposed to gaseous emission from wastes and obnoxious odour, overheating and disease-carrying animals (like rats, reptiles and insects) (Thirarattanasunthon et al. 2012).

To develop a proper waste management system, the Palestinian Development and Investment Limited (PADICO) incorporated the Palestinian Solid Waste Recycling Company (TADWEER) in 2009 to implement waste recycling in the country. JSC (the local Joint Service Council for Solid Waste Management in the Governorate of Ramallah and Al Bireh) and Municipality signed a contract making the JSC responsible for providing the main infrastructure required for the collection and transportation of the separated waste to the recycling plant whiles the municipality makes available at least 1 dunum (1000 m^2) of land for the establishment of the agricultural waste recycling and composting station. The goal set for the project was to ensure 50% recycling of the municipal solid waste. The recycling plant was designed for a capacity of 200 tons/day of solid waste and composed of screening and mechanical and manual sorting lines. The waste is separated for cartoons, plastic bottles, glass, and metals and the residual mixed waste is sent to the landfill. The recyclable materials are bagged for easy shipping to Israel and Jordan due to the absence of companies in Palestine to reuse the materials. All the non-recyclable materials are shredded to reduce the size before landfilling with the residual mixed waste after separation.

The recycling plant is unable to recycle all the daily amount of waste generated because of the presence of a robust mixture of dry and wet fractions with the wet fraction accounting for 60–70% by weight of the total waste stream (ARIJ 2005). The JSC promoted the pilot project of recycling waste in the village of Al Jalameh with the aim of expanding the recovery and recycling ratio to all the villages in Jenin area by improving differentiated collection system and organic waste composting and reducing landfilled fraction. In this way, Al Jalameh could send to the landfill only 40% of the total urban waste as the remaining 60% organic waste would be composted. In this regard, containers for the wet waste fractions were strategically located in the surroundings of the houses in the village and organic waste is collected daily by the JSC.

An Al Jalameh Agricultural Cooperative Society (ACJ) showed interest in the project, above all in the production of compost with municipal organic waste. For this reason, the ACJ, the municipality of Marij Ibn Amer and Palestinian Agricultural Relief Committee, an agricultural development association, signed an agreement to create a station for recycling and composting to be managed by Al Jalameh Agricultural Cooperative. In the composting station, wet waste from farms, mainly greenhouse residues and manure, is collected to produce compost that could be sold to farmers on the local market thereby helping to improve agricultural practices towards a more sustainable agriculture. The beneficiaries of the project are the about 2700 villagers who, thanks to a better organization of the waste collection system focused on recycling, can improve their living conditions both from the hygiene and environmental point of view.

In this context, a pilot project was established to optimize organic waste collection and composting for local agriculture. This pilot project was implemented through agreement between the Department of Civil, Chemical, Environmental and Materials Engineering (DICAM) of the University of Bologna, Italy and the Arab American University of Jenin, contributing to a common research and design activities, with the contribution of the consortium Nexus Emilia Romagna and "Meets Jenin" association in partnership with PARC NGO and JSC.

Materials and methods

Description of the project area

Al Jalameh is a village in the West Bank, located 6 km north of the city of Jenin in Jenin governorate, Palestine. The estimated terrain elevation is 120 m above sea level and the annual rainfall is 300–400 mm. According to the Palestinian Central Bureau of Statistics, the town had a population of 2560 inhabitants in 2016 (PCBS 2017). The main economic activity of the people of Al Jalameh is rainfed and irrigated agriculture and animal rearing. Farming activities are carried out both in greenhouses and on open fields. Wheat and olive are cultivated on open fields whiles vegetables are cultivated in both greenhouses and open fields. Animals reared include poultry, small ruminants, and cattle. The village is considered to be agriculturally advanced due to its proximity to the green line as plastic houses and irrigated vegetation spread throughout its relatively small basin (LRC 2004). Figure 1 is a map showing Al Jalameh in Jenin.

Project approach

To achieve the goals of the pilot project, two main steps were firstly identified and carried out:

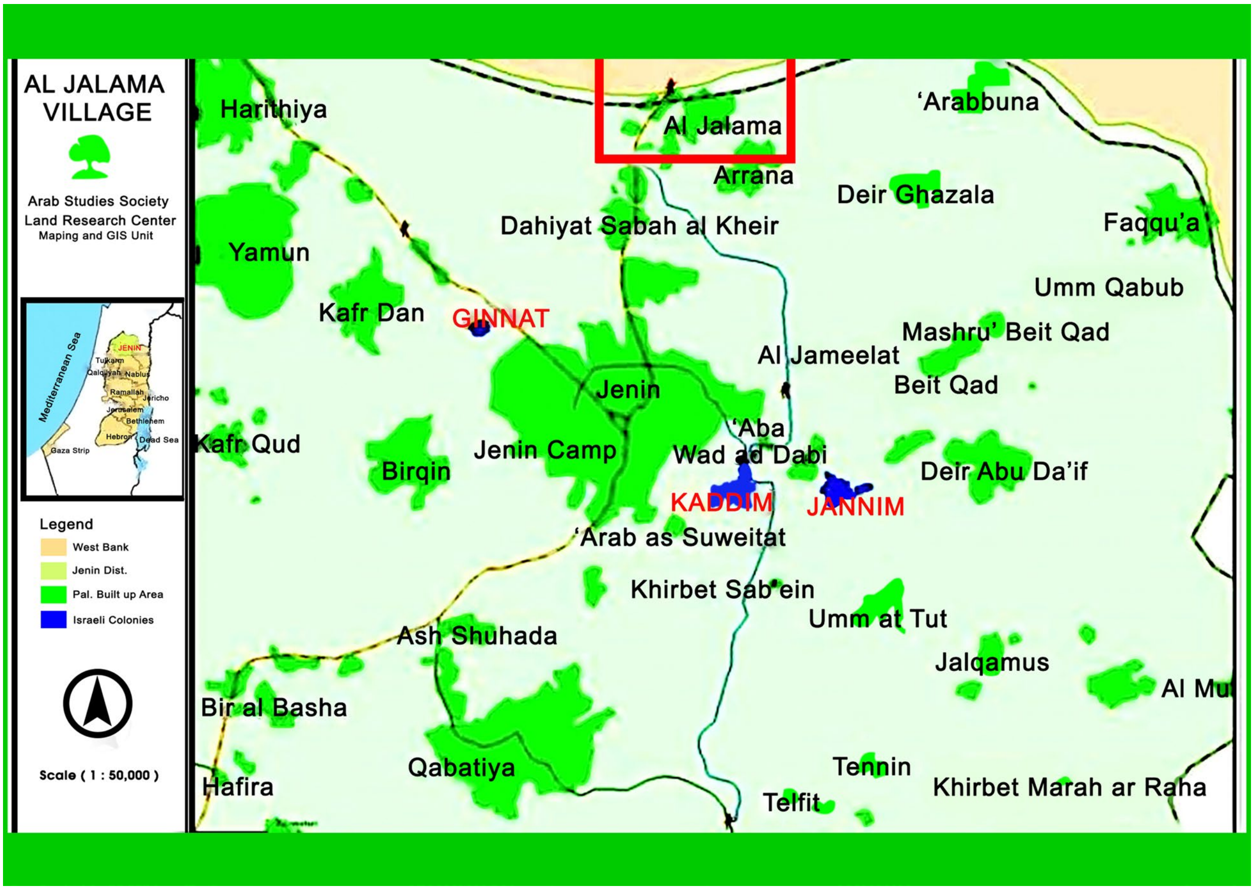


Fig. 1 Map showing Al Jalameh (LRC 2004)

1. Waste separation at the source, involving households, schools, businesses and farms.
2. Creation of a collection system for organic waste and composting station, in cooperation with the Municipality and operated by the Agricultural Cooperative.

