PLOS CLIMATE

RESEARCH ARTICLE

Tackling climate change: The Albarella island example

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Citation: Zanella A, Bolzonella C, Rosatti M, Longo E, Banas D, Fritz I, et al. (2024) Tackling climate change: The Albarella island example. PLOS Clim 3(6): e0000418. https://doi.org/10.1371/journal.pclm.0000418

Editor: Noureddine Benkeblia, University of the West Indies, JAMAICA

Received: December 15, 2023

Accepted: May 7, 2024

Published: June 27, 2024

Peer Review History: PLOS recognizes the benefits of transparency in the peer review process; therefore, we enable the publication of all of the content of peer review and author responses alongside final, published articles. The editorial history of this article is available here: https://doi.org/10.1371/journal.pclm.0000418

Data Availability Statement: All the data that served to build the models discussed in the article are in the main text or in the Supplemental information. Data regarding questionnaires and annual values of inflows and outflows of goods and

Abstract

We attempted to consider Albarella Island as a model for estimating the ability of humans and the capacity of the environment to react to climate change. On its 550 hectares, this island hosts management centers, 2800 private homes, several restaurants and hotels, shops, public and private swimming pools, a golf course, beaches, green areas equipped to satisfy the 2,000 stable inhabitants and more than 110,000 annual tourists. We collected data on the following variables: 1) net carbon storage of the semi-natural ecosystems; 2) diet of humans staying on the island; 3) currently used fossil energy; 4) electricity demand; 5) waste produced; 6) transport. A dynamic simulation model of the island's CO_2 equivalent (CO_2eq) emissions proposes two scenarios that illustrate how these variables can change over the next 10 years if the management remains that of the present day, or switching to all photovoltaics, proposing new diets to inhabitants and tourists, and planting trees on half of the island's lawns. In the second case, CO_2eq emissions lowered to 1/4 of the current value, bringing them to the level of 50-60 years ago. Running the Albarella touristic activities with renewed technology and minimum emissions impact in 2032 produces 4.8 kty^{-1}of CO_2eq: 14.5% (0.7 kty^{-1} of CO_2eq) of these emissions could be stored in the ecosystems of the island, 25% (1.2 kty^{-1}) would be produced by the solar panels construction, functionning and recycling that would furnish all the necessary domestic and industrial energy, and 60.5% (2.9 kty^{-1}) would correspond to the emissions to supply the island's food needs.

equipment from Albarella must be requested from the Albarella Island Administration. Email: info@albarella.it Website: https://www.albarella.it. The General Manager of Albarella Island is Dr Mauro Rosatti: mauro.rosatti@marcegaglia.com.

Funding: This article is part of the activities to disseminate the results of the ALBA (Albarella Laboratory Biodiversity Ambiente = environment) project. ALBA is a UNI-IMPRESA 2019 project that received funding of 100,000, half from the University of Padua and half from the Association Comunione Isola di Albarella. UNI-IMPRESA projects are selected each year by experts from the University of Padua to encourage local collaboration between university researchers and private companies or territorial institutions. Some analyses of soil samples were funded by the National Natural Science Foundation (China), and two instruments for measuring organic carbon content were funded by the University of Lorraine (France). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing interests: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. Mauro Rosatti is employed by Albarella Srl; Enrico Longo is employed by Associazione Comunione Isola di Albarella. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Theoretically, the technological response works. The implementation of the model on the island is discussed, opening up global perspectives. Maintaining the current level of consumption, with the technical and natural means available today, it is not possible to go below 20% of today's emissions.

1. Introduction

The article corresponds to a basic exercise: taking stock of a company by knowing all the inputs and outputs. The currency of exchange is tons of CO_2 equivalent (CO_2eq) and the company is a small, fairly green tourist island equipped for sporting and leisure activities. The question that this investigation would help resolve: how to change the values of the input variables over 10 years, while maintaining the island's economic and tourist activities, with the aim to reduce impact on the climate of the island?

If the principle is simple, putting the calculation into practice is quite complicated and commensurate with a real economy. The results presented here are the fruit of extensive specialized research within the framework of a collaborative program between the University of Padua and Albarella Islands Communion Association. These investigations benefited from the experience of international researchers from Australia, Austria, China and France. Part of this research was carried out with the help of students from the TESAF Department of the University of Padua. The data discussed are all included in the tables of this main document; the extrapolation of our model to a planetary scale is reported in Supporting Information (S1 Text, From Albarella to Planet Earth); in other supporting documents (S2 Text, Questionnaire template; S3 Text, A more effective solar system; S4 Text, Other Uni-Impresa project issues) readers will find other details on Albarella's experiment, with a compendium of data that will allow them to better understand/compare the spirit and social implications of the research undertaken, and to repeat the mitigation attempt of the climate in other socio-economic situations.

Since the publication of Darwin's work with his research on the Galapagos Islands [1], islands have attracted the attention of ecologists. Recently, complete studies have been published concerning the carbon cycle patterns described on islands in Denmark [2,3], and New Zealand [4,5]. In these and other examples [6,7] the sources of greenhouse gases (industries, means of transport, consumption per inhabitant, etc.) and the quantities of carbon stored in constituent ecosystems are estimated without direct field research, except to attribute known average surface values to the landscape units. There are techno-economic models with which scenarios are simulated to replace fossil energy with renewable energy and mitigate climate change [8,9].

Although we are not dealing with the long-term geological evolution of species and even though the Albarella touristic destination is connected to the mainland by a 10-km artificial embankment, this island is sufficiently circumscribed to represent a small forecast model. Halting climate change requires net greenhouse gas emissions to at least fall to zero. Theoretically and in agricultural contexts, coordinated and combined ways to land use in England can make the land-sector economy sustainable [10]. In our case, an accurate estimate of the balance between greenhouse gas emissions and carbon storage of a tourist-recreational very active small (about 5 km^2) island is realized: energy and food supply are registered by the management company of the island, and landscape changes are measured and foreseen. We collected inputs and outputs of six important determinants: 1) carbon storage of the island's semi-natural ecosystems; 2) diet of humans staying on the island; 3) fossil energy currently used to keep the island economically active; 4) electricity consumption; 5) waste produced, and 6) transport. To bring the island to as low as possible CO_2eq emissions was our ultimate goal, and in this paper we point which factors matter in achieving this.

This article is structured as follows: first of all, the dynamic budget estimation model is presented, followed by a brief illustration of the six determining variables and the corresponding data collection and estimation methods; then comes the discussion of two contrasting scenarios produced by the dynamic model, with generalizations and succinct conclusions.

2. Materials and methods

This is research that involved specialized technical personnel and different teams of students, in the context of internships in our department and on Albarella island. The study methods are diverse and complex. Although rather complex for some determinants, such as ecosystem storage and diet, some operational details are reported to help fully understand the results obtained with the dynamic model.

2.1. Ecological frame

The study area is between the peninsula of Porto Caleri, also natural reserve, and the island of Albarella, an economically exploited area for recreation and tourism. The area is located in the Municipality of Rosolina in the Province of Rovigo (Italy) and is bordered to the east by the Adriatic Sea, to the west from the Caleri Lagoon, to the north from the town of Rosolina Mare and to the south from the Po di Levante (region border shape: 45˚03'36"N-45˚06'00"N; 12˚19'12"E-12˚21'36"E). We compared the vegetation (Fig 1) and soil characteristics, including its microorganisms, of these two sites to understand how ecologically distant the island of Albarella is from its natural companion Caleri [11–13]. Not used directly in this paper, this prior research was useful for planning environmental transformation actions on Albarella island. Primarily focused on rural land use until 70 years ago, the island has gradually been transformed into a holiday centre. The original Mediterranean scrub vegetation is preserved along the coast on the edge of homes and hotels. Villas and residences have grown up in the cultivated fields, surrounded by green areas equipped for practicing sports and walking.

