LIFE18 CCM/ES/001094

Final Report
Covering the project activities from 17/06/2019[1] to 16/06/2023

Reporting Date[2]

<16/09/2023>

LIFE PROJECT NAME or Acronym

LIFE CO_2IntBio

Data Project

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[1] Project start date
[2] Include the reporting date as foreseen in part C2 of Annex II of the Grant Agreement

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1. Table of contents

2. List of keywords and abbreviations

- BdG – Bioeléctrica de Garray
- C2M – Close to Market (Neemo´s unit)
- CCU – Carbon Capture and Utilization
- CM – Carburos Metálicos
- CO_2-eq – CO_2 equivalent
- CONAMA – Congreso Nacional de Medio Ambiente (Environment National Congress)
- CSR – Corporate Social Responsibility
- ENSO – ENSO Energy Environment and Sustainability.
- EPD – Environmental Product Declaration
- EWRC – European Week of Regions and Cities
- FPNCyL – Fundación Patrimonio Natural de Castilla y León
- FTE – Full-time equivalent.
- GB – Gestamp Biomass
- GHG – Greenhouse gases
- LCA – Life Cycle Assessment
- PCR – Product Category Rules
- PEMA – Parque Empresarial del Medio Ambiente (in Garray, Soria).
- TERF - Temporary Employment Regulation File

3. Executive Summary

LIFE CO_2IntBio project was designed to support the implementation of the EU's climate policy and prepare the EU for the climate action challenges. It was focussed on design, development and implementation of innovative solutions with a long-term impact, including real industrial environments, developing economically viable solutions, processes and technologies and new raw-materials or products that allow a significant reduction in specific GHG emission intensity.

The project is focused on the use of CO_2 captured emissions from energy intensive industries, transforming these emissions in valuable products, which is the one of the key principles of circular economy, and through industrial symbiosis (as a circular economy tool) between energy industry and chemical industry.

Following these objectives, LIFE CO_2IntBio has demonstrated that carbon capture and purification technologies usually applied to the capture and use of CO_2 from fossil fuel industrial emissions, using amines, is also a technical and economic viable option in power plants that use biomass as fuel, and for this purpose the project partners have developed several technological and innovative improvements and adaptations.

As it was foreseen in the project, a new capture and purification CO_2 plant, has been built, adjacent to an existing biomass power plant, after an agreement between the owners of both infrastructures (CARBUROS and Bioelectrica de Garray).

After some delays due to the COVID sanitary emergency declared in March 2020, construction works finally finished in October 2021. Then begun the commissioning phase, also completing the adaptation of the biomass power plant to produce green CO_2. Finally, the start-up of the chemical CO_2 plant took place in June 2022.

The technology and processes used in the project for emissions capture has been chemical absorption with amines (post-combustion), and the main demonstrative value of LIFE CO_2IntBio project is the adaptation of CO_2 cleaning existing technology used in fuel combustion industries, to the biomass power plant flue gas.

The CO_2 captured stream passes through a separator and a filter to remove liquid water and particles before entering the compressors. To obtain a Food Grade Quality CO_2 it is necessary a further cleaning stage (it is filtered, cooled, and distilled). The chemical CO_2 resulting of this process is analysed to confirm the food specifications before delivering it to CO_2 customers. These high-quality standards are verified by the FSSC 22000 certification.

The results of LIFE CO_2IntBio project improves the available knowledge on the particularities of transforming CO_2 captured from biomass power plant emissions, into a chemical product (CCU) and provides relevant data of the efficiency achieved of a circular economy and an integrated approach (industrial symbiosis).

In addition to the emissions reduction in the sectors involved in the project, new value chains and a new product, liquid chemical CO_2 from renewable origin, have been created, with a high potential to lead a de-carbonization tendency in the chemical sector. This “green CO_2” is considered renewable and “net-zero emissions”, as it comes from a source 100% renewable (biomass) and because of using renewable energy during the synthesis process.

LIFE CO_2IntBio project has also developed an Environmental Product Declaration (EPD) exclusively for the new product "green CO_2". This is an added value for the products that use "green CO_2" getting more sustainable products.

In the other hand, the main deviation in the project is related to the foreseen extend of the symbiosis model achieved, to a greenhouse adjacent to the biomass power plant and the chemical CO_2 plant. The greenhouse owner was not a LIFE project beneficiary, but it was a strategic partner for the project as expected final consumer of a third part of the "green CO_2" produced. Despite the previous agreement signed between the greenhouse owner and LIFE Partners, changes in the property and financial uncertainty about the greenhouse future, finally it was not possible to continue the initial agreement with the owners and it was assumed that in the best scenario a new agreement would not be possible in the short/medium term (3/5 years). LIFE project Partners assume that actions and expected results linked to the supply of CO_2 and energy to the greenhouse could not be implemented during the LIFE Project period, neither considering a hypothetic project extension. No costs linked to the symbiosis with the greenhouse have been declared.

Nevertheless, after implementing technological adaptations, designing a Business Plan, a close-to-market assessment, and achieving quality standards for the chemical CO_2 produced, the LIFE project has demonstrated that CCU increase competitiveness of industry intensive sectors, mitigate GHG emissions, and demonstrate that circular economy is the way to reach net-zero target.

The main indicators achieved by the project are:

- 33,000 CO_2t/year captured from the Biomass Power Plant and valorised at the CO_2 cleaning plant.
- 295 CO_2t/year carbon footprint of liquified CO_2 transport to local customers avoided.
- 25,469 t/year of biomass managed at the Power Plant to supply heat and electricity to the CO_2 Plant.

The main conclusions and lessons learned from the project are:

1.- Carbon capture and purification technologies usually applied to the capture of CO_2 from industrial fossil fuel emissions, using amines, is also a technical and economic viable option in power plants that use biomass as fuel, with technological improvements and adaptations like those developed in the LIFE CO_2IntBio project.

2.- CCU as a Circular Economy model, transforming GHG emissions in products, represents an additional incentive to the development of the biogenic renewable energy sector, because of the increase of industry competitiveness and the improve of their carbon balance considered as net-zero emissions.

3.-The chemical product, CO_2 obtained through capture and purification from the emissions of biogenic origin (such as in LIFE CO_2IntBio from forest biomass combustion power plants) contributes significantly to the decarbonisation of the chemical CO_2 market, and by substituting industrial origin CO_2 by biogenic origin to obtain those same chemicals as the LIFE CO_2IntBio project has demonstrated, net-zero balance is achieved, demonstrating CCU policies contribute to EU net-zero emissions policy.

4. Introduction

The general objective of the project is to contribute to the mitigation of CO_2 emissions in energy intensive industrial sectors (biomass power plant, CO_2 commercial gas production;) by applying new techniques or methods in those sectors, through industrial integration (symbiosis) and the creation of new value chains for CO_2 as a raw material, when avoiding emissions is not possible using available technology.

The LIFE CO_2IntBio project is based on encouraging collaboration and integration between several industry sectors to mitigate CO_2 emissions. CO_2 from the emissions of the biomass power plant is captured, cleaned by means of chemical action using renewable energy and delivered to end users as "green CO_2".

This project is based on carbon capture and utilization technologies. The capture system chosen in this case is post-combustion based on chemical absorption with ammines.

The main demonstrative value of the LIFE CO_2IntBio project is the adaptation of existing CO_2 purification technology to biomass power plant flue gas. The captured CO_2 stream passes through a separator and a filter to remove liquid water and particles before entering the compressors. To obtain a food-grade quality CO_2 a further purification stage is required where it is filtered, cooled and distilled. The green CO_2 resulting from this process is analysed to confirm food specifications before delivering it to CO_2 customers. These high-quality standards are verified by the FSSC 22000 certification.

The main results obtained are:

- Demonstration of the effectiveness of an industrial symbiosis model to reduce net emissions:
    - Reduction of the biomass power plant´s CO_2 emissions by capturing part of the CO_2.
    - Reduction of CO_2 emissions from commercial CO_2 industrial production processes by substituting natural gas as a carbon source.
    - Reduction of the overall carbon footprint resulting from CO_2 transport by bringing the centre of production to its end users.

Other indirect environmental benefits obtained from the pilot project:
- Enhancement of sustainable forestry in the region by requesting Sustainability Certificates for additional biomass used in the biomass power plant
- Avoiding other fossil fuel emissions through the substitution by renewable energy
- Promoting awareness and change in CO_2 end users/clients towards a more sustainable CO_2 from renewable sources by introducing a new added value product in the market.

Performance indicators (as foreseen in the proposal) were linked to the involvement of the greenhouse company as a third party:

- 14,844 CO_2t/year emission reduction for the heat supply to the greenhouse (otherwise generated with fossil fuels).
- 5,387 CO_2 t/year emission reduction by burning greenhouse residues instead of disposing them in landfill (-256 CH_4t /y generation)

- 498 CO_2 t/year avoided in CO_2 liquid production.
- 133 CO_2 t/year carbon footprint of CO_2 transport to the greenhouse avoided.
- 175 CO_2 t/year reduced carbon footprint of CO_2 supply to third parties.
- 4.3 CO_2 t/year reduced carbon footprint of 1,863 t/y of waste not transported to landfill (considering 20 km distance).

It is not possible to assume the involvement of the greenhouse in the short/medium term. At the end of the project, the results indicators achieved are:

- 33,000 CO_2t/year captured from the biomass power plant and valorised at the CO_2 purification plant.
- 295 CO_2t/year carbon footprint of liquified CO_2 transport to local customers avoided.
- 25,469 t/year biomass managed at the power plant to supply heat and electricity to the CO_2 plant.