The first step of the project was developed on data collection, in terms of inhabitants and waste production in the East Jenin area including: Al Jalameh, Arraneh, Arrabuneh, Deir Ghazaleh, Jaloun, Faqoua'ah, Beat Qad, Deir Abu Di'ef, Um Al Tut, Jalqamous, Al Mugayer, Raba, and Arab American University (AAUJ). The best production methodology and the composting units were designed, considering the quantity and percentage of each kind of organic matter.

Composting materials and process

The compost was produced from municipal organic waste, agricultural waste and ash. Agricultural waste is generated from greenhouses (such as vegetables, damaged fruits and vegetables), animal manure and dry plants (straw and stalks of maize).

An open composting system (windrow or pile) was adopted for the case study due to the relatively short production time and less construction and operation cost. "Open" systems are the typical composting units realized in developing countries (Zurbrugg and Drescher 2002; Zurbrugg 2003). The open system of composting follows an orderly way of organizing the layers. The minimum required area for a composting unit is 1.25 m × 1.25 m (Edwards and Araya 2011), to prevent the heap from drying out quickly affecting the quality of the final compost produced. The area dedicated to the compost station in the present case study was around 3 m × 2.5 m. In the beginning, a shallow trench of depth, 20 cm and same surface area of 3 m × 2.5 m was dug. The bottom and sides of the trench were watered to prevent moisture rich in nutrients from leaking out of the base of the compost heap as proposed by Edwards and Araya (2011).

In windrow composting, the materials are piled up in elongated heaps (Rothenberger et al. 2006). The amount of heat produced is determined by the size of the pile whiles aeration is guaranteed through addition of bulky materials, passive or active ventilation or regular turning (Rothenberger et al. 2006; Strauss et al. 2003). Heat generated through thermophilic phase is used to disinfect the compost. The first layer is typically constituted by dry plant material, in this case using strong grass straw and long stalks of maize as used by Mhindu et al. (2013). The straw and stalks of maize were broken into fragments of short length and sprinkled in the shallow trench. Dry materials serve as foundation to the compost-making process by providing air-circulation spaces to ensure air supply to microorganisms for metabolism and heat production. This foundation layer also serves as drainage path for excess water from the upper layers of the heap. This layer was about 10 cm thick.

The second layer, which was 15 cm thick, consisted of animal manure obtained from herders. Animal dung has been found to contain high amount of nitrogen, phosphorous, potassium (Abbas et al. 2015; Brown 2008), and micro-nutrients (Dach and Starmans 2005) which promote microbial activity. The third layer was constituted of green plant materials, either fresh or wilted, mainly waste from operating greenhouses, such as damaged fruits and vegetables. Green materials also provide moisture and nutrients to the microorganisms for the decomposition of organic materials and humus (Edwards and Araya 2011). This layer was 25 cm thick. Some literature seems to exclude the need to sprinkle water on this layer (Dall'Ara et al. 2010, 2012), but in this case study, water was sprinkled on the layer because of the warm local climate. The importance of ash as admixture in composting has been well documented. Ash has been found to contain both macro and micro-nutrients (Kuba et al. 2008), increase microbial composition and activity (Jokinen et al. 2006), improve oxygenation and reduce odour emissions (Koivula et al. 2004), improves nutrient content and produce aesthetically appealing compost (Campbell et al. 1997). As additional step, ash was sprinkled on the pile bearing in mind that too much ash affects the quality of the compost produced as has been reported by some researchers (Campbell et al. 1997; Kurola et al. 2011). The ash was obtained from a local baker that bakes bread in the tabon (a clay oven shaped like a truncated cone). In the end, a soil cover was added, that contributed to biodegradation of the organic materials into mature compost with a complete ecosystem of bacteria, fungi, insects and small animals. The height of the heap ranged from 1.0 to 1.5 m tall. The heap was shaped such that the middle layers are thicker than at the sides forming a dome shape (Edwards and Araya 2011), which prevent excessive rainwater from entering the pile. In warm climates, as in this case study, the compost was turned after 1 month.

Table 1 Composition of municipal solid waste in Al Jalameh

Composition	Percentage
Organic and food wastes	59
Paper and cardboard	15
Plastics	12
Glass	4
Metals	4
Other waste	6

Results and discussions

Context description

The population of the communities involved in the project, on the basis of preliminary data collection, was around 27,272 (PCBS 2008), and the average solid waste generation was about 20 tons/day. For these villages, JSC collects waste three times per week using the same work plan, driver and workers. The composition of municipal solid waste in Al Jalameh is presented in Table 1.

The daily household solid waste generated in the West Bank was 1728.2 tons (PCBS 2006) and the average waste generation per capita in rural areas such as Al Jalameh (which is considered a small village based on agricultural activities), is in the range of 0.4–0.6 kg/capita/day (ARIJ 2005). The case study proved to be important to support Palestinian Authority in developing measures on sustainable use of resources, considering wider economic, social and environmental consequences. On this issue, a very important achievement was the involvement of several stakeholders for sharing and diffusion of the urban waste separation, collection and organic waste composting project. In particular, an interesting result has been the involvement of women that are the first drivers of improved waste management from children education and house behaviour points of view.

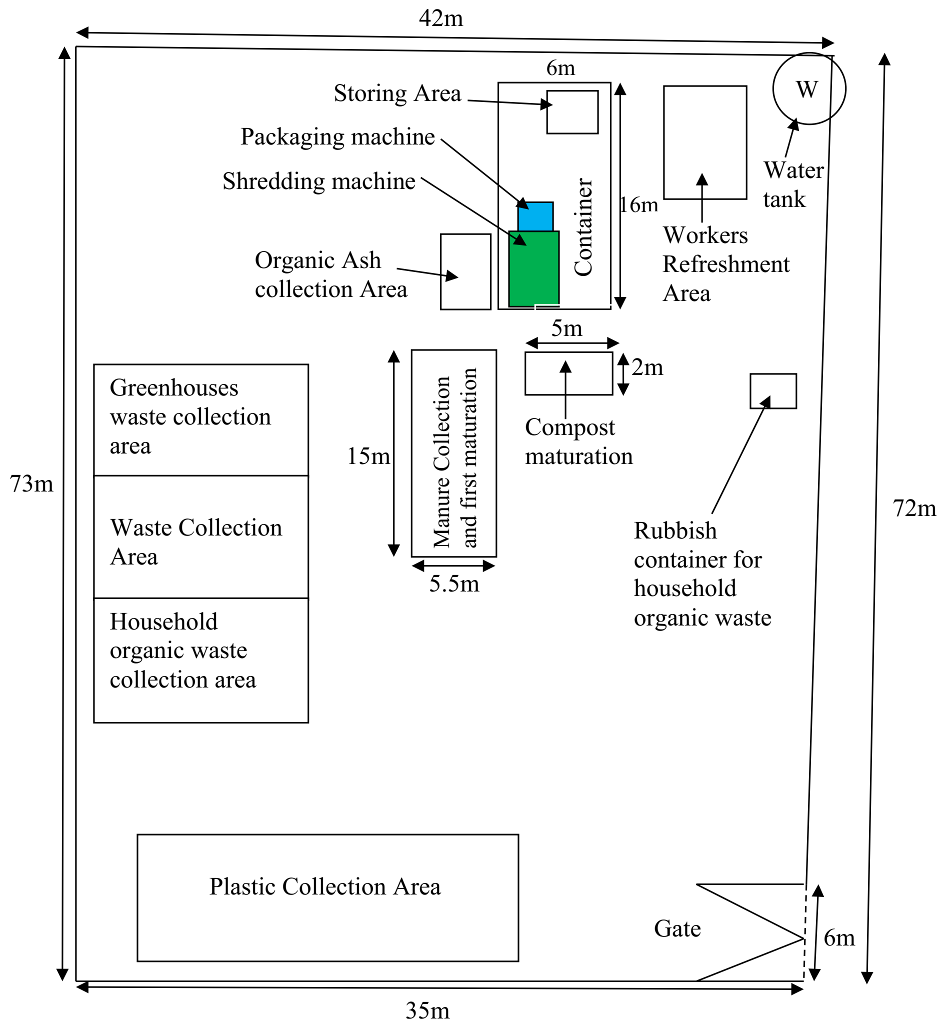
Important added value is experimenting new models of waste management for a developing country as Palestine, for environmental and human health protection and to promote valorisation of urban waste as secondary raw materials, according to the principle of circular economy.