2.2. CO_2eq balance model

Albarella is a complex system (Fig 2) where economic, social and environmental variables interact. Implemented in a system dynamics model (Ventana Systems, Vensim 8.1, 2019: https://vensim.com, visited on March 25 2024), a computerized scheme of CO_2 equivalent flux (CO_2eq = calculated quantity of CO_2 emitted to produce and recycle each economic resource) provided a 10-year process (2023 to 2032) balance (difference between emitted and stored CO_2eq).

Albarella's emissions were estimated over a 10-year period for two extreme scenarios.The number of tourists and inhabitants remain the same in both cases. In Table 1, we report a more detailed description of the percentage use of resources in both scenarios. The results produced by the calculation system depend on them.

2.3. Determinants

We collected inputs and outputs of six important determinants: ecosystem storage, diet, fossil energy, electricity, waste, and transport.

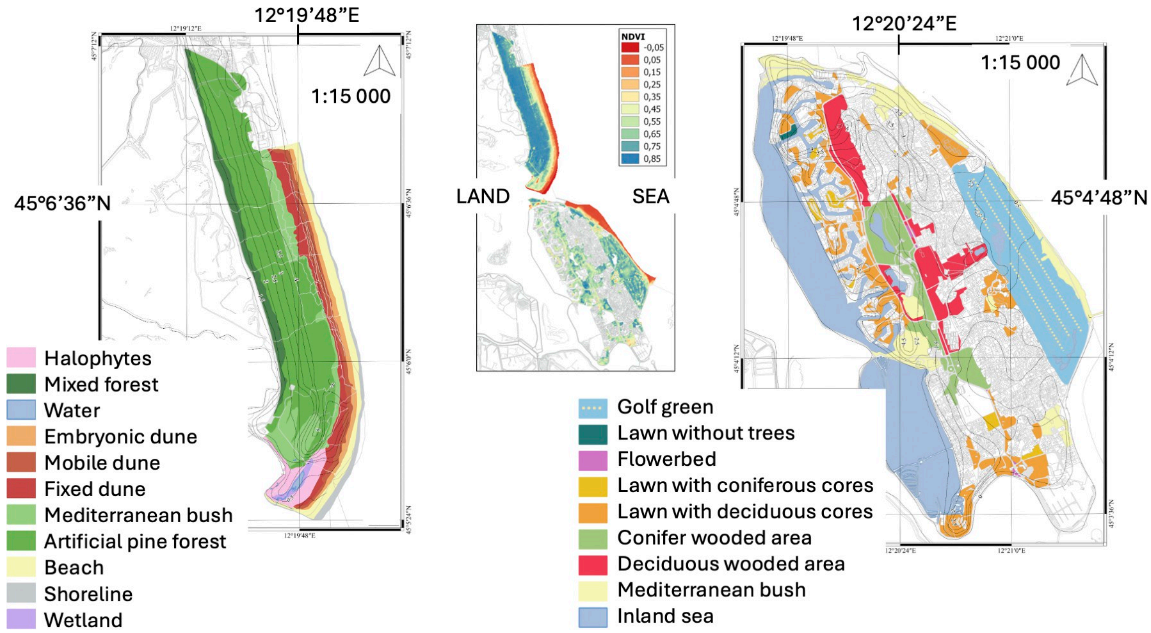

Fig 1. A look at the vegetation of Albarella and Caleri. On the left: The Caleri reserve with semi-natural vegetation in bands that respond to a micro-climate and salinity gradient that differs from the sea to the mainland; On the right: Albarella with fragmented vegetation (in the central gray part occupied by houses, the small white areas correspond to inaccessible private gardens), more suited to welcoming tourists; Middle: Mapping of the Normalized Difference Vegetation Index (NDVI) from satellite images, with a spatial resolution of 10 m. The higher the index (blue), the more complex/layered the vegetation and the more solar energy is retained by the ecosystem. One of the objectives of this research was also to increase the organic carbon storage capacity of the Albarella ecosystems, also by opting for a more natural composition of the vegetation. In meadows and wooded areas, the density of trees will be increased, with preference for Mediterranean species; in the golf green, the non-herbaceous parts will be treated to improve the consistency of the current Mediterranean shrub. Compatible with CC-BY 4.0 license.

https://doi.org/10.1371/journal.pclm.0000418.g001

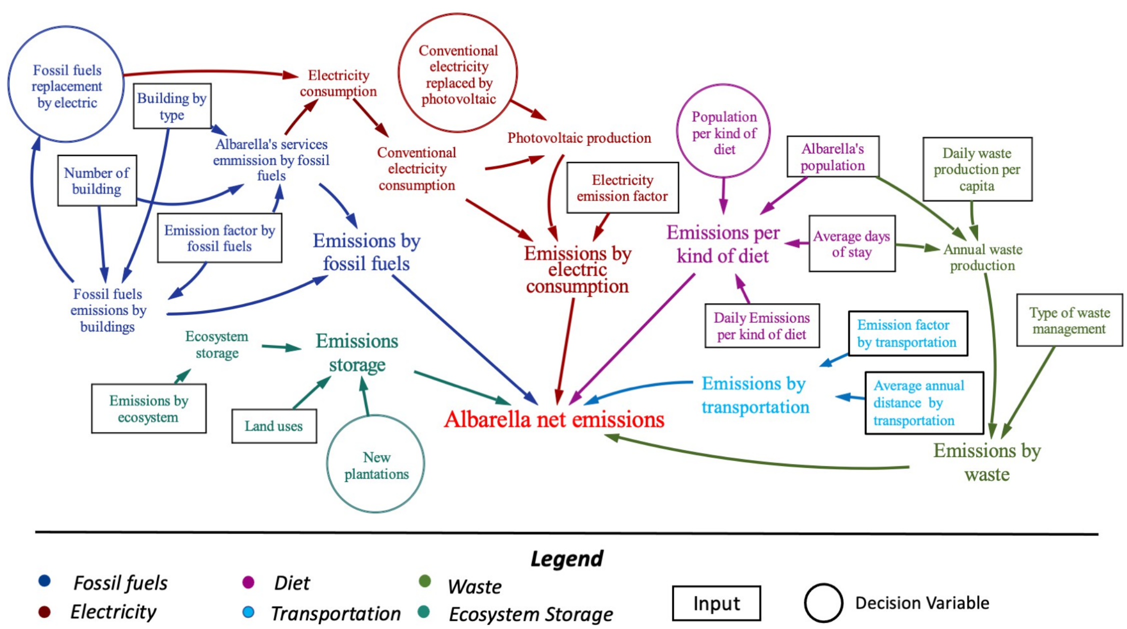

Fig 2. Vensim simplified model. Four decision (circles) and 13 input (rectangles) variables influencing the 6 main determinants (fossil fuels, electricity, diet, transport, waste and ecosystem storage) reported with different colors.

https://doi.org/10.1371/journal.pclm.0000418.g002

Table 1. Percentage use of resources in As Usual and optimistic scenarios, linked to the main 6 determinants of the Vensim model.