The pilot project is a first example of a shift towards a resource-efficient low-carbon economy: by using fewer resources and using those that are currently available more efficiently: biomass converted into heat and commercial CO_2, instead of only producing electricity, and reduction of carbon emissions for an integrated approach instead of individualized processes.

In addition, the project has the added value of proving the benefits of circular economy, by reusing waste, CO_2 emissions from the biomass power plant become raw material not only for the greenhouse process as commercial CO_2 but for the CO_2 customers in the region.

LIFE CO_2IntBio represents a high level of added value to fulfill the EU climate change mitigation objectives and introduces an innovative approach that reinforces EU strategies and policies: The proposal offers an innovative mitigation method by integrating different technologies under a new business approach with the common goal of mitigation carbon emissions.

The results of the LIFE CO_2IntBio project improve the available knowledge on the particularities of capturing CO_2 from the emissions of a biomass power plant and provide relevant data on the efficiency of an integrated approach. Evaluating future projects or reassessing current best practices or recommendations under the EU climate change mitigation targets will be an option for EU policy makers.

In addition to reducing emissions in the sectors involved, new value chains and a new product, commercial CO_2 gas from a renewable origin have been created, with a high potential to lead a de-carbonization trend in the CO_2 production processes.
This "green CO_2" is considered renewable as it comes from a 100% renewable source (biomass) and renewable energy is used during the synthesis process. The environmental impacts are described and characterized in the Environmental Product Declaration (EPD) developed exclusively for the "green CO_2". This is an added value for the products that use "green CO_2" since they are more sustainable.

5. Administrative part

The coordinator beneficiary contact, Jesús Díez, is the representative of the project before the Monitoring Team and CINEA. The communication between these parts is mainly by e-mail.

The kick-off meeting was held on 02/07/2019, establishing the management committee formed by a representative of each beneficiary, as the main interlocutor between partners. Every responsible partner has associated administrative staff. Besides this committee, a technical committee and a communication committee were formed. The first comprised the partner's technical staff in charge of coordinating the execution of the project actions, except for those of communication and dissemination which are managed by the communication committee. Every committee has discussed common decisions and have been in contact with the management committee.

The kick-off meeting also covered the scheduling of the work plan contemplating the milestones described in the proposal, and the appointment of the partner who was to be responsible for each action. The partners of the project have wide experience in their sectors, so each has contributed their technical expertise to balance the tasks assigned to each beneficiary according to their work area.

Communication with the Agency and Monitoring Team was affected by the COVID-19 pandemic restrictions. Most of the staff of the project beneficiaries worked from home (remote working). Some of the timesheets and documents corresponding to such months were electronically signed, while others were hand-signed several months later when in-office work could be resumed.

Due to the recommendations of avoiding face-to-face meetings, the two first monitoring meetings (April 2020 and April 2021) were held online. In April 2022, the mid-term report was submitted to the Agency and in June 2022 the third monitoring visit took place in Garray.

The implementation of the project was also conditioned by external administrative contingencies, such as the delay of the resolutions for obtaining the administrative licenses (the COVID-19 emergency paralyzed administrative procedures), which affected the construction of the plant.

Some specialized activities were developed through external assistance. Contracts follow the contracting and advertising rules suggested by the LIFE Programme as well as each entity's internal rules.

A request for an amendment to the Grant Agreement was submitted to the Commission in February 2021. It was validated in October 2021. The amendment concerned the change of ownership and social name of the associated beneficiary, Gestamp Biomass O&M, to ENSO O&M (Energy, Environment and Sustainability Operations and Maintenance), as well as the change of the affiliate company (the new owner of the partner GBO&M). These administrative modifications did not affect the correct implementation of the project (project objectives, results, technical actions, and budget). The new affiliate personnel were involved with this project from the start and were aware of the objective and agreement conditions.

6. Technical part

6.1Technical progress, per Action

A. Preparatory actions:

A1. Obtaining legal, administrative, and contractual licenses and agreements.

Foreseen start date:	September 2019	Actual start date:	April 2019
Foreseen end date:	April 2020	Actual end date:	September 2020.

Land lease and contractual agreements:

Before the project start in June 2019 agreements number 1 to 6 (see deliverable and documents table) were already signed.

Legal and administrative permissions:

Legal authorizations to implement and build the new CO_2 plant were required. Obtaining such permissions took longer than it was expected, due to the Covid-19 health emergency that stopped all administrative procedures in March 2020 when the state of alarm was declared in Spain. All the legal and administrative permissions were obtained in December 2020 (documents 7 to 10 of the table Deliverables-Documents)

The start of the construction of the new CO_2 plant and the necessary connexions (as is detailed in Actions C1, C2 and C3) were conditioned by the resolution of this preparatory action. The resolution of all these licenses allowed the work covered by Action C to begin.

Milestones and Deliverables: planned output and time schedule comparison.

Milestone	Foreseen date	Final date
Environmental Authorization	01/2020	04/02/2020
Signature of Land Lease agreement and commercial agreements	06/2019	17/04/2019
Commercial agreements between CM, BdG and the Greenhouse	06/2019	31/05/2019
Construction license	06/2019	10/2020

Deliverable	**Documents**	**Foreseen Date**	**Final Date**
A1.1 Commercial Agreements	1. Energy and gases supply agreement between BdG, CM and GB (now ENSO)	09/2019	04/2019
	2. Electrical energy supply and provision of auxiliary services agreement between BdG, CM and GB (now ENSO)		04/2019
	3. Thermal energy supply agreement between GB (now ENSO) and the Greenhouse		05/2019

	4. Electrical energy supply and provision of auxiliary services agreement between BdG, the Greenhouse and GB (now ENSO)		05/2019
	5. CO_2 supply: CM and the Greenhouse		05/2019
A1.2 Land Lease Agreement	6. Land Lease Agreement Between BdG and CM	09/2019	04/2019
A1.3 Legal and Administrative permits and licenses	7. Environmental authorisation and Environmental Impact Assessment public information	01/2020	02/2020
	8. Environmental Impact Statement		08/2020
	9. Integrated Environmental authorization		09/2020
	10. Construction License		12/2020

A2. Carbon Footprint Base Line determination.

Foreseen start date:	July 2019	Actual start date:	October 2019
Foreseen end date:	October 2019	Actual end date:	December 2020

The purpose of this preparatory action is to determine the current CO_2 emissions resulting from the production process of CO_2 gas from natural gas, to obtain a basis to compare the project´s achievements and benefits.

The establishment of the baseline of the project was tendered together with the elaboration of the eco-label for the "Green CO_2" product covered in action C_2, since both actions required a Life Cycle Assessment (LCA). This decision, based on technical reasons to facilitate the development of the associated tasks, led to delaying the target date set to determine the baseline (10/2019). Nevertheless, it has not affected the succesfull implementation of the rest of the project: Actions A2, C2 and D1 were carried out in parallel.

A carbon footprint monitoring tool was created to develop this action. This tool allows the analysis of different CO_2 production scenarios, enabling a comparison of the results.
Three CO_2 synthesis scenarios were considered:

1. CO_2 production from natural gas.
2. CO_2 production from industrial gases
3. CO_2 production from biomass (*Green CO_2* – LIFE CO_2IntBio project).

The Baseline Report, provides a comparison of the two current business as usual CO_2 production systems, using natural gas (Baseline 1) and Industrial gases (Baseline 2).
For a first approach to the environmental benefits of the *Green CO_2* production model, a theoretical study of this scenario (including the greenhouse) was introduced in the monitoring tool when the baseline was calculated.

Once the pilot CO_2 capture plant started its operation (June 2022), real data were collected to calculate an accurate LCA for scenario 3 (*Green CO_2*). The results obtained do not differ significantly from those yielded by the first analysis, considering that the greenhouse is not finally in the model.

The most remarkable environmental impact to compare is the Global Warming Potential (TOTAL GWP) measured in kg CO_2-eq/t CO_2 produced. The results are:

Baseline 1 (natural gas production): 535.10
Baseline 2 (industrial gases production): 638.31
Green CO_2 production (theoretical, including greenhouse): 112.32
Green CO_2 production (real): 115

We can draw two conclusions from these results:

- The reduction of GHG emissions/ for each ton of CO_2 produced with the LIFE CO_2IntBio model is:
  - 420 kg CO_2-eq regarding natural gas production.
  - 523 kg CO_2-eq regarding industrial gases production.

- Comparing the theoretical results that included the greenhouse in the model with the real data, there is only a difference of 2.68 kg CO_2-eq/t CO_2 produced.

Milestones and Deliverables: planned output and time schedule comparison.

Milestone	Foreseen date	Final date
Definition of the methodological chart for calculation of reduction of carbon emissions	07/2019	19/02/2020
Definition of project carbon monitoring tool	09/2019	02/04/2020
Definition of project carbon baseline	10/2019	02/04/2020

Deliverable	Foreseen date	Final date
A2.1 Carbon monitoring tool	09/2019	10/2020
A2.2 Carbon project baseline	10/2019	12/2020

C. Implementation actions:

C1. Implementation of a Plant for CO_2 capture and cleaning from a Biomass Power Plant.

Foreseen start date:	December 2019	Actual start date:	October 2020
Foreseen end date:	February 2022	Actual end date:	October 2022

To obtain CO_2 for the food and industry the flue gases from the biomass power plant must be captured and purified. This is a commercial pilot plant; although the technology is available and used in other plants, adjustments were needed to treat the biomass emissions which have a low CO_2 content and specific impurity and particle characteristics. The adaptation of this technology is the main demonstrative effect of the project.