Integrated composting

Unit description

The 800 tons/year capacity composting plant realized comprised an operation area and a stock area. The operation area is divided into different compartments with space for compost maturation, shredding, bagging (in the second phase) and storage. The actual composting processes are performed on an area designated for that purpose, outside the operation

Fig. 2 Layout of the integrated composting plant at Al Jalameh



area (not shown on the layout in Fig. 2). The stock area includes all the waste unloading and sorting, as well as storage space for recyclable plastics from greenhouses. The compartments have been arranged to ensure efficient workflow of the composting process. Figure 2 shows the layout of the compost station.

Description of the production processes and products

The ACJ tractor is used to purchase animal manure from herders and to collect the farm waste (hay) mainly on a seasonal manner; mostly at the beginning of summer and during autumn season. The farm waste quantities are stored in the collection area inside the compost station. As the organic waste separation starts from the household level in Al Jalameh, the domestic waste is brought to the compost station by the JSC workers in bulk to avoid leakage and start of the heap decomposition process. When all the components are on site, they are selected, prepared and the heaping process for the new pile starts. In the layout of the compost station, stockpiles are kept in a container near the shredding machine to reduce turn-around time. On the average 2000 tons/year of agricultural waste and 400 tons/year of municipal organic waste are used for composting. About 800 tons of compost is produced a year with a process efficiency of 30%. The ratio of organic waste to agricultural waste for the composting process was 1:20. The process flow diagram for the composting is shown in Fig. 3.

Business plan

According to Rouse et al. (2008) “marketing is about identifying and targeting customers and succeeding to sell products that satisfy customers at a price and in sufficient quantity to ensure the success of a business”. Similar to other products, in marketing compost, it is important to identify the target markets and potential competitors. Composting is not of common use in Al Jalameh. However, the Cooperative argued that selling the compost was not a problem as all the members of the Cooperative were encouraged to buy

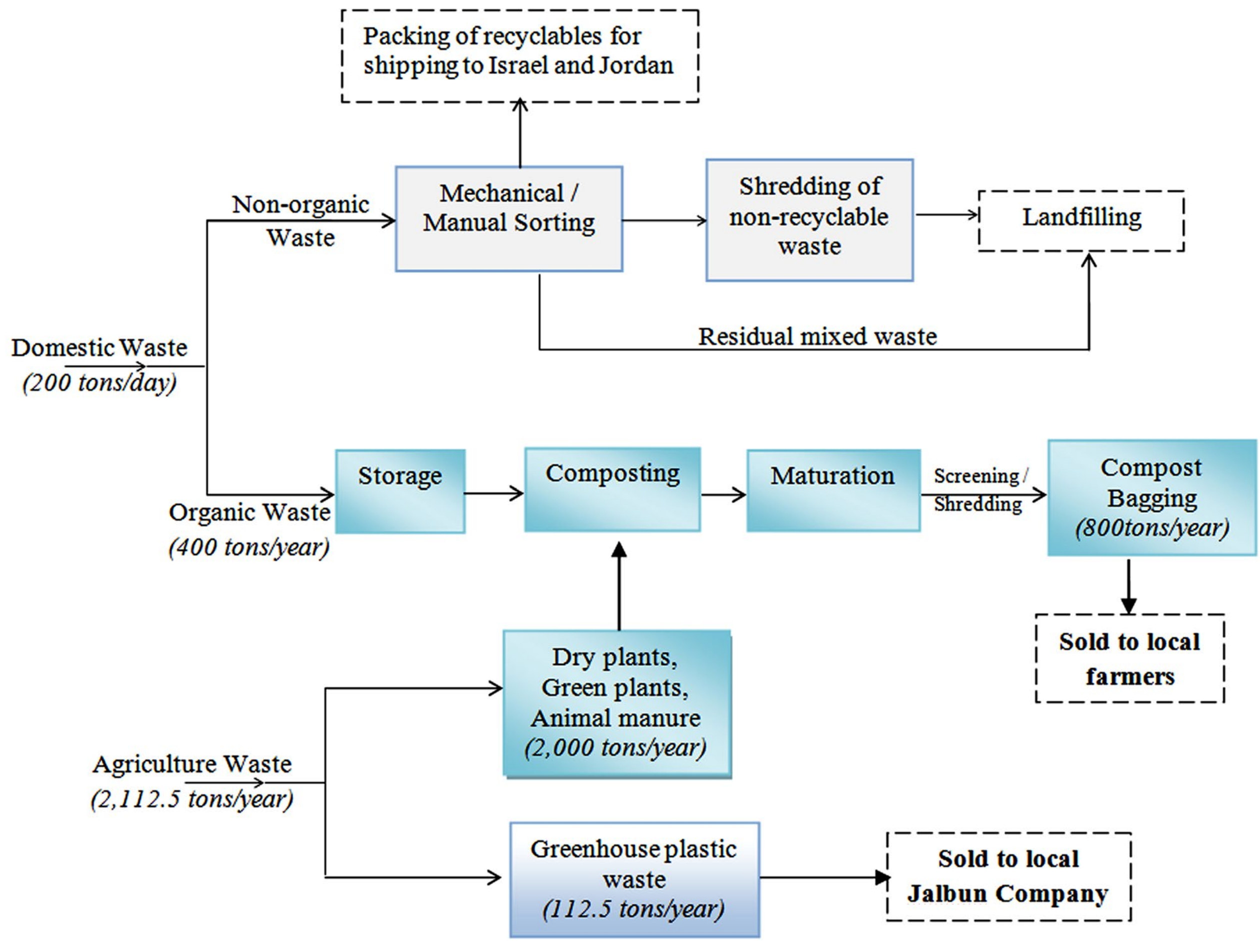


Fig. 3 Process flow diagram for waste recycling at Al Jalameh, Palestine

Table 2 Planted Areas and compost needs in Al Jalameh

Description	Planted area (1000 m^2)	Demand of compost (m^3/1000 m^2/year)	Total demand (m^3/year)
Greenhouses	450	1.5	675
Open field	1500	0.5	750

and to try the compost, forming the marketing approach for the first period of establishment of the composting plant. Table 2 presents information on agricultural status and compost needs in Al Jalameh area.

It is clear from Table 2 that there will be a total demand/need for compost of 1425 m^3 annually (based on 675 m^3 for green houses and 750 m^3 for open fields) to serve the planted areas available in Al Jalameh. However, from the perspective of the ACJ members, it was recommended to perform analysis based on compost use inside the green houses rather than for the open field agriculture. This restricted the annual demand for the compost to around 675 m^3 in Al Jalameh area.