Determinants	As Usual (2023-2032)	Optimistic (2023-2032)
Fossil fuels	100%: the consumption of fossil energy remains unchanged at 100% of the initial (2022) value	From 100% to 0% fossil fuel energy in 2032
Electricity	0% photovoltaic: in 2022, the energy produced on the island by photovoltaics is negligeable	From 0% to 100% of consumed electric energy produced by photovoltaic in 2032
Diet	Constant in time diet habits: 60% continental, 30% Mediterranean, 9% vegetarian, 1% vegan (Questionnaire realised in 2022).	New diet distribution of diet habits: 0% continental, 60% Mediterranean, 30% vegetarian, 10% vegan. Hypothetical forecasting for 2032
Transport	80% with fossil and 20% with electric energy (Questionnaire realised in 2022)	From 20% to 100% electric energy in 2032
Waste	Constant 20% recycled on the island (state of the art in 2022)	From 20% to 100% recycled on the island in 2032
Ecosystem storage	0%. The lawn area of the island remains as it is in the 10 model years, and is not used for new tree plantings	New plantations on 51.6% of the lawn realised in 2023 and effective from 2025 to 2032

https://doi.org/10.1371/journal.pclm.0000418.t001

2.3.1. Ecosystem storage. We subdivided the public green area of the island into 12 ecosystems (Table 2, column 1). We investigated each ecosystem by measuring the organic carbon concentration in the soil (SOC = soil organic carbon) and above the soil in the herbaceous, shrub and tree parts of these ecosystems (VOC = vegetation organic carbon). The publicly accessible component of the island's vegetation is managed by the local council run by an association of inhabitants, which financially supported the project.

With the agreement of the inhabitants and of the company managing the island, the following hypothetical but realistic interventions on the vegetation were planned: a) private green areas are considered to have negligeable influence on the budget and not accounted for in our scenarios; b) carbon storage standard management is adopted until 2022, i.e. As Usual scenario, or c) new plantations (shrub 10 ha, holm oak tree 5 ha, other tree species 10 ha) on half the present day "Lawn with trees' cores", i.e. Optimistic scenario.

Soil sampling and measurements

Two soil measurement campaigns were carried out, one in 2019 on 10 ecosystems and one in 2020 in the same 10 ecosystems plus in 2 other new ecosystems. In the two years we visited 24 points, two points in each of the 12 ecosystems. In each point we collected (with a AMS EZ Eject Soil probe sampler (https://www.ams-samplers.com/1-1-8-x-33-ez-eject-soil-probe/, visited on March 25 2024) 6 cylindrical soil cores, 12 inches (= 30.34 cm) long and 1 inch (= 2.54 cm) in diameter. Once air-dried, the weight of the six mixed carrots collected in each ecosystem amounted to 1250-1300 g. Half of each sample was analyzed with the Yeomans Carbon Still, using a Loss On Ignition (LOI) process (LOI temperature: 400˚C: https://yeomansconcepts.com/7-video-library-good-referrals/, visited on March 25 2024). The second half of the sample was used for chemical and physical analyzes, including the measurement of organic carbon with the Skalar Primacs analyzer (https://www.skalar.com/products/primacs-total-organic-carbon-total-nitrogen-analyzers/, visited on March 25 2024). The samples were sieved with a 2 mm mesh, and only the organic part that passed through the sieve was considered in the calculation of the soil organic carbon (SOC). SOC entered in the Vensim model for each ecosystem correspond to the average of the two methods (Carbon Still and Skalar Primacs measures). The measurements are close to those estimated for equivalent Mediterranean ecosystems [14] and FAO [15].

Out of soil vegetation sampling and measurements

The total non-submersed surface of Albarella measures 550 ha, subdivided in 80 ha of waterproofed surface (houses, buildings and roads =14.55%), 239 ha of private green areas (house

Table 2. Organic carbon storage in the public semi-natural ecosystems of Albarella.

Ecosystem type	**Ecosystems' surface As Usual scenario**		**Out of soil Vegetation Organic Carbon (VOC)**		**Total Organic Carbon (TOC = VOC + SOC)**
1	**2**	**3**	**4**	**5**	**6 (= 4 + 5)**
	ha		**tVOC/ha**	**tSOC/ha**	**tTOC/ha**
1. Beach without plants	28.85		0.00	28.97	28.97
2. Young artificial dune	1.63		3.74	14.08	17.82
3. Old artificial dune	1.63		6.55	7.73	14.28
4. Flowerbeds	0.72		3.28	49.33	52.61
5. Reeds dune	30.00		49.60	28.66	78.26
6. Fresh grassland	0.63		3.28	80.73	84.01
7. Golf green	51.43		3.28	82.15	85.42
8. Mediterranean bush	28.85		30.52	60.47	90.99
9. Holm oak forest	0.09		31.41	58.82	90.23
10. Semi-natural pine forest	11.44		29.76	74.17	103.93
11. Artificial pine forest	10.28		23.28	89.68	112.96
12. Lawn with trees' cores	64.57		11.69	24.14	35.83
New shrubby mantle	0.00	10.00	28.34	56.03	84.37
New holm oak forest	0.00	5.00	31.41	58.82	90.23
New plantation	0.00	10.00	28.15	74.22	102.37
Total	230.11	255.11	284.28	788.01	1072.28
Average (out of Total)			18.95	52.53	71.49
Ecosystem type	TOC x ecosystem surface: 7 As usual; 8 Optimistic		Annual TOC/ha storage in each ecosystem		
1	7 = 2 x 6	8 = 3 x 6	9	10	
	tTOC		tTOC/ha/y	tCO2eq/ha/y	
1. Beach without plants	835.71		0.15	0.56	
2. Young artificial dune	29.04		0.02	0.07	
3. Old artificial dune	23.29		0.01	0.05	
4. Flowerbeds	37.84		0.00	0.00	
5. Reeds dune	2347.92		1.09	3.99	
6. Fresh grassland	53.03		0.03	0.09	
7. Golf green	4393.19		0.03	0.10	
8. Mediterranean bush	2625.12		1.82	6.67	
9. Holm oak forest	8.12		1.85	6.77	
10. Semi-natural pine forest	1188.59		1.10	4.05	
11. Artificial pine forest	1160.87		1.20	4.40	
12. Lawn with trees' cores	2313.25		0.73	2.69	
New shrubby mantle	0.00	843.74	1.10	4.04	
New holm oak forest	0.00	902.26	1.85	6.77	
New plantation	0.00	511.87	2.03	7.45	
Total	15015.97	17273.84	13.01	47.69	
Average (out of Total)			0.87	3.18	
Ecosystem type	As Usual scenario - Annual TOC storge all ecosystem surface		Optimistic scenario - Annual TOC storage all ecosystem surface		
1	11 = 2 x 9	12 = 2 x 10	13 = 3 x 9	14 = 3 x 10	
	tTOC/y	tCO2eq/y	tTOC/y	tCO2eq/y	
1. Beach without plants	4.44	16.28	4.44	16.28	
2. Young artificial dune	0.03	0.11	0.03	0.11	
3. Old artificial dune	0.02	0.09	0.02	0.09	

(*Continued*)

Table 2. (Continued)

Ecosystem type	Ecosystems' surface As Usual scenario		Out of soil Vegetation Organic Carbon (VOC)		Total Organic Carbon (TOC = VOC + SOC)
1	2	3	4	5	6 (= 4 + 5)
	ha		tVOC/ha	tSOC/ha	tTOC/ha
4. Flowerbeds	0.00	0.00	0.00	0.00	
5. Reeds dune	32.62	119.61	32.62	119.61	
6. Fresh grassland	0.02	0.06	0.02	0.06	
7. Golf green	1.34	4.92	1.34	4.92	
8. Mediterranean bush	52.47	192.38	52.47	192.38	
9. Holm oak forest	0.17	0.61	0.17	0.61	
10. Semi-natural pine forest	12.63	46.30	12.63	46.30	
11. Artificial pine forest	12.33	45.22	12.33	45.22	
12. Lawn with trees' cores	47.33	173.53	47.33	173.53	
New shrubby mantle	0.00	0.00	11.02	40.39	
New holm oak forest	0.00	0.00	9.23	33.83	
New plantation	0.00	0.00	20.32	74.52	
Total	163.39	599.10	203.96	747.84	
Average (out of Total)	10.89	39.94	13.60	49.86	