The first step of the process is to clean the flue gases to eliminate some of the contaminants in the emissions. Once purified, the CO_2 is captured through an amine-based chemical absorption process; then the CO_2 is compressed and cooled. The chemical CO_2 obtained can be available in gas or liquid form. Once it is in liquid phase the non-condensable gases are eliminated and the liquid CO_2 is stored in tanks where it will be analysed to make sure it complies with food market specifications.

The key innovations of this project are the introduction of the following elements in the CO_2 plant:

- Filtering system to capture all the particles from the biomass combustion flue gases.
- Raw CO_2 pressure increase system.
- NOx removal system.
- Continuous MEA purification system (CO_2 chemical absorption).

The construction and the equipment of the CO_2 plant was tendered by partner CM in September 2019. The procedure was announced in the press and on the CM´s website.

On 17 December 2019 and 21 January 2020, two meetings involving technicians from GB (now ENSO), BdG and CM, were held at the biomass plant in Garray (Soria). The purpose was to analyse the planning and technical requirements of the works for the construction of the CO_2 plant.

In September 2020, most of the equipment for the plant was received and stored in a warehouse near Garray. On 14 September 2020, BdG and CM as project partners, held a work start-up coordination meeting with the construction company, and the work safety coordinator.

This action was determined by obtaining the licenses and agreements detailed in preparatory action A1. Once those permits have been obtained, it was possible to start the execution of the works in October 2020. Below are the more significant events during the construction:

- October – December 2020: Civil works - excavation.
- January – February 2021: Mounting and lifting of the plant's main towers.
- February – May 2021: Civil works related to the compressor building construction, the electrical stand, and other foundations. Besides, the rest of the equipment was installed, and the skids were assembled.
- June 2021: Installation of equipment connection pipes and electrical connection cells.
- June 2021: Technical stop made by BdG and used to carry out the connections between the biomass power plant and the new CO2 plant.
- September 2021: Final construction inspections and verifications before the commissioning of the plant, as well as TV modifications.
- September - December 2021: Direct feeding of the CO_2 plant with renewable energy from the biomass power plant. This type of electrical contract is a very novel approach in the Spanish electrical market (self-consumption – Type 2). Legalizing this connection took several months, which was not foreseen in the project plan.
  Nevertheless, Carburos Metálicos rented a power generation unit to be able to continue the commissioning work, although at a slower pace.
- January – March 22: Commissioning of the plant equipment and installations that could not be accomplished with the power generation unit but required the final electrical connection from the biomass power plant.
- March 22 – June 22: Plant operation tests to ensure performance in terms of production, quality, and consumption. Performance tests were successfully accomplished at the end of June.
- Plant handover for beneficial operation (internal AP document transferring management, operation, and security responsibilities from the Engineering Department to the Operations Department), signed on July 22.

The total area of the CO_2 plant is 1,050 m^2, including the capture facilities (40 x 20 m), tanks and other services.

The start of operation of the new plant has been delayed thirteen months later than initially planned in the Grant Agreement. The final acceptance of the plant has been in September 2022. For this reason, the actions that depended on the CO_2 plant operation have also been delayed: Action C2 (green CO_2 supply and DAP development), Action C4 (partner visits for replicability and transferability of results), Action D1 (KPI monitoring), Action D2 (socioeconomic impact report) and other communication and dissemination activities (including replicability and student visits to the plant).

Milestones and Deliverables: planned output and time schedule comparison.

The deliverables of this action have been redefined. The *First operation of the CO_2 plant report* was scheduled in the Grant Agreement for delivery one year after the operation of the plant start, but this first deliverable will collect the results of the commissioning and start-up of the plant and the *Second operation of the CO_2 plant report* describes the results obtained over a four-month period

Milestone	Foreseen date	Final date
Connection between the biomass power plant and the CO_2 plant	12/2019	06/2021
Completing and start of operation the CO_2 plant	02/2021	06/2022
Definitive acceptance of the plant	02/2022	09 /2022
Achieve one-year operation since provisional acceptance to compare results with baseline data from project	06/2022	06/2023
Achieve one-year operation since definitive acceptance to compare results with baseline data from project	09/2022	9/2023

Deliverable	Foreseen date	Final date
C1.1 Commissioning and Start-up Report	02/2022	06/2022
C1.2 First Operation of the CO_2 plant report	02/2023	10/2022

C2. Creating CO_2 value chains: Renewable Heat and green CO_2 supply to a Greenhouse.

Foreseen start date:	December 2019	Actual start date:	October 2020
Foreseen end date:	December 2022	Actual end date:	Partially Unrealized

C2.1 CO_2, renewable heat and electricity supply to the greenhouse.

The CO_2 plant was to be linked to an existing greenhouse near the biomass power plant via a CO_2 gas pipeline, as well as to the biomass power plant via a steam pipeline. Work to design the connection to the greenhouse began with the public authorities responsible of legal permits and different technical options were analysed. However, the events with the greenhouse have not been developed as expected.

Uncertainty regarding the future of the greenhouse led to the decision to postpone the building of the CO_2 gas pipeline until the greenhouse finishes testing the new crops and defines its needs. Nevertheless, the CO_2 pilot plant is prepared to connect the pipeline for the supply of CO_2 to the greenhouse if necessary.

No new synergies could be established during the lifetime of the project, despite efforts to find alternatives to the greenhouse as the final consumer:

- Search for high-tech greenhouses with a potential interest in expanding their business.
- New industrial symbiosis options, especially with a new hydrogen production plant that is to be built near the LIFE CO_2IntBio plants, with the possibility of producing e-methanol combining green H_2 and green CO_2.

Nevertheless, new value chains for CO_2 have been implemented: as the LCA in Action A2 shows, liquid *Green CO_2* supply to local customers reduces the emissions related to road transport from the current CO_2 production plant (Tarragona). In addition, the utilization of *Green CO_2* is an opportunity to decarbonize business models of CO_2 consumers that use renewable CO2 as raw material.

C2.2 Eco-labelling development: EPD for new products derived from renewable CO_2.

An ecolabel system for the renewable and circular CO_2 commercial gas produced in the pilot plant was developed, to strengthen replicability, market potential and environmental awareness regarding the mitigation of climate change by avoiding emissions and transforming them into new valuable products.

The methodology used to define the ecolabel was similar to a voluntary Type III ecolabel "Environmental Product Declaration" (EPD) by calculating their Life Cycle (LCA). An external assistance has been recruited trhough public tender to implement this action together with action A2.

Once the pilot plant was fully operative (June 2022), data for the LCA were collected over a four month period. Data were regarded as correct considering a stable CO_2 production. The EPD was developed following the *PCR 2021:03 Basic Chemicals*, which includes CO_2, and it is valid until 2025. In January 2023 it was verified and registered in Environdec: https://www.environdec.com/library/epd7550

Certification with a EPD is an added value to the CO_2 produced in the project. To highlight this value, Carburos Metálicos is including this information in their marketing campaigns.

Milestones and Deliverables: planned output and time schedule comparison.

Operation reports of the use of renewable CO_2 as added value product in a greenhouse have been substituted for a new deliverable: "CO_2 value chains".

Milestone	Foreseen date	Final date
Ecolabel / Environmental Declaration implemented	12/2022	01/2023
Work start (pipelines construction)	12/2019	
Start-up trials and tests (heat and CO_2 supply)	02/2020	
Commercial operation (heat supply)	06/2020	

Deliverable	Foreseen date	Final date
C2.1 Operation report of the use of renewable CO_2 as added value product in a greenhouse	12/2022	
C2.2 Second operation report of the use of renewable CO_2 as added value product in a greenhouse	12/2022	

C2.1 CO2 Value Chain		06/2023
C2.2 Ecolabel / Environmental Declaration Report	12/2021	01/2023

C3. Adaptation of the Biomass Power Plant to produce added value green CO_2 (Industrial and Food Grade Quality).

Foreseen start date:	October 2019	Actual start date:	October 2020
Foreseen end date:	July 2020	Actual end date:	June 2021

A certain number of adaptations were carried out inside BdG to improve and adapt previous infrastructures to allow the installation of a CO_2 Plant.

In the meetings mentioned in C1, the necessary adaptation works for the existing biomass power plant, owned by BdG, were also analysed. On the 16th of March 2020, an internal meeting was held to define the electrical and mechanical connection between the two plants, reaching the following conclusions:

- Definition of scale and battery limits.
- Definition of control system between plants.
- Definition of water consumption (and type).
- Current weighing design. Mechanical interface definition (pending details).
- Adaptation of current land network.
- Connection configuration. Electrical interface definition (at 45 kV).

A crucial point in the adaptation of the biomass plant was the need to modify the existing steam turbine to supply steam/heat to the new CO2 carbon capture and purification pilot plant. External assistance for its adaptation was directly acquired, instead of requesting three offers as the budget volume required. This had been stated in the Project Life Proposal and discussed in the first progress meeting with the Neemo monitor in April 2020.

This equipment is the core of the biomass power plant and is subject to guarantee by the manufacturer since a Long-Term Service Agreement (LTSA) with a six-year contractual period was in force, ending in October 2021. The proposed modifications have affected the carriers of some blade stages as well as other key components such as bearings (thrust bearing), seals, etc. These components and elements are tailor-made and subject to supplier patents, which makes the installation of different elements unfeasible without engaging in risky and expensive reverse engineering. Against this background, allocating the modification order to any party/contractor other than the supplier (MAN) was a risk that could not be assumed.