Farmers in Al Jalameh use different types of fertilisers; chemical, organic, and compost fertilisers from Israel, Jordanian and individual local suppliers. Recent use of different types, sources, quantities and cost of fertilisers in Al Jalameh is presented in Table 3.

From Table 3, the cost of fertilisers for 1000 m^2 of farmland ranges from NIS 720–900 for compost up to NIS 1500 for chemical fertiliser. The farmers using the compost were supplied mainly from Israeli sources. This implies that it is economically feasible to obtain a market share for the compost produced locally. In terms of composting, there are limited initiatives in the region that might be classified as actual competitors for the compost production in Al Jalameh. An analysis of local competitors for the compost revealed selling price as NIS 12.00–15.00 per 25 L of product (equivalent to NIS 480.00–600.00 per m^3), with a production of 1333 m^3 per year or 53.3 m^3 per season. Similar to the findings from India (Drescher and Zurbrügg 2004) financial profits from compost sales proved to be very small, far from obtaining

Table 3 Recent use of fertilisers in Al Jalameh area

Fertilisers type	Source	Quantities used (per 1000 m^2)	Unit cost of fertilisers (NIS[b])	Cost of fertiliser (NIS/1000 m^2)
Chemical fertilisers	Israeli and Jordanian through whole seller	300 kg	5/kg	1500
Animal manure	70% from Israel and 30% from locals	10 m^3	40–45/m^3	400–450
Compost[a]	Israel and individual producers	1.5 m^3 for green house 0.5 m^3 for open field	12–15/25 L	720–900

[a]Compost use is very limited in the area, around 10% of the farmers use compost, they purchase it from Israel, or from individual that produce compost

[b]*NIS* Israeli New Shekel (the currency used in Palestine)

'gold from waste'. However, the objective of the composting project was not to make profit but for farmers to use the compost produced at the plant which is cheaper (about 40–52%) than chemical fertiliser. In addition, the long-term benefits from composting is likely to be higher with local government interests in composting coupled with increased and sustained public awareness on the benefits of compost relative to chemical fertilisers.

Compost application in agriculture

Compost is unable to compete favourably with inorganic fertilisers because the latter shows results very quickly (Harper 2004; Rouse et al. 2008). This affects the uptake of compost by farmers and other potential users particularly in low-income areas such as Al Jalameh. But given adequate time, compost has been reported to sustainably improve soil fertility (Diacono and Montemurro 2011; Golabi et al. 2004; Ouédraogo et al. 2001). Farmers in developing countries often cannot afford to wait for long-term results. As shown in Table 3, farmers in this region use large quantities of inorganic fertilisers. Restoring the soil structure due to years of dependence on inorganic fertilisers require relatively large quantities of and high investments in compost which serve as disincentive for local farmers. More often, farmers are not well informed on compost application and performance. This knowledge gap creates unrealistic expectations which leads to disappointment (Rouse et al. 2008) and, consequently, to a switch from compost back to inorganic fertilisers. For this reason, an effort has been made to enhance the awareness of farmers of Al Jalameh and to educate them on the effectiveness of compost as soil conditioner, which may lead to reduction in the need for chemical fertilisers. In addition, the marketing approach of encouraging members of the cooperative to use the compost would lead to a real breakthrough.

Fig. 4 Plastic storage for recycling

Plastic recycling for sustaining compost project

As it is unlikely to recover all the production costs from compost sales, a supplementary source of revenue was identified in reselling of plastics used in greenhouses. Part of the compost plant unit functions is to collect the damaged plastics from the green houses and sell these plastics to a factory in Jalbun area. Damaged plastic sheets and pipes are collected during the changing sheets period. Each farmer, informed of this possibility, contacts the Agricultural Cooperative (ACJ) involved in plastic collection and transport. The ACJ tractor is in charge of collecting the plastic sheets from the farms and storing it (Fig. 4), until the amount of plastics is around one tonne, i.e., the transport lot for the plastic recycling facility in Jalbun. The Jalbun factory is about 15 km from the Al Jalameh village and it is interested in buying plastics from greenhouses, the plastic sheets and the plastic pipes used for irrigation. At the Jalbun factory, the plastics are sorted (Fig. 5) and shredded, washed, dried and plasticised by outside heating or dissolved in a heating chamber and then forced by a plunger into cold moulds to set or extruded. In this case, it is extruded through a sieve, which results in a continuous pipe to be cut into lengths or coiled (extrusion moulding). In this way, the plastics from greenhouses and irrigation

Fig. 5 Plastic selection laboratory

pipes are used to produce plastic pipes to be used as conduit for electrical cabling.

From analysis, each 1000 m^2 of farmland may be able to return 250 kg of plastic sheets from greenhouses annually. In effect, 60 kg of plastic sheets are expected to be produced by each greenhouse, in this way.

In Al Jalameh village there are 450,000 m^2 of area used for greenhouses (Table 1). The total production of plastic sheets from greenhouses will, therefore, be about 112,500 kg/year. Obviously not all the farmers are expected to change the plastic sheets in the greenhouse every year, but approximately every 4 years. Assuming a 4-year changing rate as average, around 28,125 kg of plastic sheets could be available for recycling each year.

Based on an agreement with Jalbun Company Board of Directors, the plastic sheets would be purchased from the Cooperative for 200.00 Jordanian Dinar (JOD) (equivalent to 280 USD) per tonne. In this way, the Cooperative could have a stable income of 5625.00 JOD (equivalent to 7900.00 USD) per year. In the layout of the composting station (Fig. 2), a dedicated area has been identified to stock the plastics coming from the farmers. The Cooperative goes to pick the plastics up from each farmer, thus solving the big issue of greenhouse waste disposal.

Conclusions

Given the large amount of biodegradable waste (about 60%) in the waste stream in Al Jalameh, composting for local agricultural use would provide considerable benefits for the solid waste management system. The organic waste composting is decentralised as the separation of organic fraction and composting is performed as near to the source of generation as possible. This reduces the cost and environmental and health risks associated with the collection and transportation of organic waste. In Al Jalameh village, the farmers are economically encouraged by compost production that could solve the organic waste management issue and at the same time guarantee a sort of "self-production" of fertilisers useful for local agriculture. An annual demand of about 1425 m^3 is required by local farmers for planted areas whiles 800 tons/year of compost is produced at Al Jalameh. Using the market price of compost as basis, farmers would still enjoy cheaper prices from the purchase of the compost produced (about 40–52%) compared to chemical fertiliser. The compost production at Al Jalameh was adequate and meets the needs of local farmers, but the financial returns is very small. To address the low financial returns from the sale of compost, a stable annual income of 5625.00 JOD (equivalent to 7900.00 USD) was obtained from the sale of 28,125 kg of plastic sheets from greenhouses to a local recycling company at Jalbun. In addition, majority of the farmers are members of the Agricultural Cooperative Society and so the marketing approach of encouraging members of the cooperative to use the compost produced would ensure sustainability of the project. The strong local stakeholder involvement and the management of the composting plant by a local agricultural cooperative is one of the greatest strengths of the composting project in Al Jalameh. Based on the successes of the pilot composting project, the initiative could be extended to other villages in Jenin and generally to low-income communities in developing countries where agriculture is the major occupation.