Column 1 = Ecosystem type.
Column 2 = Surface covered by the present-day (As Usual scenario, as in 2022) semi-natural ecosystem.
Column 3 = Surface covered by the present-day semi-natural ecosystems + 10 ha of new shrubs + 5 ha of holm oak forest + 10 ha of other plantations (Optimistic scenario). Measures from Google earth after establishing land boundaries.
Column 4 = VOC = Organic Carbon in out of soil Vegetation; estimated in each ecosystem; using tree specific tables after inventory, and weighing plants in sample areas for shrubs and grasses.
Column 5 = SOC = Soil Organic Carbon in the first 30 cm of soil, organic matter fragments > 2 mm excluded, except for the logs on the "Beach without plants" ecosystem; measurements from samples in each ecosystem.
Column 6 = TOC = VOC (column 4) + SOC (column 5).
Column 7 = TOC * ecosystem surface in As Usual scenario (columns 2 * 6).
Column 8 = TOC * ecosystem surface in Optimistic scenario (columns 3 * 6).
Column 9 = Annual TOC increase (t TOC); calculated by taking the measurements made in each ecosystem (VOC, TOC, age of each ecosystem), attributing a percentage increase in total soil carbon equal to that measured in the vegetation above the ground.
Column 10 = Annual TOC increase in CO_2eq = TOC * 44/12. This coefficient represents the ratio between the atomic weight of the CO_2 molecule and the atomic weight of carbon.
Column 11 = Annual TOC storage on all surfaces of each ecosystem in tons of TOC in As Usual scenario.
Column 12 = Annual TOC storage on all surfaces of each ecosystem in tons of CO_2eq in As Usual scenario.
Column 13= Annual TOC storage in all surface of each ecosystem in tons of TOC in Optimistic scenario.
Column 14 = Annual TOC storage in all surface of each ecosystem in tons of CO_2eq in Optimistic scenario.

https://doi.org/10.1371/journal.pclm.0000418.t002

and gardens = 43.45%) and 231 ha of public green areas (meadows, tree-lined meadows, woods, scrubland, golf course, beach = 42%).

All the 1896 trees in the public area of the island were counted by species and their diameter measured. Height and woody accretions were taken only on sample trees and representative of the groups of trees (trees' cores that populate open areas of the island). To estimate the volume, we considered the tables of cubic volume by species published by the Ministry of Agriculture and Forests [16]. To estimate the age of the trees we measured their diameter and counted the number of rings in the last two centimeters of radius, taken twice on the trunk at 90˚ from each other, and at 130 cm in height.

The Trephor tool (https://intra.tesaf.unipd.it/sanvito/doc/trephor.pdf, visited on March 25 2024) was used for the extraction of microcores from living trees. When possible, we checked by also counting the rings on stumps of fallen and cut trees. The average age of the tree clusters ranged from 67 to 96 years; the oldest trees in the groups were 124-142 years old. As a precautionary measure, the annual growth of the trees was calculated by dividing the volume by the average age of the oldest trees, in localized areas of each ecosystem, species by species, considering the density of the wood and its carbon content.

Thanks to documents used to create the 1983 Veneto Regional Technical Map, it was possible to reconstruct the variation in the wooded area of the Island of Albarella between 1954 and 2008 [17]. Photographs provided by the inhabitants show that 70-100 years ago Albarella was a rural area dotted with trees and Mediterranean scrubs. The measured VOC annual growth corresponds to approximately 1% of the organic carbon that constitutes the current ecosystems. This annual increase tells us that it took approximately 100 years to build the present day island's ecosystems, starting from the situation described also in other historical documents [18,19]. We assigned this 1% growth value to soil carbon (SOC) as well.

The quantities of organic carbon of the shrubby and herbaceous parts of each area (meadows, lawns and even reeds) were calculated through the cutting and mowing of 2 sample areas of 1 m^2 each in the ecosystems where these were mostly represented; this biomass was chopped and then air dried for several weeks before being weighed; the calculation of the carbon content was done by dividing by two (organic carbon = air-dried biomass/2), reducing this weight by 15% due to residual moisture. For the annual growth of shrubs and reeds, we considered that managed shrubs can reinvest in biomass 1/10 of redistributed on soil pruning, with the assimilation, after biodegradation, of 1/10 of this artificial litter addition. In this way we interpreted the pruning as if was annual growth and considered that 10% of this growth could become new biomass (with a biomass growth of about 1% per year, therefore, which, as an order of magnitude, can be fine). Note how the 10% value considered resembles the Lindeman ecosystem efficiency coefficient, used as a "plant consuming plant" process [20]. Thanks to the records of the company that deals with cutting of shrubs, we were also able to know the weight of the pruning of certain areas of the island. We were able to expand the data to all similar areas. For lawn and herbaceous dune areas, we considered possible to lightly improve the biomass in these sites and we cautiously estimated the annual growth as 1/1,000 of the total organic carbon content in such type of vegetation (Table 2).

To decide how to distribute the new wooded surfaces on the island of Albarella in order to respect its potential vegetation, we made use of cartography produced with the aid of satellite images from the European Space Agency (Sentinel-2 mission, year 2022). By also calculating the Normalized Difference Vegetation Index (NDVI), it was possible to compare the vegetation of Caleri (more natural) and Albarella (artificialised), to define a more sustainable development of the vegetation on the island of Albarella (Fig 1, details in Ranzani G. [17]).

2.3.2. Diet. We calculated the annual CO_2eq emissions due to food for four types of diets (continental, Mediterranean, vegan, and vegetarian) estimating the daily emissions of an average consumer of each diet by referring to tables that give the CO_2eq value emitted for each consumed product [21,22].

The analysis of a questionnaire distributed to inhabitants and tourists of the island made it possible to assign a number of consumers to the four diets used in the As Usual model: 60% continental; 30% Mediterranean; 9% vegetarian; 1% vegan.

In absolute value, nutrition today makes up 6.9 of the 15.9 kt of CO_2 eq per year (= 43.4%) of Albarella's total emissions. We considered all the emissions of the whole Agri food chain (production, processes, delivery and conservation). In the Optimistic scenario, we completely replaced the continental diet with Mediterranean, vegetarian and vegan diets.

Questionnaire on Eating Habits on the Island of Albarella

Some owners have private gardens, but most of the island's food consumption is imported from outside. The island offers a shopping center and numerous restaurants.

A group of students, including a student whose family owns a secondary house on the island, interviewed 667 people (Albarella inhabitants 306, others 361; total 667), submitting a questionnaire to each of them (distribution and collection period: June 03, 2021 - July 31, 2021). Participation was voluntary, and all questionnaire participants remained anonymous. The 9 minors ($<$ 18 years) were accompanied by parents. When requesting participation in the questionnaire, volunteers were provided with the following information: the purpose of the questionnaire in the context of ALBA research; the name and email address of the research manager from whom the research results could be requested at the end of the project; the generic content of the questions and the answer method; that the anonymous personal data would have been used for scientific research purposes to formulate proposals for reducing greenhouse gas emissions from the Island of Albarella; that participation was anonymous, free, and that it could be abandoned even during the drafting of the answers without providing explanations.

Each questionnaire is divided into five main question groups:

1. General questions: age, nationality, gender, numerical composition of the family unit, the educational qualification, average income, tobacco consumption, consumption of alcoholic beverages.
2. Eating habits and frequency of consumption of the following foods: beef, pork, poultry, fish; cheese, eggs or derivatives; oil; dried fruit, legumes; sweets; fruit or vegetables; milk, carbonated drinks, alcoholic drinks (wine or beer) and coffee; pasta or rice.
3. Place and frequency of consumption of meals: places of consumption of meals; weekly frequency of meals in the restaurant.
4. Reasons to choose a stay in Albarella: safety; contact with nature; ratio quality/price; sports related services. The score in the answer ranged from 1 to 7.
5. Sports, consumption of organic food products, travel around the island: frequency in which sport is practiced; sport type; frequency of purchase of organic products; car used, power and type of engine / energy used.