To install the turbine, it was necessary to stop the biomass power plant. Although the time expected for its completion was one month, there was an almost two-month delay in the delivery of the turbine. This issue was completely unpredictable and beyond the control of the LIFE consortium; BdG decided to paralyze payments until the turbine arrived because of the consequences of the biomass power plant stoppage. Finally, in June 2021, after all the adaptations were completed, the connection between the power plant and the carbon capture and purification plant was accomplished.

Milestones and Deliverables: planned output and time schedule comparison.

Deliverables C3.1 and C3.2 have been unified in a single document, "Deliverable C3: Biomass plant adaptation and new adapted protocols".

Milestone	Foreseen date	Final date
Work start (connection to CO_2 plant)	10/2019	10/2020
Mechanical and electrical completion	03/2020	06/2021
Acceptance tests (connection to CO_2 plant)	05/2020	06/2021
Start of Integration of control systems	07/2020	06/2021

Deliverable	Foreseen date	Final date
C3.1 Report on achievement of all needed changes/adaptations	05/2020	02/2022
C3.2 New adapted protocols	07/2020	02/2022

C4. Replicability to other places and Transferability to other industrial processes.

Foreseen start date:	January 2021	Actual start date:	March 2021
Foreseen end date:	May 2023	Actual end date:	February 2023

To develop this action the consortium has worked in parallel with an external assistance and Close to Market (C2M) NEEMO´s unit to support specialised issued. To complete both activities contemplated in Action C3 and to draw up the socioeconomic report (Action D2), FPNCyL issued an external assistance tender in April 2021. Since all the studies were related, all the tasks were awarded in a single contract for more efficient budget management.

Results are divided into a Business Plan and Replicability and Transferability activities.

BUSINESS PLAN
An internal CM working group was created to prepare the Business Plan. The project´s first contact with Neemo´s C2M unit took place in March 2020. Then, the work was focused in developing a Business Canvas and a Basic Business Plan that were sent to Neemo´s C2M in October 2020 receiving its feedback to complete the proposal.

The external assistance hired prepared a CO_2 market research to provide information about the current volume of t CO_2 that is used worldwide, sales and especially, future market growth expectations. Emphasis should be placed on the potential of the multiple uses of CO_2 and research aimed at developing novel applications to achieve more sustainable chemistry. In this context a renewable product like *Green CO_2* could be well accepted in the market. A business case file with the most relevant information completes the Business Plan Deliverable.

REPLICABILITY AND TRANSFERABILITY PLAN AND ACTIVITIES

In June 2021, the external assistance, NUVE Consulting, started to work in the replicability and transferability plan contributing with an analysis of the potential to replicate the porject´s symbiosis model.

This involved searching biogenic carbon sources, considering the main parameters to determine the viability of a CO_2 capture project:
- CO_2 emissions volume: minimum 30,000t/year.
- CO_2 emissions flow: constancy over time is required.

In addition, possible customers near the biogenic CO_2 sources were located.

Finally, to disseminate the results among key stakeholders and promote replicability and transferability, three meetings with groups of interests were scheduled:

- 30/01/2023 - National policymakers in the area of climate change mitigation. It was carried out online to ensure the participation of as many Spanish regional government representatives as possible.
- 31/01/2023 – Biomass and energy sector.
- 09/02/2023 – CO_2 customers.

The last two sessions took place at the Garray facilities, which made an on-site tour of the biomass power-plant and the CO_2 plant possible.

Milestones and Deliverables: planned output and time schedule comparison.

Milestone	Foreseen date	Final date
Assess the potential replicability on other geographical areas	04/2022	04/2022
Asses the transferability to other geographical areas	04/2022	04/2022
Business Plan	05/2022	06/2022
Reevaluated Business Plan	02/2023	10/2022
Drafting Replication Plan	05/2022	10/2022

Deliverable	Foreseen date	Final date
C4.1 Business Plan	05/2022	11/2022
C4.2 Report on replication and transferability activities	05/2023	03/2023
C4.3 Replication Plan	05/2022	06/2022

D. Monitoring of the impact of the project actions:

D1. Monitoring project performance and key level indicators.

Foreseen start date:	October 2020	Actual start date:	November 2020
Foreseen end date:	March 2023	Actual end date:	June 2023

This action is aimed at monitoring the results and impact of the project in terms of climate change mitigation, quantitatively and qualitatively, collecting data for a relevant set of performance and key-level indicators. To obtain appropriate information, this action is connected to preparatory action A2, where the baseline for the indicators is established (monitoring tool includes an exclusive tab for calculating the LIFE project´s KPI).

In addition to this internal monitoring tool, KPI data have been completed on the KPI webtool.: KPI have been redefined and/or recalculated assuming that the greenhouse does not participate in the project (more info in paragraph 7 KPI).

Milestones and Deliverables: planned output and time schedule comparison.

Milestone	Foreseen date	Final date
Data validation for Performance indicator Progress Report	10/2020	11/2021

Data validation for Performance indicators Mid-term report	03/2022	03/2022
Data validation for Performance indicators Final report	05/2023	05/2023

Deliverable	Foreseen date	Final date
D1.1 Performance indicators progress report	11/2020	11/2020
D1.2 Performance indicators Mid-term report	04/2022	02/2022
D1.3Performance indicators Final report	09/2023	09/2023

D2. Monitoring Socio economic impact.

Foreseen start date:	October 2019	Actual start date:	September 2020
Foreseen end date:	November 2022	Actual end date:	December 2022

The impact must be also measured in terms of the socioeconomic effect of the implementation of a pilot project and integrated business approach to capture and purify CO_2 from biomass and use it in a greenhouse and by other end users. Some of these results are also reflected in the project KPIs (jobs created, number of customers, number of entities or individuals aware or changing behaviour).

A tender for external assistance was issued in April 2021 (with C4 actions – Replicability and Transferability Plan and Business Plan-). The partners collected the data needed to calculate the socioeconomic indicators from May 2022 (commissioning and start-up of the CO_2 plant) to July 2022. Considering that completing a year of operation would have been optimum for data gathering, further information was estimated based on the precedent real data.

From a time perspective, two phases were analysed: the first phase where the new CO_2 plant was constructed and the existing biomass plant was adapted; and the second phase involving the CO_2 plant operation. The methodology used is the same as the one followed for the annual accounts of Spain, with input-output tables of economic impact calculations, according to the national statistics.

The main conclusions are:

- The total economic impact (direct and indirect) during the project is estimated to be 37,893,259.65€ (biomass powerplant adaptation + carbon capture plant construction + first year operation)
- With a stable production of 33,000 CO_2 t/year (only liquid CO_2 production), the project impact could be of 31,852,548.33 €/year.
- With a stable production of 55,000 CO_2 t/year (maximum capacity of the plant) the project impact could be of 50,611,264.34 €/year.

At the social level, the most significant indicator considered was employment creation: 24 posts during the first phase (plant construction and biomass plant adaptation) and 2 highly qualified jobs to manage the new plant.

Milestones and Deliverables: planned output and time schedule comparison.

Milestone	Foreseen date	Final date
Drafting key data and indicators for the socioeconomic impact report	10/2019	09/2020

Validate of socioeconomic report	01/2022	12/2022
Feedback from stakeholders	11/2022	01/2022

Deliverable	Foreseen date	Final date
D2.1 Socio-economic report	02/2022	03/2023

E. Communication and dissemination of results:

E1. Dissemination Plan.

Foreseen start date:	September 2019	Actual start date:	September 2019
Foreseen end date:	May 2023	Actual end date:	May 2023

The first step to implement this action was the creation in November 2019 of a specific Dissemination Committee created in November 2019 with at least one representative of the project partners. Once the committee was formed, in keeping with the date of the Grant Agreement, a Dissemination Strategy including different plans and protocols was developed. The activities are described in Deliverables E1.1 to E1. 6 and can be summarized as follows:

DISSEMINATION MATERIALS:
The logo and other materials, such us roll-up, photocall and noticeboard have been developed in the first six months of the project (updated with the logo change of GB to ENSO in 09/2020).

FPNCyL has contracted through a public tender the external assistance to prepare specific dissemination material for the project, including 5 infographics, 5 micro videos, and a general video that offers a general vision of the project. In addition, complementary material (brochures, other infographics or videos have been also created by the partners.

NOTICE BOARDS:
All the partners have already the Notice Boards located at a strategic place in their headquarters fulfilling the objectives.

PROJECT WEBSITE:
It has been created a specifically project website managed by coordinator FPNCyL. The website has been operational since December 2019.
The domain www.lifeCO2intbio.eu has been reserved. Also, an email address for contacts and information: lifeco2intbio@lifeco2intbio.eu.

The data of users and visits to the web in February 2022 are 8.435 users and 24.926 visits what supposes a media of 2.109 unique visits per year. The objective was having 4.000 visits per year.

All the web sites of the partners, make a specific mention of the LIFE project.

SOCIAL MEDIA:
The Communication Committee decided not to create LIFE project social media because the partners profiles are well positioned, active and update with significant content and have a

solid group of followers that assure the dissemination of the LIFE project. Professional profiles of the project staff intensify the social media impacts.

147 publications have been made using the hashtag #lifeCO2IntBio, in partners profiles in LinkedIn, Twitter, Facebook and Instagram and also by some key stakeholders, with a total 63.169 views and 2.389 interactions. The expected results for the complete period of the project are 2.000 impacts both in LinkedIn and Twitter obtaining 37.280 views/1.584 interactions and 24.151 views/677 interactions respectively.