Research on this topic is of great importance within this region because of the political and environmental sensitivity, particularly due to the restrictions on the water supply and system imposed by the prevailing political context and the ongoing Palestinian-Israeli conflict. This project highlights the major factors determining solid waste policy making in a socio-political system in transition.

The research investigated technical, economic, and socio-institutional factors that determine biological treatment of waste and it identifies the agencies involved in waste management, but the complexity of the internal and external forces and networks for the different actors and links for decision makers is left for future research.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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Annex 5

Paper 5

Bioeconomía y biodiversidad preservada en Centroamérica.

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ESTUDIOS

Bioeconomía y biodiversidad preservada en Centroamérica

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Resumen: La economía circular y la bioeconomía han resultado ser una alternativa a nivel mundial a los modelos de producción lineales y basados en combustibles fósiles y materias primas muchas veces no–renovables. Aunque en Centroamérica existen iniciativas de este tipo, principalmente en el sector bioenergético, se debe impulsar la aplicación de estos principios en sectores más amplios como la bio–remediación, la fabricación de bio–fertilizantes e incluso de materiales de más alto valor como bio–polímeros y bio–cosméticos. De igual manera, la preservación de la biodiversidad debe ser un objetivo común centroamericano, aunado a esto, se debe añadir el efecto sinérgico entre los países centroamericanos, en donde el SICA puede jugar un rol institucional neutro, más no pasivo, de coordinación y articulación entre los países. La migración hacia una economía bio–basada y circular con enfoque ambientalmente sostenible es viable en la región considerando las tecnologías actuales y el potencial de biodiversidad de Centroamérica.

Palabras clave: *Centroamérica, integración, potencial, biodiversidad, bioeconomía, economía circular.*

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Protecting the bioeconomy and biodiversity in Central America

Abstract: Circular economy and bioeconomy models have turned out to be a global alternative to linear production models that are based on fossil fuels and often rely on non-renewable primary resources. Although initiatives of this type do exist in Central America, mostly in the bioenergy sector, the implementation of such principles must be promoted in a wider range of sectors such as bioremediation, the production of biofertilisers and other higher-value materials such as biopolymers and biocosmetics. Similarly, the preservation of biodiversity must be a common Central American project, fostering synergy that allows SICA to play a neutral rather than passive institutional role, acting as a coordinating nexus between countries. Taking current technologies and the biodiversity potential in Central America into consideration, migrating towards a bio-based, circular economy with a focus on environmental sustainability is a viable route for the region.

Key words: *Central America, integration, potential, biodiversity, bioeconomy, circular economy.*

Bioéconomie et biodiversité préservée en Amérique Centrale

Résumé: Les modèles d'économie circulaire et de bioéconomie se sont révélés être une alternative globale aux modèles de production linéaires qui sont basés sur les combustibles fossiles et dépendent souvent sur des ressources primaires non renouvelables. Bien que des initiatives de ce type existent en Amérique centrale, principalement dans le secteur de la bioénergie, la mise en œuvre de ces principes doit être encouragée dans un plus grand nombre de secteurs tels que la bio-remédiation, la production de bio-fertilisants et d'autres matériaux de valeur plus élevés comme les bio-polymères et les bio-cosmétiques. De même, la préservation de la biodiversité doit être un projet commun à l'Amérique centrale, en favorisant une synergie qui permette au SICA de jouer un rôle institutionnel neutre plutôt que passif, en faisant office de lien de coordination entre les pays. En tenant compte des technologies actuelles et du potentiel de biodiversité en Amérique centrale, la migration vers une économie circulaire et bio-sourcée, axée sur la durabilité environnementale, est une voie viable pour la région.

Mots clé: *Amérique Centrale, intégration, potentiel, biodiversité, bioéconomie, économie circulaire.*

1. Introducción

La región centroamericana, así como el resto del mundo, se enfrenta a serios desafíos globales. La seguridad alimentaria, el suministro de energía y el cambio climático se encuentran entre los mayores retos para las naciones en el futuro próximo (Motola, De Bari, Pierro, & Giocoli, 2018). De igual manera, existe un riesgo real de desabastecimiento de materias primas esenciales para la industria. Las reservas mundiales conocidas de elementos como zinc, plata, oro, cobre, incluso el petróleo mismo, están en peligro de desaparecer en los próximos 50 años si los patrones de consumo siguen creciendo al ritmo actual (Mudd, 2010). Sumado a esto, se observa una profunda problemática en términos de residuos, principalmente plásticos. En 2017 se fabricaron en todo el mundo más de 320 millones de toneladas de polímeros, excluidas las fibras (Paletta, Leal Filho, lateef Balogun, Foschi, & Bonoli, 2019), y se estima que para el 2050 habrá (en peso) más plástico que peces en el océano (Ellen Macarthur Foundation, 2020). Son necesarios, por tanto, cambios radicales en la economía para enfrentar estos desafíos.

Junto a los cambios en los sistemas económicos, es necesaria una restructuración de las sociedades mismas. La estabilidad política y social de las naciones ha demostrado ser un desencadenante de prosperidad económica. Existen ejemplos en donde la integración regional ha servido para solventar necesidades inminentes. La llamada "Comunidad Europea del carbón y el acero" creada en 1951, base de la actual Unión Europea, valida el potencial de la integración regional para salvaguardar los intereses y objetivos comunes. "La paz mundial solo puede salvaguardarse mediante esfuerzos creadores proporcionales a los peligros que la amenazan" (Oficina de publicaciones de la Unión Europea, 2020). En la región centroamericana, por su parte, se observan ya importantes hitos integracionistas. Desde los llamados "Acuerdos de paz Esquipulas I y Esquipulas II", en 1986 y 1987, la creación del Mercado Común Centroamericano en 1960 hasta la conformación del Sistema de Integración Centroamericana (SICA) (Chamorro, 2015).

En este marco de integración centroamericana, el presente documento tiene como objetivo proporcionar una visión holística sobre las perspectivas y oportunidades de la región centroamericana para aplicar modelos económicos alternativos como las llamadas economía circular y bioeconomía, cuyos conceptos están estrechamente relacionados entre sí. Conceptualmente se puede entender la bioeconomía como la rama de la economía que comprende cualquier cadena de valor que utilice biomateriales y productos de fuentes agrícolas, acuáticas o forestales como punto de partida. (Consejo Alemán de Bioeconomía, 2018) El cambio de recursos no renovables a biomateriales es un aspecto de innovación importante en una agenda de la economía circular, la cual persigue mantener en el mercado el valor de los productos y servicios el mayor tiempo posible minimizando el uso de materias primas y la revalorización de los residuos generados (Agencia Ambiental Europea (EEA), 2018).

Al final del presente documento, se discutirán algunas propuestas generales con alcance regional para optimizar y maximizar el potencial de la región en la aplicación de la economía circular y bioeconomía, relacionadas transversalmente con los Objetivos de Desarrollo Sostenible (ODS) de la llamada Agenda 2030. Por decisión del Parlamento Centroamericano, los ODS fueron incorporados en las agendas estratégicas de los diversos países del SICA luego de su aprobación en la 48° Reunión de Jefes de Estado y de Gobierno del SICA, celebrada en Roatán, Honduras el 30 de junio de 2016 (Sistema Económico Latinoamericano y del Caribe (SELA), 2020).

2. Marco conceptual

El término de economía circular no es reciente, sus fundamentos ya habían sido considerados por diversas líneas de pensamiento en los años 90, pasando desde la filosofía de diseño "cradle to cradle" de William McDonough y Michael Braungart hasta el enfoque de sistemas de economía azul descrito por Gunter Pauli (Fundación Ellen MacArthur, 2015). Aunque existen diversas concepciones, los autores coinciden que estamos de frente a una economía circular cuando "el valor de los productos y materiales se mantiene durante el mayor tiempo posible. Se minimizan los desechos y el uso de recursos, y cuando un producto llega al final de su vida útil, se vuelve a utilizar para crear más valor" (Comisión Europea, 2015).