In the present research we used the answers to the second, third and fifth groups of questions to determine the percentage of people to be attributed to four types of diets (Continental-with beef, Mediterranean-without beef, Vegetarian and Vegan) and to complete de data that the administration had given us about travel on the island.

Once the daily emission of an average consumer of each diet in known, emissions were calculated with this formula:

$$Food\ emissions = \sum_{n=1}^{4} (a_n b_n c_n)$$

Where:

Food emissions = total emission due to the annual feeding of inhabitants and tourists of Albarella (tons of CO_2eq);

a_n = daily CO_2eq emissions (tons of CO_2eq) of one single average consumer of diet "n";

b_n = number of consumers of diet "n";

c_n = average number of days of stay in Albarella of all consumers of diet "n";

n = type of diet: 1. continental, 2. Mediterranean, 3. Vegan, and 4. vegetarian.

A questionnaire template is reported in full in Supporting Information (S2 Text).

Ethical committee assessment

Name(s) of the Institutional Review Board(s) or Ethics Committee(s):

Ethical Committee for the Research at the Department of Land, Environment, Agriculture and Forestry, of the University of Padua (Italy).

President: Prof. Eugenio Pomarici.

The approval number(s), or a statement that approval was granted by the named board(s):

Request no. 0003893 del 15/12/2023 – [UOR: D320000 – Classif. 1/18].

Reason consent was not obtained:

The questionnaires were anonymous and were aimed at calculating carbon emission by focusing on general food consumption information.

2.3.3. Fossil energy. To calculate fossil energy emissions, we collected data from the island's administration, hotels, restaurants, sports centres, swimming pools and offices. Private inhabitants of Albarella answered a questionnaire.

Putting all these data together, Albarella today emits 4.8 kt of CO_2eq per year from fossil fuels as propane gas, diesel and petrol burned for energy (31% of the total). Coefficients published by the IPCC [23] allowed quantities to be converted to CO_2eq. In the Optimistic scenario, fossil energy emissions were progressively brought to zero. More than half of this private or public energy consumption is linked to the heating and maintenance of swimming pools, which are widely used during the summer holidays.

2.3.4. Electricity. For the estimation of electricity consumption, public data come from the administration of the island, which manages the distribution of electricity coming from outside the island, and private data from questionnaires answered by a sample of inhabitants. Among the public consumptions are those of seaports, conference rooms, club houses, water purification plants, sports centres and swimming pools. Private electricity consumption comes from the use of domestic facilities and drinking water production.

Today, Albarella produces electricity from photovoltaics in a negligible quantity. By equipping the roofs of the 2800 houses on the island with 6 m^2 of photovoltaic panels each, we can produce all the energy necessary for the functioning of the island.

The emissions of solar panels (emissions associated with the manufacture, transport and recycling of solar panels) were calculated considering an optimistic foot print of 20 g of CO_2eq per kWh of energy produced [24]. Three years ago, the published solar panel foot prints were 2-4 times higher [25,26]. A structured and generalized recycling plan is necessary worldwide for this type of energy to become truly renewable [26].

Not satisfied with the result obtained with solar panels placed on all the roofs of private houses, we also financed research into more effective alternatives. The estimates of these most recent investigations reached us while this article was being published, are recalled in 4. Discussion. This report is only available in Italian and is summarized in English in Supporting information, S3 Text, A more effective solar system.

2.3.5. Waste. The emissions due to recycling were calculated on the basis of the quantities and type of waste (garbage, trash etc.) linked to the number of inhabitants and the management of the green areas of the island.

Currently, 20% of waste is recycled on the island, and CO_2eq emissions derived from not recycling garbage amount to 0.9 kt annually. The Optimistic scenario envisages a total on-site recycling of waste until emissions are negligible.

2.3.6. Transport. Albarella is 3.5 km long and 1.5 km wide. A barrier at the entrance to the island prevents free access to vehicles, with personnel and cameras to control entrances and exits. The island administration furnished in and out number and type of vehicles. For transport on the island, we distributed a questionnaire and obtained the number of km that each conveyance traveled on average per year on foot or by car. There are even vehicles that people use for short trips within the island; 20% of them are small electric cars. The calculation gave emissions of approximately 0.1 kt of CO_2eq per year. By bringing electric vehicles to 100%, emissions became negligible (Optimistic scenario).

3. Results

Sensitive to the climate problems, in interviews the inhabitants of the island expressed their willingness to intervene and mitigate in their own small way what we know is happening globally. Under the Optimistic scenario, they decided to progressively abandon fossil energy, opting for photovoltaics, to abandon the continental diet based on beef, preferring both the Mediterranean diet based on other meats and the vegetarian and vegan diets. The inhabitants of Albarella have also opted to plant more bushes and trees to increase the storage capacity of the island's ecosystems. Below is a comparison of today's situation, which has been prolonged over the next 10 years (As Usual scenario), and the corresponding improvement produced by the progressive transformation of consumption habits (Optimistic scenario).

3.1. Extrapolation of the As Usual scenario (2023-2032)

This scenario shows the evolution of the island's emissions as if the current use of the island continued, with the necessary maintenance and improvement operations, as done until 2022 (Fig 3). Data in Table 3.

The observed decrease in energy emissions from electricity consumption and increase in emissions stored in ecosystems are due to improvement of efficiency in the use of electricity and accumulated unrespired biomass and necromass, respectively. The restructuring of ecosystems is ensured by naturalistic management of the existing land. Note that the ratio between

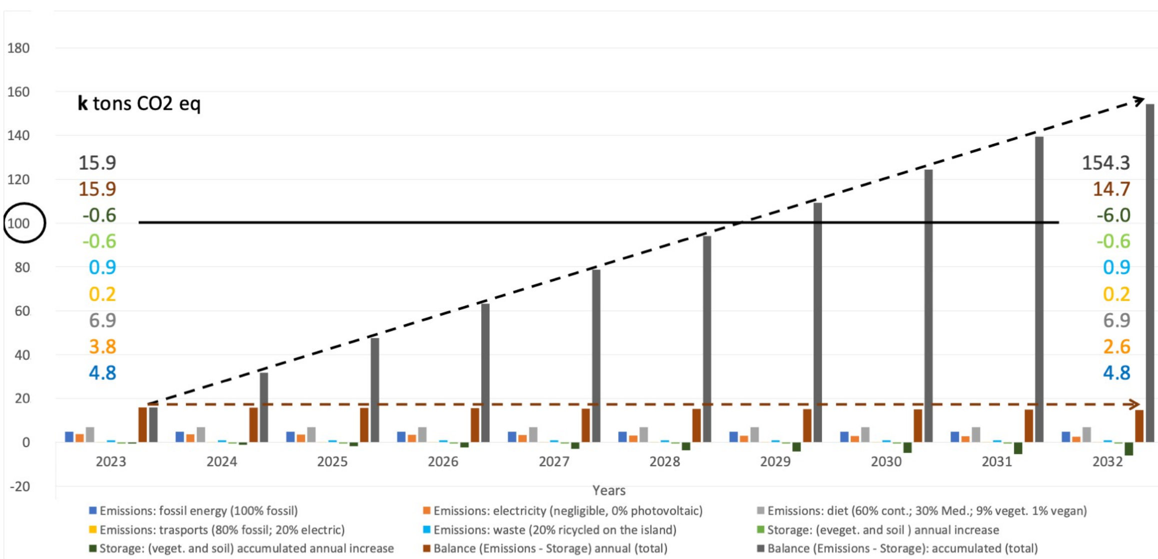

Fig 3. Albarella As Usual scenario, emissions and carbon storage. Histograms of the change over time of the emissions of the 6 budget drivers, plus the whole annual amount of these emissions and the carbon storages accumulated by the ecosystems at the end of the 10-year assay; these are the 9 variables shown below the graph with the colored values written vertically on the left (2023) and right (2032) of the graph.

https://doi.org/10.1371/journal.pclm.0000418.g003

Table 3. As Usual scenario, Vensim estimations. Emissions, Storage, Balance (kilo tons).