SPECIALIZED EVENTS:

Until December 2021 the project has been presented in 19 related events and specialized fairs about biomass, circular economy or sustainability.
The impact of this action is of 579 people that have participated directly in the conferences, but the real impact is far much thanks to the visibility of the project in Fairs of a big affluence (about 74.795 assistants) and because some of the presentations are available in video (with 1.912 visualizations in Youtube until the moment).
The goal in this activity was to achieve about 18.000 indirect impacts / year and 500 direct participants. The cancelation of presential events, due to preventive health care, has made difficult to achieve the objectives of direct impacts.

In CONAMA (Spanish Environment Congress), it was organized an event aimed to policy makers, not only from Castilla y León as it was indicated in the Grant Agreement, but also from the rest of the Spanish Regions. This meeting ("CO_2 transformation in raw material: new strategies of climate change mitigation) had the objective of analyse the inclusion of CCU in climate change mitigation policies. This event inspired one of the replicability activities.

EUROPEAN WEEK OF REGIONS AND CITIES (EWRC):
A CCU International Meeting in Brussels for EU regional authorities and CCU stakeholders was foreseen as a dissemination activity–. Fundación Patrimonio Natural of Castilla y León managed together with the Regional Government of Castilla y León the candidature to introduce the project in the activities organized by the EU Committee of Regions and Cities. The online Workshop "Our Forests, our Future" was developed in the 19th European Week of Regions and Cities (11-15 October 2021). This seminar analysed the role of Europe´s forests in achieving climate targets supporting European policies.

ACTIVITIES WITH UNIVERSITY STUDENTS have been also made, both face to face and online, achieving an impact in 2.737 students

NETWORKING:
A database of possible project was elaborated in 2020. In March 2021 contact via e-mail was made with 48 entities. Some networking activities have been developed with the next results:

- A document with a review of the state of CCU in regional and national strategies in Spain has been sent to the Eccselerate project to complete the information included about Spain policies in the deliverable D4.1 of the H2020 project.
- Collaboration in the MOOC of Circular Economy created by the Interreg-Poctep Circular Labs
- Participation in a seminar organized by LIFE Smart Agromobility

- Organisation of the seminar with Spanish policymakers with the objective of introducing CCU in national climate change mitigation policies.
- Organisation with the EWRC of the session Our Forest, Our Futures.

Milestones and Deliverables: planned output and time schedule comparison.

In collaboration with the greenhouse, it was intended to develop a "Green Roses Environmental Campaign" that has not been possible to make.

Milestone	Foreseen date	Final date
Drafting Layman´s Report	02/2023	02/2023
Project website available	09/2019	09/2019
Drafting Communication and Dissemination Plan	11/2019	11/2019
Identify and contacting stakeholder and networking projects	11/2019	11/2020
CONAMA National Environmental Congress (Madrid)	11/2020	06/2021
CCU International Meeting in Brussels for EU regional authorities and CCU stakeholders	05/2021	10/2021
Green roses environmental awareness campaign	03/2022	Not done
Mailing to stakeholder	05/2021	03/2021
EU Funding Environmental Authorities Network – CCU Meeting	10/2021	10/2021
CCU meeting in Castilla y León for stakeholder and innovation policy maker of region	04/2020	06/2021

Deliverable	Foreseen date	Final date
E1.1 Project website	09/2019	12/2019
E1.2 Notice Boards	11/2019	06/2020
E1.3 Communication and Dissemination Report 1	10/2020	11/2020
E1.4 Communication and Dissemination Report 2	03/2022	02/2022
E1.5 Layman´s Report	03/2023	03/2023
E1.6 Communication and Dissemination Report 3	05/2023	06/2023

F. Project management:

F1. Project Management.

Foreseen start date:	June 2019	Actual start date:	June 2019
Foreseen end date:	May 2023	Actual end date:	May 2023

The different committees of the project have communicated with each other fluently via email, phone, and online meetings. Although in ENSO there have been certain internal organizational changes, the project management has not been affected.

A project launch meeting (kick-off) that was attended by all the partners was held in the city of Valladolid on 2 July 2019. The climate project's kick-off meeting was held in Brussels on 3-4 October 2019.

The first monitoring report was prepared in March 2020 and presented together with the financial update (June 2019 – February 2020) at the first monitoring meeting held with the

assigned Neemo monitoring team on 15 April 2020. The meeting took place online due to the COVID-19 health emergency. The main contingency analyzed was the change of owner and name of the business group Gestamp Biomass (now ENSO Energy Environment and Sustainability) and the need for an amendment.

In December 2020 the Progress Report was sent to the Agency.

In February 2021 a request for an administrative amendment was sent to the Agency on the subject of the change of ownership and social name of the associated beneficiary Gestamp Biomass O&M to ENSO O&M (Energy, Environment and Sustainability Operations and Maintenance). It also concerned the change of the affiliate company (the new owner of the Partner GBO&M). These administrative modifications did not affect the correct implementation of the project (project objectives, results, technical actions, and budget). In December 2021, the letter from the CINEA Team regarding the amendment to the Grant Agreement was received with the approval of the request.

The second monitoring meeting was held online on 15 April 2021. The EC sent a post-mission letter on 15 July 2021 requesting a report of the situation to be delivered before 30 September 2021. This report was sent on time to the Agency, explaining the current situation of the project and the challenges that were to be faced in the following months, especially the negotiations with the new greenhouse owner and the delays in the CO2 plant construction.

In April 2022, the Mid-term Report was sent to the EC and the request for the second pre-financing payment. Before receiving the mid-term letter, the third monitoring meeting was held on 20 June 2022. It was finally held face-to-face in Garray with the advantage of being able to visit the carbon capture plant when already operative. One of the main issues addressed during the meeting was the fact that the greenhouse owned by Ondara would not participate in the project activities in the medium term.

The last monitoring visit was held on 12 June 2023 in Garray, near the end date of the project (16 June 2023). This meeting was an interesting recap of the entire project and is considered the final project meeting.

Milestones and Deliverables: planned output and time schedule comparison.

Milestone	Foreseen date	Final date
Legal-administrative formalization with the Commission	06/2019	06/2019
Partneres Kick-off meeting	07/2019	07/2019
Teams, committes and work groups: operatives	09/2019	09/2019
Drafting Progress Report 1	10/2020	11/2020
Drafting Midterm Report	03/2022	03/2022
Drafting After LIFE Plan	03/2023	03/2023
Drafting Final Report	05/2023	05/2023

Deliverable	Foreseen date	Final date
F1.1 Dossier on procedures, work protocols and communications, tasks distribution, and execution schedules and budgetary Annex	09/2019	12/2019
F1.2 Progress Report 1	11/2020	12/2020
F1.3 Midterm Report	04/2022	04/2022
F1.4 After LIFE Plan	05/2023	05/2023

F1.5 Financial Audit	07/2023	07/2023
F1.6 Final Report	09/2023	09/2023

6.2Main deviations, problems and corrective actions implemented.

Some of the problems and difficulties encountered have been administrative, including changes of ownerships of partners and third parties involved in the project:

- Change of ownership of the partner GESTAMP and change commercial name to ENSO: An amendment to the Grant Agreement was made to update the ownership of GESTAMP but this change was not relevant to the course of the project.
- Change of ownership of the adjacent greenhouse (green CO_2 gas consumer). This has been one of the main challenges that the project faced. Aleia Roses was the company that owned the greenhouse when the proposal was approved. Aleia Roses signed commercial agreements with CM and GESTAMP (ENSO) for the supply of CO_2 gas and energy. Aleia Roses suffered several legal changes from 2019 to 2021. The greenhouse was sold to Full Moon, an investment fund that renamed the company Ondara. It has also changed the industrial crop from roses to medical cannabis.

The CO_2 gas and energy contracts had to be renegotiated with the new owner of the greenhouse. Ondara has been testing the new crop during this time, but they still need to define their future CO_2 and energy needs. At the end of the project, was no consumption of CO_2 from Carburos Metálicos. The challenges associated to this situation are:

- Uncertainty on the CO_2 production: 1/3 of the expected green CO_2 to be produced by the new CO_2 plant is obtained in gas phase and was going to be delivered to the greenhouse. The plant cannot liquify this CO_2 as the maximum liquefaction capability is 2/3 of the total CO_2 production. So, it will not be possible to use the total production capacity of the CO_2 capture plant with the current design.
- Delay of pipeline construction: the CO_2 gas was going to be delivered to the greenhouse via a new pipeline. The pipeline connection has not been built in the project duration and the costs associated have not been declared. Nevertheless, the connections are prepared to construct the pipeline if there is the possibility of deliver CO_2 gas to the greenhouse or to any other new industry located in the nearby in the future. In addition to the CO_2 delivery from the CO_2 plant, the biomass power plant is prepared to provide renewable energy stimulating the industrial symbiosis model and the use of renewable energy.
- Change in the industrial symbiosis approach of the project: the circular economy model included the greenhouse as a proximity consumer but also integrated their plant residue as biomass fuel for the power plant.

To overcome the challenges that the difficult situation of the greenhouse has generated, the project members have been looking for alternatives. We have made contacts with high-tech greenhouses to explore the possibility of settle down in Garray in the next years. Within the options we find also, the possibility of the production of sustainable e-methanol or e-kerosene. These products are achieved by combining CO_2 with H_2. At the end of the LIFE project there are new projects in phase of construction in the PEMA of Garray, such as a new Green Hydrogen Plant, with future potential to develop synergies with the CO_2 plant.