Por otro lado, la bioeconomía se puede concebir como "la producción, utilización y conservación de recursos biológicos, incluidos los conocimientos, la ciencia, la tecnología y la innovación relacionados, para proporcionar información, productos, procesos y servicios en todos los sectores económicos, con el propósito de avanzar hacia una economía sostenible" (Rodríguez, Rodrigues, & Sotomayor, 2019)

En síntesis, la bioeconomía está siendo conceptualizada como uno de los dos pilares de la sostenibilidad, junto con la economía circular. El objetivo es reducir los desechos que pueden aprovecharse de manera productiva para generar nuevas cadenas de valor agregado, y promover la eficiencia en el uso de los recursos. La economía circular es vista como una alternativa para enfrentar el enfoque derrochador de "tomar, hacer, disponer"; y la bioeconomía como alternativa a la producción a partir de materias fósiles sustituidas por materiales biológicos (Aramendis, Rodríguez, & Krieger Merico, 2018). Para enfatizar el elemento de circularidad en la bioeconomía se ha acuñado el término bioeconomía circular, que destaca la convergencia entre la economía circular y la bioeconomía, en lo relativo al aprovechamiento pleno de la biomasa (Rodríguez & Aramendis, 2019).

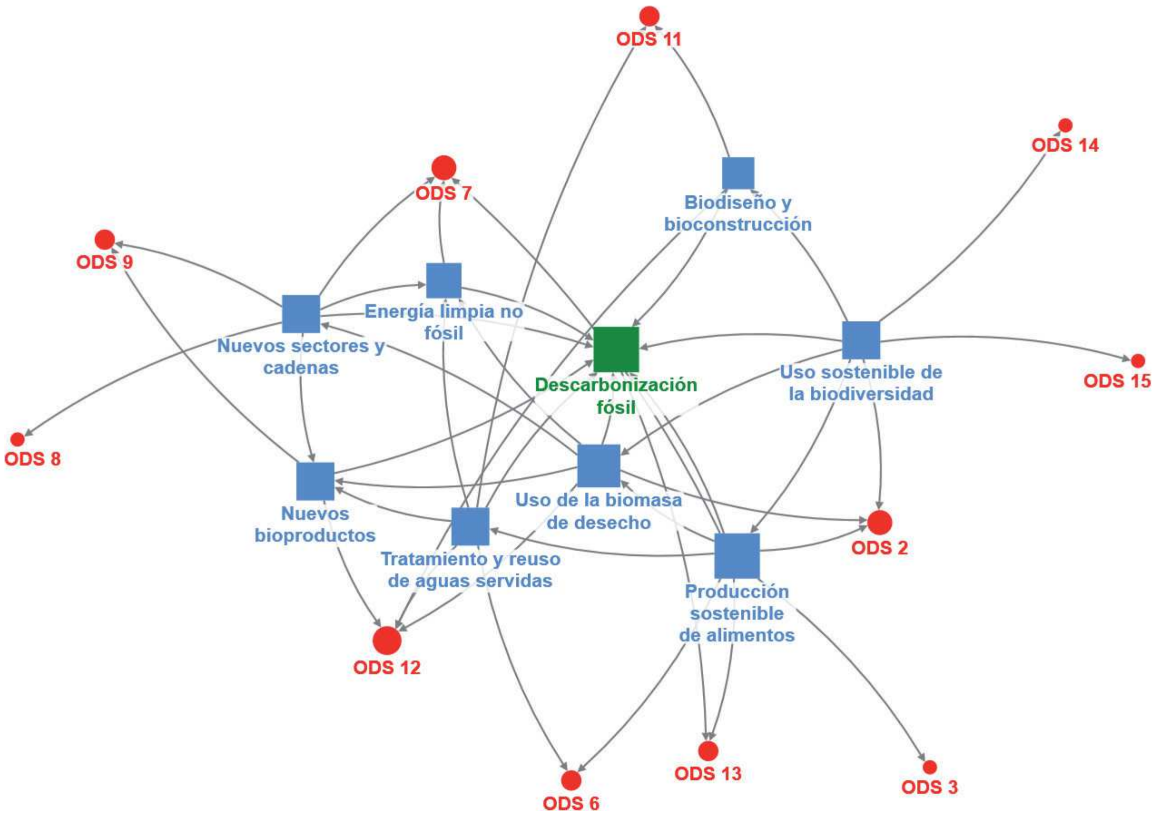
En términos de viabilidad de la economía circular en esferas más prácticas, las primeras etapas de la crisis sanitaria generada por la llamada COVID 19, pusieron de relieve la fragilidad de muchas cadenas de suministro mundiales, y aunque no se limitó a los problemas de disponibilidad de equipos médicos, quedó en evidencia la deficiencia en la gestión de estos ámbitos en medios de las crisis. Bajo este concepto, la economía circular ofrece el potencial para reconstruir a un costo menor, reducir la probabilidad de futuras crisis y crear una mayor resiliencia dentro de la industria y la sociedad, lo cual es valioso más allá de la situación actual (Ellen Macarthur Foundation, 2020).

En términos de perspectivas de proyección de la bioeconomía, algunos autores estimaban que aproximadamente un tercio de los productos químicos y materiales que se producirán provendrán de fuentes biológicas y procesos biocatalíticos avanzados. Los ingresos previstos, incluidos los de los biocombustibles, ascenderían a un volumen de 300.000 millones de euros mundialmente (DE, 2007).

Sin embargo, es importante mencionar que la transición a la bioeconomía a menudo se asocia con una serie de beneficios económicos, ambientales y sociales, no obstante, la bioeconomía no es sostenible per se. Varios riesgos ambientales y socioeconómicos podrían socavar la sostenibilidad de la bioeconomía, como el aumento de la competencia por la tierra entre cultivos alimentarios y cultivos para combustible, cambios directos e indirectos en el uso de la tierra, uso de tierras marginales con efectos negativos sobre la biodiversidad, emisiones de gases de efecto invernadero entre otros (Bracco, Tani, Çalıcıoğlu, Gomez, & Bogdanski, 2019)**.** A nivel latinoamericano ya en el año 2014 se registraron cerca de 4,6 Giga toneladas de CO_2, de las cuales el 50% asociadas a actividades agrícolas y uso del suelo. Por otro lado, solo en Centroamérica entre 1990 y 2017 se han perdido cerca de 20 millones de hectáreas de bosques debido a cambios en el uso de suelos (Gligo et al, 2020).

Por las razones antes mencionadas, la bioeconomía debe seguir un enfoque holístico de sostenibilidad basado en aspectos ambientales, económicos y sociales. (Bracco, Tani, Çalıcıoğlu, Gomez, & Bogdanski, 2019). Son estos tres aspectos lo que proveen a la economía circular y a la bioeconomía un marco conceptual para desarrollar estrategias enfocadas en enfrentar los retos de desarrollo sostenibles planteados en la llamada Agenda 2030. Estos van desde la creación de alternativas a los modelos basados en el petróleo, hasta el desarrollo de productos procesos y sistemas replicando lo observado en los fenómenos naturales ya existentes (Rodríguez, Rodrigues, & Sotomayor, 2019). La siguiente figura ilustra la interconexión entre los diferentes ODS y los fundamentos de la bioeconomía.