Year	2023	2024	2025	2026	2027
Emissions: fossil energy (100%)	4.8	4.8	4.8	4.8	4.8
Emissions: electricity (negligible =0% photovoltaic)	3.8	3.6	3.5	3.4	3.2
Emissions: diet (60% continental; 40% others)	6.9	6.9	6.9	6.9	6.9
Emissions: transports (20% electric)	0.2	0.2	0.2	0.2	0.2
Emissions: waste (20% recycled on the island)	0.9	0.9	0.9	0.9	0.9
Storage: vegetation and soil annual increase	-0.6	-0.6	-0.6	-0.6	-0.6
Storage: sum of vegetation and soil annual increases	-0.6	-1.2	-1.8	-2.4	-3.0
Balance (Emissions - Storage) annual (total)	15.9	15.8	15.6	15.5	15.4
Balance (Emissions - Storage): accumulated (total)	15.9	31.8	47.6	63.2	78.7
Year	2028	2029	2030	2031	2032
Emissions: fossil energy (100%)	4.8	4.8	4.8	4.8	4.8
Emissions: electricity (negligible =0% photovoltaic)	3.1	3.0	2.8	2.7	2.6
Emissions: diet (60% continental; 40% others)	6.9	6.9	6.9	6.9	6.9
Emissions: transports (20% electric)	0.2	0.2	0.2	0.2	0.2
Emissions: waste (20% recycled on the island)	0.9	0.9	0.9	0.9	0.9
Storage: vegetation and soil annual increase	-0.6	-0.6	-0.6	-0.6	-0.6
Storage: sum of vegetation and soil annual increases	-3.6	-4.2	-4.8	-5.4	-6.0
Balance (Emissions - Storage) annual (total)	15.2	15.1	15.0	14.8	14.7
Balance (Emissions - Storage): accumulated (total)	94.1	109.4	124.5	139.4	154.3

https://doi.org/10.1371/journal.pclm.0000418.t003

accumulated emissions due to activities and accumulated storage in ecosystems is 20:1. Emissions drop following the slow pace of storage of the island's ecosystems, which is growing on average by approximately 1% per year (Fig 3 and Table 3). This corresponds to an annual storage of 0.599 tons of CO_2eq. These quantities accumulated as living and dead organic matter (in recycling but still increasing as soil organic matter) in the island's ecosystems continue to grow for the next 10 years. Emissions drop as a consequence, while the other parameters remain stable, except electricity, because we introduced a gradual improvement of its use due to current technological progress. Total annual emissions slightly change; total accumulated emissions vertiginously increase.

3.2. Extrapolation of the Optimistic scenario (2023-2032)

With the provisions planned by the Optimist scenario, the final emissions balance would reach 3.4 kt year^{-1} of CO_2eq (Fig 4). The largest contributions to the reduction of emissions come from the elimination of the use of fossil energy: 4.8 (kt year^{-1}) and the provision of 6 m^2 solar panels in every 2,800 individual houses before 2032: (3.4 – 1.2 = 2.2 kt year^{-1}). The estimated storage of the island's ecosystems would amount to approximately 0.7 kt year^{-1}. Data in Table 4.

In this Optimistic scenario, the ratio between accumulated storage (dark green) and accumulated emissions (dark grey) remains low (7.5/93.9 = 8%); the balance of annual emissions minus annual storage (brown) tends towards a limit value of approximately 3.4 kt (almost ¼ the value in As Usual scenario, 14.7 kt in Fig 3); in 2032, annual emissions are mainly due to the diet (2.9 kt, light grey); the annual storage of ecosystems (0.7 kt, light green barely visible at this scale) cannot compensate for either the emissions due to electricity (1.2 kt, orange) or diet (light grey). Note that the change in diet lowered emissions from this sector by 58% (from 6.9 to 2.9). On the other hand, a large contribution is required from ecosystems: after 10 years, the ecosystem storage reaches 7.478 kt of CO_2eq, which corresponds to 7.478 * 12/44 = 2.040 kt of

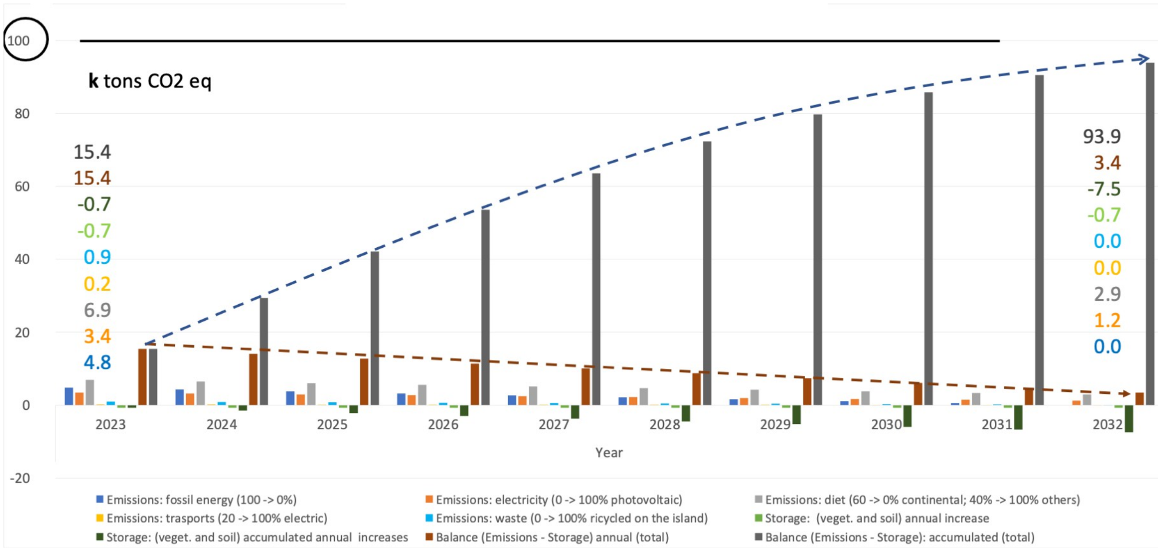

Fig 4. Albarella Optimistic scenario, emissions and carbon storage. Histograms of the change over time of the emissions of the 6 determinants, balance between the annual amount of these emissions and storage of the ecosystems; these are the 9 variables shown below the graph with the colored values written vertically on the left (2023) and right (2032) of the graph. The range corresponds to the maximum that can be foreseen as a technological improvement of the island, using techniques already existing on the market, maintaining the tourist-recreational land use in today's values and for the next 10 years. Note the zeroing of the use of fossil energy (dark blue) to the advantage of photovoltaics (orange) and the abandonment of the continental diet, in favour of Mediterranean, vegetarian, or vegan diets (light grey).

https://doi.org/10.1371/journal.pclm.0000418.g004

total organic carbon (TOC = VOC vegetation out of soil + SOC in the first 30 cm of soil; 12/44 is the ratio between the weight of C and that of a CO_2 molecule). If we divide this value by the 230 hectares occupied by ecosystems (Table 2, column 1), we find the expected TOC growth of

Table 4. Optimistic scenario, Vensim estimations. Emissions, Storage, Balance (kilo tons).