There have been also technical delays, mostly due to the restrictions during the pandemic:

- Delay in obtaining administrative and legal licences. Delay on the construction of the CO_2 capture and purification plant and start-up: the construction of the new plant was foreseen to start in December 2019 and it started in October 2020. (Described in A.1 and C.1)
- The biomass power plant needed an important modification in the turbine to adapt the steam stream to the CO_2 capture plant requirements. (Described in C.3)
- The legalization of the power contract connexion between the biomass power plant and the CO_2 plant took longer than expected as it is a new contract type. (Described in C.1)

These problems impacted with a delay in the CO_2 Plant and other related works execution of one year. It was expected that the carbon cleaning plant started its operation in February 2021. Finally, the plant started to produce CO_2 in April 2022, completing the plant commissioning works in June 2022. This fact has conditioned other project activities, especially the obtaining of the EPD and the development of the Socioeconomic Report since both actions required data collected for at least three to six months of the CO_2 plant operation. Nevertheless, the final acceptance of the CO_2 plant was achieved in a shorter time (five months) than it was expected (one year), in September 2022 after obtaining the FSSC 22000 certification (food-grade quality).

The LIFE CO2IntBio project was considered as an industrial pilot close-to- market project with expectations of introducing the new product obtained, renewable CO_2, into the market. The C2M unit of the Neemo´s team supported the project in the elaboration of a Business Plan to assess the economic viability of this product in the market at the end of the project. The works developed by the technical team of the project contributed to obtain sooner as expected a high-quality chemical CO_2 in the carbon capture plant making it possible to start with the delivery to local customers at an earlier stage that it was expected, at least to test the acceptance of the new product by customers.

But, at the same time, during 2022 the situation registered in the European carbon dioxide supply chain (gas crisis due to the war in Ucrania) caused a great impact due to the situation of exhausted shortages, as industrial sector based on fossil-fuel where emissions are captured to produce chemical CO_2 (business-as-usual), stopped their operations. To guarantee the supply to customers (food and beverage sector mainly) CARBUROS decided to accelerate and optimise the production of chemical CO_2 at the plant in Garray, beginning to deliver green CO_2 from Garray to their regular customers, generating unexpected income to the project. (More details can be found in Annex III).

These is an additional lesson learned, as the chemical CO_2 product obtained by capture and purification of biogenic origin emissions, contributes to the energy independence, according to the objectives of REPOWER EU. CO_2 captured in energy plants, that use biomass as fuel are using local biogenic resources, and allows a territorial decentralization, energy independence and guarantees the supply of the chemical product obtained in the capture and purification of their emissions process.

6.3Evaluation of Project Implementation

The main target of the project, the demonstration of the feasibility of carbon emissions capture and cleaning technologies for utilization as raw material to generate new products and mitigate emissions at Biomass Power Plants has been achieved.

The CO_2 capture and purification plant was constructed and started its operation in April 2022, working regurlarly since June 2022 once the adaptation, testing and technical inputs from the project demonstrated its technical and environmental viability. In addition, the new product Green CO_2 has been successfully introduced into the market.

These means that the total budget allocated is over the foreseen budget approved at the Grant Agreement due to external contingencies (delays due to pandemic restrictions, increase in the cost of products and freight, etc) and additional non foreseen costs.

Activities linked to the start-up of the CO_2 plant, have been implemented once the carbon capture plant was operative to collect reliable data for the reports. However, actions and targets linked to the involvement of the greenhouse in the project have not been achieved. Final Report KPI have been recalculated without the greenhouse involvement.

The state of implementation of the project results can be seen in the following table:

Action	Foreseen in the revised proposal	Achieved	Evaluation
A2	**Objectives**: to determine the carbon footprint baseline of the project. **Expected results**: monitoring footprint tool	Yes	A footprint monitoring tool was created including the KPIs to manage a unique monitoring tool.
C1	**Objectives**: implementation of a new carbon capture and purification plant. **Expected results**: carbon capture and purification plant operative	Yes	The CO_2 plant was constructed and passed several operation tests. Start-up operations from April to June 22. Plant performance test at the end of June. Handover from Engineering to Operations July 22.
C2	**Objectives**: to demonstrate and certify the benefits and CO_2 reduction of an integrated business approach. **Expected results**: to reduce emissions from three different industrial sectors: <u>Carbon capture production</u>: 498 CO_2 t/y avoided in CO_2 liquid production. 133 CO_2 t/year carbon footprint of CO_2 transport to the greenhouse avoided. 175 CO_2 t/y reduced carbon footprint to CO_2 supply to third parties <u>Heat supply</u>: 14,844 CO_2 t/year emission reduction for the heat supply to the greenhouse. <u>Greenhouse reduction</u>: 5,387 CO_2 t/year emission reduction by burning greenhouse residues instead of disposing them in landfill. 4.3 CO_2 t/y reduced carbon footprint of 1,863 t/y of waste not transported to landfill (considering 20 km distance)	Partially achieved	These results have been calculated with real data assuming that it has been not possible to involve the greenhouse in the symbiosis model approach. Carbon capture production: 13,866 CO_2 t/y avoided in CO_2 liquid production. Transport emissions reduction is calculated considering CO_2 proximity delivery: - Reduction of 116,347 km of truck transport - Reduction of 295 t/y in CO_2 supply (taking into account 2/3 within a radio of 200km from Garray and 1/3 of 800 km from Tarragona to supply the same quantity of the baseline). The indicators depending on the greenhouse activity cannot be calculated (reductions due to heat supply to the greenhouse and related to greenhouse´s waste management).

C2	**Objectives**: to create a new value chain and product in the commercial CO_2 industry (green CO_2 from renewable origin). **Expected results**: - Creating a voluntary environmental declaration / label	Yes	An ecolabel i type III, an Environmental Product Declaration (EPD) has been developed and published.
C1/C2	**Objectives:** to increase energy efficiency in the industrial processes and increase the use of renewable energy in EU. **Expected results**: - Reduction on transport energy for CO_2 and for residues will account to about:1,281,295 kWh/y.	Yes	Energy savings in terms of transport are of 3,637,725 kWh/y (2/3 transport from Garray, distance 200km + 1/3 transport from Tarragona, distance 800 km) Waste reduction from the greenhouse could not be calculated. BdG also provides renewable energy and combustion gasses to the CO_2 capture and purification plant, cannot supply energy to the greenhouse: - 1.758.600 kWh/y of renewable electricity - 10.668.590 kWh/y of renewable thermal energy (water steam).
C1/C2	**Objectives**: to enhance circular economy by turning two waste flows into new materials for other processes (flue gas from biomass combustion and vegetable waste currently landfilled). **Expected results**: - Sustainable forestry: Additional requirements of 19,363 t of biomass /year will lead to enhance sustainable forest management in the area. - Waste valorization: 1,863 t/year less in terms of landfilling, transport, etc	Yes	Flue gas was evaluated in the CO2 plant testing phase, obtaining the FSSC 22000 certification that guarantees high quality of the CO2 recovered Sustainable forestry partly linked to the CO2 capture and purification plant is estimated to be 25,469 t/y. In addition, BdG is certified under the SURE scheme according to the REDII Directive. Sustainable forestry linked to the foreseen increase in the capacity of the greenhouse could not be achieved. By the end of the project, waste valorisation from the greenhouse had not been achieved.
C4	**Objectives:** to demonstrate the technical and economic viability of a continuous and sustainable capture and purification of CO_2 from biomass flue gas in order to define replicability. **Expected results**: Determining actual consumption of components for the plant versus expected ones to quantify technical and economical results	Yes	During the commissioning phase, the CO2 plant technology was tested and some technical issues were solved. Consumptions of the carbon capture plant: - Electricity: 1.758.600 kWh/y - Water steam: 10.668.590 kWh/y - Water: 9.936 t/y - Sosa: 3,26 t/y - Amine: 2,47 t/y - Activated carbon: 0,201 t/y - Other materials of the process and equipments (filters, catalysts…): 0,002 t/y
C4	**Objectives**: to disseminate project results to replicate it or transfer it to other industrial sectors, locations, technologies. **Expected results**: replicability and transferability plan and business plan.	Yes	A Replicability and Transferability Report has been developed. 3 specific replicability meetings have been done. A business plan has also been elaborated.
D2	**Objectives**: monitoring the socioeconomic impact. **Expected results**: Socio-economic report.	Yes	A socio-economic report has been done. .

- Indicate which project results have been immediately visible and which results will only become apparent after a certain time period.

  The results described above are visible at the end of the project. To develop the Life Cycle Assessment of the Green CO_2 (necessary to obtain the Environmental Product Declaration) and to elaborate the socioeconomic report, data of the carbon capture plant have been collected for four months (June to August 2022). These data have been used to calculate environmental and socioeconomic indicators; to obtain yearly indicators the data have been extrapolated, considering that the carbon capture plant is working on a regular basis.

– Describe the results of the replication efforts.

  The possibilities to replicate this project have been assessed in the Replicability and Transferability Report. The key elements that have been identified are the following:

  - Need to identify CO_2 emitters that use renewable energy, and the CO_2 has a renewable origin.
  - To make the CO_2 capture and purification feasible we need high CO_2 concentration in the raw gas and limited concentration of particles and impurities.
  - Only those emitters with a CO_2 user with big demand nearby will justify the CO_2 gas pipeline.