FIGURA 1. **Relación bioeconomía y Agenda 2030** (Rodríguez, Rodrigues, & Sotomayor, 2019)



3. Recursos potenciales

Centroamérica posee diversos factores estructurales, intrínsecos a su vocación territorial eminentemente agrícola, que pueden fomentar una aplicación eficaz de los pilares de una economía "más verde". Estos factores incluyen: la alta concentración de biodiversidad en el territorio, el alto potencial de generación de biomasa y la disposición de grandes cantidades de residuos de biomasa. Este último factor, considerado como una problemática desde el punto de vista lineal de la economía, puede ser de elevada trascendencia en la creación de nuevas cadenas de valor. (Rodríguez, Rodrigues, & Sotomayor, 2019).

En términos de biodiversidad, el área mesoamericana, comprendida por el sur de México, los países del istmo Centroamericano y la República Dominicana, es clasificada como un "hotspot" de riqueza de especies de flora y fauna. Con tan solo el 1% de la superficie del planeta, alberga cerca del 7% del patrimonio biológico del mundo (Andreson, Cherrignton, Sempris, & Flores, 2008). Además, las Naciones Unidas identifica a Europa y América Latina y el Caribe como las regiones con mayor cubierta forestal (25% cada una). En Centroamérica, esta cifra es de cerca de 19.499.000 hectáreas, el 38 %de su superficie (UNEP–WCMC, 2016). Respecto a la disponibilidad del territorio, algunos estudios estiman que para el 2050 podrían estar disponibles, 300 millones de hectáreas para desarrollar actividades relacionadas con la bioeconomía (MINCyT–CIRAD, 2016).

Así mismo, considerando que las economías de los países dentro de la Región Centroamericana son comprensiblemente dependientes de los recursos naturales (UNEP–WCMC, 2016), existe un espacio potencial de valorización de residuos de biomasa que podrían ser incorporados a otros procesos productivos, por ejemplo: cáscara del arroz, desperdicio post mortem de un bovino, mucílago, pulpa y borra del café y el cacao, residuos de la caña de azúcar, cáscara de los cítricos, desperdicios de papa, desechos de piña, suero de leche entre otros (IICA, 2019).

Por otro lado, existe un potencial de recursos hídricos significativo en todos los países que conforman el SICA. En términos medibles de estrés hídrico (relación entre cantidad, calidad y acceso al agua), a excepción de Guatemala y El Salvador que presentan niveles de estrés "medio–alto" y "medio bajo" respectivamente, el resto de los países del bloque goza de niveles de estrés hídrico considerados "bajos", indicando mediamente una buena "salud hídrica" (Gligo & otros, 2020).

Adicionalmente, un factor social de oportunidad de considerarse es la población indígena nativa presente en la Región Centroamericana, la cual asciende, según diversos estudios, a casi 8 millones de personas (Gligo & otros, 2020), las cuales pueden contribuir, a través de su riqueza histórica, a entender el potencial de cultivos ya existentes en la región y su uso potencial en las cadenas de valor de la bioeconomía (Montero Vega & Quirós Madrigal, 2017).

La siguiente tabla muestra algunos productos convencionales cosechados en Centroamérica y su uso potencial en el ámbito de la biotecnología:

TABLA 1. **Mercados y usos tradicional y en la bioeconomía de algunos productos agrícolas** (Montero Vega & Quirós Madrigal, 2017)

Tipo de producto	Producto	Región / países	Usos tradicionales	Usos en la bioeconomía
Mercado	Caña de azúcar	Toda Centroamérica excepto El Salvador	Azúcar	Biomasa, producción de energía, biocombustibles (etanol)
	Café	Toda Centroamérica	Bebida tradicional	Fertilizadores orgánicos, biogás, alcohol
	Piña	Costa Rica y Honduras	Fruta fresca o deshidratada, jugos	Fibras, Biomasa, Fertilizadores orgánicos, alcohol
	Banana	Toda Centroamérica excepto El Salvador	Fruta fresca o deshidratada	Biomasa, Fertilizadores orgánicos,
	Aceite de palma	Toda Centroamérica excepto El Salvador	Aceite	Biomasa, biodiesel
	Arroz	Toda Centroamérica excepto El Salvador	Arroz	Biomasa y electricidad
Tradicional	Jícama (pachyrhizus spp.)	Toda Centroamérica	Consumo fresco	Seguridad alimentaria
	Árbol de pan	Toda Centroamérica	Consumo fresco	Seguridad alimentaria
	Chan (Hyptis suaveolens)	Costa Rica	Consumo fresco	Seguridad alimentaria
	Jícaro (Crescentia cujete)	Nicaragua y Costa Rica	Consumo fresco	Seguridad alimentaria

Al interno de la bioeconomía, las estructuras de transformación de las materias primas en productos de más alto rango en las cadenas de valor son conocida como biorefinerías. El proceso principal en torno a las biorefinerías es la llamada biotransformación, la cual al ser integrada con procesos de pretratamientos de la biomasa (bioinsumos) permite la obtención de productos químicos biogénicos, como biopolímeros o biocosméticos de alto valor agregado en el mercado (Fava, et al., 2015)

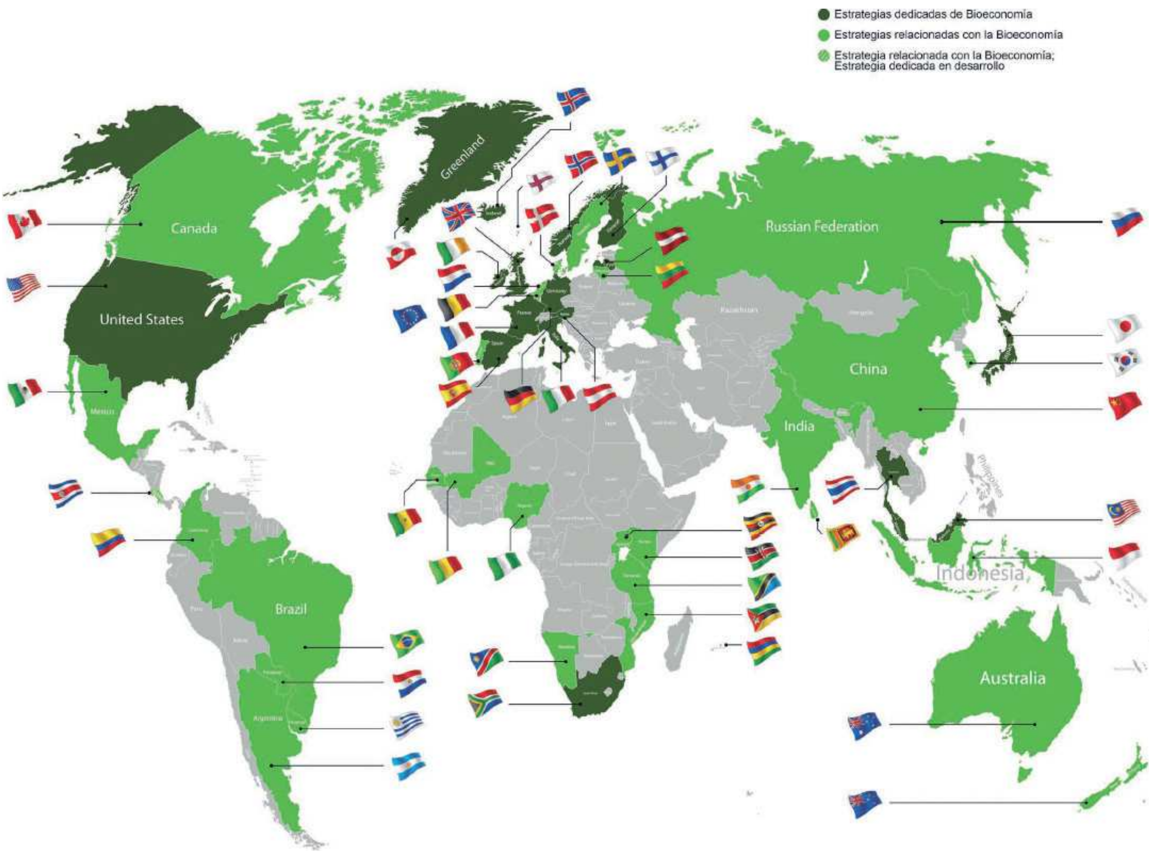
Respecto a las políticas públicas de carácter ambiental, en términos generales, éstas pueden ser clasificadas en políticas explícitas o implícitas; las primeras son aquellas que tienen objetivos ambientales declarados, en tanto que las segundas son las que tienen consecuencias ambientales no declaradas, generalmente negativas y que muy a menudo son propiciadas por la falta de atribuciones necesarias por parte de las autoridad ambientales para influir en los grandes proyectos de infraestructura (Gligo, et al, 2020).