Year	2023	2024	2025	2026	2027
Emissions: fossil energy (100 -> 0%)	4.77	4.24	3.71	3.18	2.65
Emissions: electricity (0 -> 100% photovoltaic)	3.40	3.16	2.91	2.67	2.42
Emissions: diet (60->0% continental; 40->100% others)	6.88	6.44	5.99	5.54	5.09
Emissions: transports (20 -> 100% electric)	0.16	0.15	0.13	0.12	0.11
Emissions: waste (0 -> 100% recycled on the island)	0.92	0.82	0.72	0.63	0.53
Storage: vegetation and soil annual increase	-0.75	-0.75	-0.75	-0.75	-0.75
Storage: sum of vegetation and soil annual increases	-0.75	-1.50	-2.24	-2.99	-3.74
Balance (Emissions minus Storage) annual (total)	15.39	14.06	12.72	11.39	10.06
Balance (Emissions minus Storage): accumulated (total)	15.39	29.44	42.17	53.56	63.61
Year	2028	2029	2030	2031	2032
Emissions: fossil energy (100 -> 0%)	2.12	1.59	1.06	0.53	0.00
Emissions: electricity (0 -> 100% photovoltaic)	2.18	1.93	1.69	1.44	1.20
Emissions: diet (60->0% continental; 40->100% others)	4.65	4.20	3.75	3.31	2.86
Emissions: transports (20 -> 100% electric)	0.09	0.08	0.06	0.05	0.03
Emissions: waste (0 -> 100% recycled on the island)	0.43	0.34	0.24	0.14	0.05
Storage: vegetation and soil annual increase	-0.75	-0.75	-0.75	-0.75	-0.75
Storage: sum of vegetation and soil annual increases	-4.49	-5.23	-5.98	-6.73	-7.48
Balance (Emissions minus Storage) annual (total)	8.72	7.39	6.06	4.72	3.39
Balance (Emissions minus Storage): accumulated (total)	72.34	79.73	85.78	90.51	93.90

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these ecosystems: 2040/230 = 8.87 t of TOC per hectare in 10 years, which corresponds to approximately 0.89 t ha^{-1} y^{-1} (to compare with the estimated average value of 0.87 t ha^{-1} y^{-1} in column 9 of Table 2). The highest contributions are expected from new plantations with trees (2 t ha^{-1} y^{-1}).

A curiosity: the wood transported by the waves and deposited on the beach makes it possible to store (Table 2, last column) 16.28 of the 747.84 t CO_2eq y^{-1} stored by ecosystems (= 2.17%). Certainly, wood remains cannot be left on the bathing beach among the umbrellas, but in the free and more natural sites, this wood can have a positive influence on the biodiversity of the island. Ecologically speaking, this material will collect innumerable agents of biodegradation and become the habitat of some of these species, and, finally, will increase soil organic matter and soil fertility [27].

3.3. Net storage of the island's ecosystems

By manipulating the ecosystems in place, we could double the mass of the island's semi-natural ecosystem TOC, coming up to an average of 150-200 t ha^{-1} of TOC, which is not an unreasonable figure in this geographic and ecological situation. However, ecosystems allow for storage as long as they are young and growing. Then, once a climax state is reached in which consumption and growth equalize, their storage remains stable. As estimated above in the optimistic scenario, we can accumulate on average 1 t ha^{-1} y^{-1} of TOC. Starting from the current 71.49 t ha^{-1} (Table 2, last line of column 4), in today's climatic conditions, we have 80-100 years to reach the theoretical maximum admissible of the whole ecosystem. Knowing that the climate is changing and becoming hotter and drier in the region and that annual tree growth will progressively decline, we could conservatively hope for half of these values and have 40-50 years to use the vegetation as a storage element. On an island such as Albarella, we can say that we are able to use vegetation for 40-50 years to take away from emissions 10% of the amount produced to run the island's economy.

Natural biodiversity is more functionally connected than artificial biodiversity [13]. In the new plantings we recommended using native species and provided lists of those from the nearby Caleri reserve. Since species are more interconnected, they may have less need of external interventions to keep them healthy and growing, with savings also in terms of CO_2eq emissions.

4. Discussion

4.1. Not up to zero, but around 1/4 of current emissions (emissions equivalent to those of the 1960s)

With the support of the economic management of the island and using technical advanced methodologies, we attempted to achieve zero CO_2 equivalent emissions in Albarella.

We collected data on the natural environment ranging from microorganisms to vegetation and soil types, and studied human activities from energy consumption, as well as transport, diet of inhabitants and the type of recycling. The forecast model could potentially benefit from considering economic parameters linked to the economic development and growth of the island. However, the management intends to improve the quality of the environment and the cultural and recreational offerings of the site without increasing the number of tourists. A more natural and beneficial lifestyle with less impact on the environment is what is sought.

We used the responses to a questionnaire and had access to administrative data recorded in the island's past. We couldn't get to zero emissions even by planting more than half of the island's grassed areas with trees and switching to a beef-free diet. However, the more efficient operating model reached 1/4 of current emissions, which corresponds to values from 50-60 years ago. The result obtained with solar panels placed on all the roofs of houses could be improved. A more efficient solution is summarized in Supporting Information (S3 Text). These most recent estimates show that 1500 m^2 of photovoltaic panels subdivided in 4 production and self-consumption points could generate approximately 200 MWh/year. 79% of this energy production would be self-consumed, while approximately 40 MWh/year would be shared with other 3 consumption-only points. Just over 2.5 MWh/year could be sold on the market. The system would have a duration of 25 years, and the initial investment of 200k would be covered by the benefits after approximately 6 years. Theoretically, by increasing the surface area of panels (by covering the many parking spaces, for example), it would be possible to produce and sell energy to offset the emissions from the production and recycling of the panels themselves and even to absorb those remaining from the Optimistic scenario.

In other words: on a small scale and in 10 years, while having the necessary funds, with the help of incentives and the goodwill of the population, it is possible to drastically reduce emissions due to energy production and consumption. The managers of Albarella are trying to adopt the recommended measures.

For planet Earth the path remains complicated and full of pushbacks. Dividing the total energy consumption of human activities (120,000 TWh/y) by the number of hours in a year (365*24 = 8,760) Johnson Cade [28] calculated that the annual demand for electricity today would be on average 14 TW.

Today, the annual production of solar energy is 4 TW [29]. The growth of the current production of electricity from solar sources at global level is approximately 100 GW = 0.1 TW per year. To reach the annual 14 TW needed to run our global economy, another 10 TW would be necessary, which at the rate of 0.1/year would be achieved in 100 years. These rough global estimates tell us that in 2030, only 1/10 of the global energy demand will be produced by solar installations.

Good news: by focusing on technologies that generate electricity (without counting all the materials that would be needed to store and use that electricity, such as electric vehicle batteries or grid storage), Casey Crownhart [30] says "we have enough materials to power the world with renewable energy, we won't run out of key ingredients for climate action" and "the total emissions from mining and processing those materials are significant, but over the next 30 years they add up to less than a year's worth of global emissions from fossil fuels".

The problem of diet and emissions due to the food production and consumption chain is more complex. It involves cultural habits and customs and is linked to the ecological transition of agriculture[31–33]. If we consider Albarella's Optimistic model, at least half of the emissions in this sector can be avoided by changing human eating habits, and by limiting the consumption of beef. Opinions on the nutritional value of meat in the human diet are still divergent [34–36]. This aspect is reconsidered more carefully below.