  Three specific visits with strategic partners (biomass sector, CO_2 consumers and climate change policymakers) have been performanced during the first trimester of 2023. Some companies have also visited the project (Gonvarri in June 2023) for the interest in replicating a similar model of carbon capture.

– Indicate the effectiveness of the dissemination activities and comment on any major drawbacks.

  Dissemination activities effectiveness has been conditioned by the pandemic situation and the restrictions to develop face to face activities. Nevertheless, some of the activities foreseen have been adapted to online formats, achieving results near to objectives expected.
  Other drawback that the project has faced about dissemination activities has been the CO_2 crises considering more cautious to minimize project communication during those months.

  Visits to the web page have achieved almost 25.000 visits, but only 8.435 unique visits (users in Google Analytics). The objective has not been achieved (4.000 unique visits/year) although the promotion made in partnership social media, where is always included a reference to the web are not accounted. Social media strategy has also been successful; the decision of using beneficiary's social media profiles instead of creating a specific project profile, has allow a bigger impact.

– Policy impact

  LIFE CO_2IntBio project has implemented several activities addressed to policymakers to give visibility to CCU as a climate change mitigation strategy:

- In 2020, at the National Environmental Congress (CONAMA) was organized an event: "CO_2 transformation in raw material: new strategies of climate change mitigation"

addressed to policy makers and enterprises. 15 presential participants and 59 participants online. (covid restrictions applicable)

- In October 2021 following this line at a EU level, Fundación Patrimonio Natural of Castilla y León (Regional Government of Castilla y León), took part in the 19th European Week of Regions and Cities (online meeting) exposing the role of CCU in climate change mitigation and opening the discussion of including CCU in climate change mitigation policies in a European context. 82 representatives from European regions and other stakeholder participated at the meeting.

- In 2023 an online event addressed to assess the role of CCU at Climate Change Strategies in Spain, together with policy-makers at National and Regional levels: "CO_2 utilization as climate change mitigation strategy". 17 policy-makers participated at the meeting representing the Spanish climate change office (3 representatives) and 14 representatives from 5 regional governments.

The LIFE project has also been included as part of the Circular Systemic Solution developed by the Regional Government of Castilla y León as a pilot region of the European Commission Circular Cities and Regions Initiative (CCRI) launched as part of the EC Circular Economy Action Plan, and we have been able to introduce LIFE CO2IntBio project to the CCRU stakeholder (regions, cities, EIB, OECD, Horizon projects, and other institutions).

The LIFE CO_2IntBio Project lessons have contributed to the regional policy in Castilla y León as in the draft of the future law of Climate Change of Castilla y León, the Regional Government has included a paragraph about CCU technologies as mitigation tool.

The coordinator of the LIFE CO_2IntBio Project has participated in public consultation of the new Spanish Integrated Climate and Energy Plan (PNIEC 2023/2030) enhancing the visibility of CCU at several measures proposed at the Plan.

6.4Analysis of benefits

1. Environmental benefits

a. <u>Direct / quantitative environmental benefits:</u>
With the start-up of the CO_2 plant, a new sustainable product, green CO_2 will be available in the market. According to the theoretical LCA calculated in action A2 it will be possible a reduction of 420 kg CO_2-eq. for every ton of CO_2 produced. This means that the project methodology expects a CO_2 reduction of 13.866 t/year (52,09%) at the end of the project and a reduction of 20.900 CO_2 t/year (78,51%) five years after the end of the project.

Indirect economic effects will benefit local transport or fuel suppliers for the CO_2 produced at the LIFE CO_2IntBio plant. It is expected than almost 33,000 t/year of chemical CO_2 will be supplied to local customers (at a distance of 200 km – round trip-). This means the need of.1,650 travels by truck (20 tonnes capacity) and a consumption of fuel of 132,000 liter approximately with a direct impact in local economy, but in the other hand, reducing CO_2 emissions (savings of 528,000 fuel liter/year) of business-as-usual transport from long distance CO_2 producers (around 800 km round trip).

b. Qualitative environmental benefits

The technology tested in the LIFE CO_2IntBio project has allowed to escalate a system of chemical absorption with ammines to an industrial level for gases resulting from the biomass combustion. This technology has been proven and demonstrated with this project encouraging green chemistry with more sustainable products derived from green CO_2

The new product "green CO_2" will be used as a sustainable raw material and will permit to their consumers to improve their Corporate Social Responsibility (CSR) and to reduce the carbon footprint of their products. It will also increase the awareness of final consumers having a high impact in change of behaviour.

This new productive model for CO_2 based in an industrial symbiosis approach, is a reference of sustainable production for intensive energy industries. It contributes to enhance climate resilience not only for the industries involved, but also for regional and national governments in order to achieve their climate goals.

2. Economic benefits

The economic impact has been assessed in action D2. It estimated that the influence (direct + indirect) of the project in the economy is of 37,893,259.65 € (including all the activities of the project), with a potential of 31,852,548.33 €/year of economic influence with the operation of the plant, that can be increased to 50,611,264.34 €/year if the production of CO_2 reaches the maximum capacity of the plant.

3. Social benefits

Socio-economic impacts are detailed in the Socio-economic Report. The project has directly created 2 new jobs (FTE) for the operation of the CO_2 plant (since January 2021). During the plant construction period 24 jobs were also necessary to cover works developed.

This project improves not only the sectors involved (biomass power plants and CO_2 production), but also the regional CO_2 consumers, that will get a local supply of CO_2 from a renewable origin. This is an added value for the whole CO_2 value chain, enhancing sustainable products.

The benefits for the forest sector are also remarkable. Forests have many values and the use of the forests residues as biomass increases their value for society. This biomass not only turns into energy (electricity or heating) and helps preserving the forest (forest fires are a potential threat), but now can be also the source of new raw materials such as green CO_2. These activities can help new industries to settle in rural and depopulated areas.

It is interesting to highlight that the establishment of a high tech level industry in the PEMA of Garray (Parque Empresarial de Medio Ambiental – Environmental Business Park) has boosted new industry projects in the area.

4. Replicability, transferability, cooperation:

The key factors to assess the replicability and transferability potential are the existence of a CO_2 emitter with a constant flow of CO_2 from a renewable origin with high CO_2

concentration and a small content of impurities. This emitter needs to be nearby a final consumer that requires big volumes of CO_2.
The first conclusions of the replicability plan shows that the best renewable sources with a constant stream of CO_2 to be captured are biomass power-plants and bioethanol producers. District Heating have also been considered but the CO_2 flow is seasonal conditioned. The consumers considered are mainly in the agri-food sector, but there are also potential consumers in the water purification sector and in new applications for the CO_2, as biofuels or green methanol production.

For industries planning to develop new sites the potential is higher as they can take into account these factors when choosing the location to settle down. Networking visits to the plant with stakeholders are planned to identify their replication interest.

5. Best Practice lessons:

Some lessons learned from the project are:

-Carbon capture and purification technologies usually applied to the capture of CO_2 from industrial and fossil fuel emissions, using amines, is also a technical and economic viable option in power plants that use biomass as fuel, with technological improvements and adaptations similar to those developed in the LIFE CO2IntBio project.

-The use of CO_2 captured emissions from energy intensive industries, transforming these emissions in valuable products, (CCU) is directly linked to the principles of Circular Economy, which are strengthened through industrial symbiosis (as a circular economy tool) between energy industry and chemical industry. Capture and utilisation of CO2 emissions from combustion power plants powered by forest biomass, developed with industrial symbiosis with other companies that require CO_2, heat and electricity, represent an additional incentive to the development of the renewable energy of biogenic origin sector because of the increase of the economic profitability and improve their carbon balance considered as net-zero emissions.

-The chemical product, CO_2 obtained through capture and purification from the emissions of biogenic origin (such as in LIFE CO_2IntBio from forest biomass combustion power plants) contributes significantly to the decarbonisation of the chemical CO_2 market, considering the LCA emissions compared with other business as usual production processes from industrial facilities that usually use fossil fuels.
As CO_2Value Europe Platform remarks not all CCU pathways are “net-zero” by essence, for example when reusing industrial CO_2 to make CCU chemicals and replace fossil resources, it contributes to GHG reduction, but it is not per se net zero. But by substituting industrial CO_2 with biogenic to make those same CCU chemicals as the LIFECO_2IntBio project has demonstrated, net-zero balance is achieved.

-The chemical CO_2 product obtained by capture and purification of biogenic origin emissions, contributes to the energy independence, according to the objectives of REPOWER EU. During the natural gas prices crises due to Ukrainian war, it has been possible to make aware the necessity of diversification energy resources, when companies of different industrial sectors energy intensive, from the CO_2 it is currently captured, stopped their productions because of the natural gas high costs, creating a shortage and increase of the price of this chemical product.

CO_2 capture in energy plants, that use biomass as fuel are using local biogenic resources, and allows a territorial decentralization, energy independence and guarantees the supply of the chemical product obtained in the capture and purification of their emissions process.

-Carbon captured utilization as chemical product for agri-food industries or agricultural greenhouses, or its use to produce biofuels are not a long-term carbon retention/storage option, in opposition to the CO_2 capture mineralization to obtain building materials. Nevertheless, the CCU value for manufacturing chemical products of fuels lies in the contribution of capture technologies to reach net-zero emissions, avoiding the additional use of fossil fuels to produce them.