Al interno del SICA, se observan políticas integradas con relación explicita con la bioeconomía, entre ellas la "Política agropecuaria de la región SICA 2019–2030", que indica de manera directa el término de bioeconomía entre sus 5 programas de acción. (IICA, 2019). De igual manera, se observa una "Estrategia energética sustentable centroamericana 2020", en donde se alude claramente al fomento de los biocombustibles y las energías renovables a partir de biomasa, esta última responsable de cubrir cerca del 38% de la demanda total de energía en Centroamérica. Por otro lado, aunque existe una "Política de Integración de Pesca y Acuicultura 2015–2015" en donde se fomentan las buenas prácticas para la pesca y la acuicultura, no hay una indicación explicita de aprovechamiento de los recursos marinos ligada directamente a la bioeconomía.

Otras políticas relevantes observadas entorno a la bioeconomía, son evidentes en Nicaragua y Costa Rica. En el caso de Nicaragua, se observa la creación de un Plan Nacional de Biotecnología, con asociación público–privada. (Marinero Orantes, Vargas Cañas, Martínez, L, Sardiñas Gómez, & Zúniga González, 2015). En el caso de Costa Rica, se evidencia con más claridad y relevancia, contando desde agosto del 2020 una estrategia ad hoc de bioeconomía (CEPAL, 2020). Se puede observar que, aunque existen elementos desencadenantes, el estado de las políticas públicas en términos de economía circular, biotecnología y bioeconomía son todavía incipientes (Huete–Pérez, 2008). En particular, se observan limitaciones en la ausencia de armonización en los criterios de clasificación para nuevos productos relacionados con la bioeconomía incluidos subproductos que por su falta de clasificación analítica, no pueden ser oportunamente utilizados como insumos para procesos de valorización y recuperación (Rodríguez, Rodrigues, & Sotomayor, 2019).

En relación a las estrategias de bioeconomía establecidas por los países a nivel mundial, la figura que sigue ilustra los principales países que cuentan con iniciativas ad hoc de bioeconomía (Consejo Alemán de Bioeconomía, 2018) citado en (Gobierno de Costa Rica, 2020).

FIGURA 2. **Políticas para la bioeconomía alrededor del mundo**
(Consejo Alemán de Bioeconomía, 2018)



En términos de acceso a información y financiamiento de la bioeconomía circular, diversas iniciativas a diferentes escalas están dedicadas a este fin. Espacios como el Foro Global para la alimentación y agricultura y los Encuentros globales de Bioeconomía (Global Bioeconomy Summit), proveen una plataforma que permiten obtener una visión global del estado actual en la aplicación de estos dos enfoques (Bracco, Tani, Çalıcıoğlu, Gomez, & Bogdanski, 2019).

En términos gestión de grandes volumen de datos e información (BIG DATA) sobre indicadores de productividad en la bioeconomía, pueden ser consultadas plataformas como "databio" (https://www.databio.eu/en/), que proporcionan información geoespacial para monitorear y potenciar las aplicaciones de bioeconomía.

Otro punto de acceso es el programa COPERNICUS, de la Agencia Espacial Europea, cuya labor está dedicada a generar imágenes satelitales de alta resolución en las áreas de cobertura de la superficie terrestre (land cover), predicción climática y monitoreo de los océanos. Sigue un ejemplo del material recuperable del sitio del programa COPERNICUS sobre la cobertura terrestre en mesoamerica:

FIGURA 3. **Imagen de la cobertura terrestre sobre Centroamérica**. (Europa, 2020)

Con referencia a los mecanismos e iniciativas de financiamiento para la aplicación de la economía circular y bioeconomía, existe una tendencia creciente a la disponibilidad de recursos con este objetivo. En algunos sectores se observa un incremento de 10 veces en el número de fondos del mercado privado con enfoque en la economía circular (Ellen Macarthur Foundation, 2020).

De igual manera, organismos como la Comisión Económica para América Latina y el Caribe (CEPAL) ha identificado y clasificado estas opciones en 5 categorías: mecanismos nacionales, la banca multilateral, las organizaciones internacionales, los fondos y mecanismos de cooperación internacional para el desarrollo, la cooperación bilateral y mecanismos financieros (Rodríguez & Aramendis, 2019).

Las principales instituciones identificadas como facilitadores de recursos financieros son: Banco Mundial, Programa de las Naciones Unidas para el Desarrollo (PNUD), Organización de las Naciones Unidas para el Desarrollo Industrial (ONUDI), Global Environmental Facility–GEF, Fondo Verde para el Clima (FVC), Fondo para los Objetivos de Desarrollo Sostenible–Fondo ODS entre otros (Rodríguez & Aramendis, 2019).

Otra buena oportunidad de mercado para colocar productos "bio–based" es el mercado común de la Unión Europea (UE), a través de los mecanismos establecidos del Acuerdo de asociación firmado entre los países centroamericanos y la UE.

4. Conclusiones y recomendaciones

En conclusión, se observa un potencial real en la región, sin embargo, las bases deben ser aún consolidadas para la migración hacia una bioeconomía circular sostenible.

La siguiente tabla indica algunas recomendaciones divididas por sectores con sus respectivos entes competentes asociados:

TABLA 2. **Recomendaciones** (Elaboración propia)

Tipo de recomendación	Alcance	Titulo recomendación	Descripción recomendación	Ente regional relacionado o competente
Políticas publicas	Regional	Armonización del sistema de clasificación de residuos	Establecer mecanismos de normalización a través de certificación de laboratorios especializados con capacidad analíticas para la clasificación precisa de materiales con usos potenciales en la bioeconomía circular (material genético, residuos de biomasa, etc.)	Foro Centroamericano de Acreditación (FOCA).
Estrategias de formación profesional	Regional	Síntesis de experiencias regionales	Establecer a mecanismos regionales de alta formación para facilitar el acceso, uso y aplicación de datos de plataformas como el programa Copernicus de la Agencia Espacial Europea	Consejo Superior Universitario Centroamericano (CSUCA)
Estrategias de acceso a financiamiento	Regional	Sintetizar información dispersa sobre iniciativas de financiamiento	Elaborar una base de datos de proyectos ya financiados y ejecutados	Sistema Integración Económica Centroamericana (SIECA)

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