-The costs production of chemical products (CO_2) as result of the emissions capture and purification with amine in biomass plants is acceptable but does not have a high economic rentability because the production costs are almost similar to the manufacturing costs.
To incentivize this type of facilities, it is possible to propose different options not mutually exclusive:

To account in the carbon balance of the consumers companies of this chemical product (that are using this CO_2 as a raw material in their products or productive processes), as reduction of GHG emissions.
To reduce production costs through technological development or research in reactives that can substitute amine and allow to obtain a high quality chemical product.
To diversify industrial symbiosis activities using the CO_2 captured for other processes and industrial sectors, for example, to produce methanol in symbiosis with green hydrogen production plants.

-In the last three years, CCU has aroused interest in business projects, generating numerous research and investment projects, thanks to European financing, both in the research field and in the industrial field (H2020, European Innovation Fund, Recovery and Resilience Facility, REPOWER EU, Just Transition Fund). The greatest interest and almost all of these projects, are focused on methanol production, in an industrial symbiosis with hydrogen production plants. (More information in Deliverable C2.1).

6. Innovation and demonstration value:

The innovation and demonstration value of the project is based in two key elements:

- An industrial symbiosis model between several industrial sectors (biomass energy plant, chemical CO_2 production and CO_2 users). Until now, the symbiosis model has been well developed between the biomass energy plant and the chemical CO_2 production plant. Close cooperation and agreements between the Partners BdG, ENSO (Energy sector Partners) and CARBUROS (Chemical Partner). The CO_2 cleaning plant has been constructed inside the Biomass energy plant installations and the supply of flue gasses from and electricity from the biomass to the CO_2 cleaning plant has been also implemented.

- Adaptation of CO_2 capture and cleaning technology used widely tested and proven at natural gas installations to a new industrial sector (biomass energy installations):
The key innovations of this project are the introduction of the following elements in the CO_2 plant are described in Deliverable C1.1:

7. Policy implications:

In the year 2018, when LIFE CO_2IntBio proposal was submitted, EU policy was mainly focussed on developing carbon capture. At that moment carbon utilization was not a priority or considered as a mitigation tool, so the value of LIFE CO_2IntBio project was to demonstrate the potential contribution to EU Climate policy targets of CCU.

EU policy has evolved in the meantime during the period of LIFECO_2IntBio project implementation, as can be seen at the EC website (both climate and energy sections)

As the EC website remarks "*the utilisation of carbon dioxide in production processes refers to technologies and procedures, which use CO_2 as a feedstock rather than releasing it to the atmosphere, e.g. by*

- *directly using CO_2 in soft drinks or greenhouses,*
- *using it as a working fluid or solvent such as for enhanced oil recovery (EOR),*
- *using CO_2 as a feedstock and converting it into value-added products such as polymers, building materials, chemicals and synthetic fuels.*

The latter family of novel technologies using CO_2 as a feedstock may contribute to the circular economy and the climate mitigation objectives".

Furthermore, the EC, through the work of the CCUS Forum, announced the publication by the end of 2023 of a strategy on Industrial Carbon Management, specifically to explore the role of CCU, CCS, and CDR pathways and highlight the importance of both technological value chains to help decrease emissions from hard to abate sectors.

The 6th Assessment report of the IPCC has recognized CCU as an important technological solution to mitigate climate change. It further adds that: "*Carbon is a key building block in organic chemicals, fuels and materials and will remain important. In order to reach net zero CO_2 emissions for the carbon needed in society (e.g., plastics, wood, aviation fuels, solvents, etc.), it is important to close the use loops for carbon and carbon dioxide through increased circularity with mechanical and chemical recycling, more efficient use of biomass feedstock with addition of low GHG hydrogen to increase product yields…"*

Eu Policy on CCU has paid attention mainly to utilization of captured CO_2 as biofuels, as of 2021, the recast of the Renewable Energy Directive will encourage fuels produced by CCU, but other uses are gaining presence in the climate agenda every day, and the LIFE CO_2IntBio project has demonstrated the contribution to climate mitigation in other sectors as producing soft drinks.

The European Net Zero Industry Act COM(2023) 161, SWD(2023) 68, aims to help deploying net-zero technologies throughout Europe to help the EU economy and industries to decrease GHG emissions. The proposal mentions CCU as a net-zero technology.

Not all CCU pathways are "net-zero" by essence, for example when reusing industrial CO_2 to make CCU chemicals and replace fossil resources, it contributes to GHG reduction, but it is not per se net zero. But all CCU technologies can become "net zero": for example by substituting industrial CO_2 when available with biogenic CO_2 to make those same CCU chemicals.

In the LIFE CO_2IntBio project CO_2 from biogenic origin (biomass) has been captured and transformed into a chemical product, and it has made possible to reduce emissions from two sectors:

- Energy production from biomass combustion: avoiding 33.000 tons/year of emissions.
- Commercial CO_2 production: avoiding 420 kg of CO_2-eq for every ton produced in comparison to the business-as-usual production.

Circular Economy Action Plan:

The circular economy approach of the project, based on the integration of two productive systems and the industrial symbiosis, achieve the objective of the New Circular Economy Action Plan of "Circularity as a prerequisite for climate neutrality" where it is also mentioned the "re-use and storage of carbon in products." The project also provides a secondary raw material (green CO_2) recovering residual flows of the biomass combustion.

For these reasons, the project is being highlighted as a good practice to link EU Clima and Circular Economy targets at the EU Circular Cities and Regions Initiative (CCRI), and has been integrated in the Circular Systemic Solution proposed by Castilla y León as pilot region.

The proposal for an Ecodesign for Sustainable Products Regulation (ESPR) -COM(2022) 142 final- aims to improve EU products' circularity, energy performance and other environmental sustainability aspects. As mentioned by the Platform CO_2 Value Europe "CCU can play a key providing alternative carbon feedstock for the production of daily products through carbon circularity, rather than extracting additional fossil resources from the ground to use carbon in everyday products, Europe should support circular carbon solutions by reusing unavoidable emissions on one end to deliver essential products to another."

Despite the EC proposal shall not apply to food products, which is one of the main applications of LIFE CO_2IntBio produced "green CO_2", that chemical CO_2 has many uses in other kind of products. This LIFE project new product is being selling to customers providing them technical information about the environmental performance of the product, verified as an Environmental Product Declaration (DAP) and in the future scenery of the proposed Regulation could be part of the improvement of climate results and sustainability of the products containing or using chemical CO_2.

Other European policies: European Industrial Strategy, European Energy Strategy, Forest Strategy.

The project has also contributed to the European Industrial Strategy objectives, promoting industrial alliances and European industrial autonomy. In addition to this, the biomass used in the power plant is certified under the voluntary scheme SURE according to the Directive RED II of renewable energy. This also contributes to a sustainable forest management and subsequently to the Forest Strategy 2030.

7. Key Project-level Indicators

A tool has been created to monitoring KPI (Included in action A1, carbon footprint monitoring tool – baseline). In addition, the project KPI have been actualized in KPI database webtool in June 2023 coinciding with the preparation of the Final Report.

In this table, there is an abstract of the KPI registered in KPI webtool in June 2023. Furthermore, in Deliverable D1.3 KPI Final Report it is possible to find more details about the calculation where the results depending on the greenhouse have been removed.,

Indicator		Baseline	Mid-term Report	Project End	Comments
1.5 Project area/length (m^2)		1.740		1050	Data actualized (total area of all facilities, including equipment tanks and other services)
1.6 Humans influenced (persons)	Dissemination	0	1,232	12,843	It includes participants of dissemination activities
	Change of behaviour	0	0	2	Green CO_2 customers are accounting for this indicator.
	Knowledge improvement	0	0	188	Persons that have participated in thematic activities
3.1 Waste management (tons/year)	Non-appropriately managed waste	2.250	2.250	0	This indicator showed the results of industrial symbiosis with a third part (residue from greenhouse). as long as the greenhouse is not included in the symbiosis approach, this indicator has been removed
	Mass reduction due to energy recovery	0	0	2.250	
	Amount collected by project	0	0	2.250	
4.1.1 Energy consumption (kWh/year)	Diesel consumption	7,812,925	7,812,925	6,170,921	This indicator has been adapted without the greenhouse
	Natural gas consumption	23,713,835	23,713,835	16,056,828	
4.2.1 Sustainable Forest Management (has)		0	0	260	This indicator has been removed because is not possible to establish a direct relation between the increment of biomass consumption and the increment of sustainable management areas.
8.GHG emissions	8.1.1CO_2 reduction (kg CO_2/unit produced)	535,10	535,1	399.39	CO_2 emissions have been calculated with real data collected for the LCA .

	Tonnes of CO_2/year	26,610	26,610	19,865	
	8.1.2 Other GHG gases - CH4 (kg GHG/kg produced in agriculture)	0,01137	0,01137	0	This Indicator was related to the greenhouse activity, so it has been eliminated.
10.2 Involvement of NGOs and stakeholders (number of stakeholders)		0	6	13	Results achieved in collaborations with stakeholders
11.1 Website (visits)		0	5,151	8,435	Results recalculated only with unique visits
12.1 Networking (number of individuals)		0	4	16	Individuals of other UE funded projects which there has been any collaboration.
13. Jobs (number of FTE)		0	0	2	Direct jobs created for the operation of the CO_2 plant.
14.1 Running costs		0	8,945,200	13,088,378	Running costs = total costs incurred during the project
14.2.3 Revenue expected (€)				2,395,649	Annual incomes
14.3 Future funding (€)				80,000	Future own investments expected in 5 years
14.4.2 Entry into new sectors (number)				1	Indicators calculates as future entries into new sectors and geographic areas.
14.4.3 Entry into new geographic areas (number)				2	