4.2. Science for society statement

It makes sense to think that humans have personal priorities regarding climate change, such as health, a minimum level of economic well-being (including having a job, a home, children who are in school), and time for rest and leisure. Until most humans reach these minimums of personal satisfaction, the climate will remain at the expense of everyone else. The thought that climate affects everyone is misleading in practice. In a study just published in preprint [37], Simsek et al. illustrate the problem from an economic point of view: when climate benefits are included into the models, a positive response is only obtained in the long term, which could be too late. We could think of solving the problem with negative impact technologies, such as the direct capture of CO_2 from the air [38]. These too can generate a growth in inequalities [39], with consequent and dangerous delays in the large-scale implementation of policies against global warming.

A relatively frivolous local problem could give an idea of the complex problem to be solved at a planetary level. A population of fallow deer also lives on the island of Albarella, a species introduced in the past and which reproduces very well. Based on a recent accurate census of these animals, knowing their dietary needs and the extent of the island's meadows, the carrying capacity of the system was calculated (347 animals). With the new plantings of trees and forests envisaged by the optimistic model of calculating the CO_2eq balance, the deer would lose grazing surface. Furthermore, by introducing 2 foxes that could capture 26 young each year, and taking 25 adults through hunting, a Vensim model of the system predicts that today's rapidly growing population of 270 individuals could stabilize at around 332 animals in three years. The discussion is underway among the island's inhabitants to decide how to intervene: there are pros and cons of both, the introduction of predators and harvesting through hunting. It was also calculated that this deer population would reduce CO_2 emissions because it would slightly increase the total storage of ecosystems. Nobody thinks about this last aspect: animal-loving people can't stand hunters, those whose gardens have been devastated by deer require the killing of some of the animals. Even ecologists disagree, because the fallow deer is an invasive species, although many people with children do not understand that such a gentle animal could be considered 'invasive'. People argue and in the meantime the deer population grows. And there are other ecological problems to monitor, such as the presence of contaminants or microplastics in water and the environment (S4 Text, 2. Punctual ecological investigations). It's nothing compared to what occurs in wealthy countries that are already suffering the consequences of global warming: people buy air conditioners, which are machines that increase global warming. Cooling is already responsible for over seven per cent of global greenhouse gas emissions and demand for cooling is expected to triple by 2050 [40]. Or worse: they increase the part of the state budget dedicated to the purchase of weapons and bombs, or they even use them [41].

"How and what to eat" can also be a source of worry connected to global warming. With the Optimistic Albarella scenario, the net emissions (removing those stored in ecosystems) fall to ¼ of current emissions, from 15.4 in 2023 to 3.4 kt CO_2eq y^{-1} in 2032. Those generated by human food consumption decrease from 6.9 to 2.9 kt CO_2eq y^{-1} in the same period and correspond to 85% of total net emissions (2.9 on 3.4 kt CO_2eq y^{-1}: Fig 4 and Table 4).

At a planetary level, it is a figure linked to the global food-system emissions (15.8 GtCO_2eq [31], equating to 20% of the world's greenhouse gases emissions in 2023 [31,32]. In an Optimistic scenario of an Albarella-like planet Earth detailed in Supporting information (S1 Text), the net emissions (removing those stored in ecosystems) fall to 1/5 of current emissions; those due to human nutrition with a low impact diet (60% Mediterranean, 30% vegetarian and 10% vegan) reach 55% (= 7.1/12.9, Fig A in S1 Text, Table A in S1 Text) of the total net emissions.

These low values emissions due to human nutrition correspond to minima below which it is impossible to go. Beyond the fact that they are questionable values (is it realistic and judicious/sensible to think of eliminating beef from the human diet?) they are threshold values that reveal a crucial meaning: even reducing emissions to values of 20-25% of current ones, at least half of these (10-12.5%) are due to incompressible human nutrition.

For completeness we report that the optimistic models considered for Albarella and for Albarella-like planet allow ecosystem storage equal to 69% (7.5 out of 10.9 kt CO_2 y^{-1}) and 63% (21.6 out of 34.5 Gt CO_2 y^{-1}) of the total emissions respectively. The terrestrial storage (sink) estimated by Friendlingstein et al. (data 2021) [42] with dynamic models of global vegetation amounts to 10.6 ± 3.6 Gt CO_2 y^{-1} (approximately 28% of total; for comparison, the one reported by the same authors for the oceanic system is worth 29% of the total). The Albarella-like planet ecosystems' sink (21.6 Gt CO_2 y^{-1}) is decidedly superior, which could ideally be the one of a restored planet biodiversity (twice the current one) and that could support a functional and long-lasting living Earth system [43,44].

Calculating the human carrying capacity of terrestrial ecosystems is more complex than for animals because this considers living standards, technological advances, cooperation and economic development. The concept is simple, but it involves ethical and religious obstacles and limits [45].

To people who would like to go and live on the nearby moon (or stars), we recommend the film entitled "First Man" by Damien Chazelle [46]. It illustrates the courage that few astronauts had just to walk some hours on the lunar soil, leaving us to imagine how far we are just now from being able to go and live up there for years or to go even farther. It is easier to continue living on our planet, adapt our style of life and produce energy in a sustainable way. For those who want recent scientific explanations on the health difficulties of astronauts, we recommend Cao's article [47].

Recently, to understand microbiome dynamics during the path of adaptation to new resources, Bisschop *et al.* [48] performed an evolutionary experiment on spider mites and their host plant. After 12 generations, the spider mite performance (number of eggs and longevity) was different and clearly correlated with microbiome composition. Microbiomes are involved in most vital processes, such as immune response, detoxification, and digestion. If it works in us as in spiders, we humans are closely related to all the rest of the living, without knowing it.

Today, we evolve in a living mantle (the biosphere) which is transforming the planet [49–51]. We are part of it [52]. On average, although with large fluctuations, the biodiversity of this mantle has continued to grow, from the absence of living beings at the time of the formation of our planet 4.6 billion years ago, to countless species today. We know that many organic molecules are present in sidereal space. Since Miller Urey's experiment [53], we also know that from very simple molecules (present on site or arriving from space) placed in a primordial soup (imitation of a possible environment on the planet at the time of its formation, a primordial "soil") can form the organic molecules that make up living cells. Then, fossils revealed that increasingly complex organisms adapted to the different environments of our planet emerged and composed all the planet's ecosystems. These combined transformations of biodiversity and the environment, which also produced the human species, are still in action. This may explain why instinctively, when humans observe nature and the universe, they feel deep emotions [54]. Unconsciously, humans know that they depend on this biodiversity (Fig 5).

Permanent outdoor artistic exhibition on the island of Albarella recall to the spirit the senses of rebirth, fear, listening, admiration and respect for mystery. Environmental Audit (2010) at the Museum of Contemporary Art in Sydney focused on an historical question: how the effects and costs of human culture can be measured? (Fig 6).

The DDT is not just a dismissed poison. In human brains, the "Delay Discounting Task" (DDT) measures individuals' preference for immediate small rewards versus large but delayed rewards. A large proportion of humans belong to the RED archetype, stressed people preferring immediate small rewards [56]. Their numbers will probably grow with increasing social tensions due to global warming.

Microorganisms are widely unknown organisms. We move in a cloud of microorganisms which are everywhere, in the air and clouds, in soil, in water, on our hands, etc [57–59]. We also have them in our digestion tract: they eat what we ingest, and we must live off their remains. They are related to the genesis of planet life [60], and they built and continue to modify the planet soil [61–63]. They are living beings intimately linked to the climate [49,64], they

Fig 5. New horizons. Upper part of the figure by Karine Bonneval, left: "Eating the Soil" where a human couple finds an eatable magical soil that takes them to a higher stage and transforms them into half-plant-half-human hybrid; right: "Se planter", "plant yourself", which in French also means "to make mistakes". This is an invitation to imagine yourself rooted in the soil. Lower part, photographs by Augusto Zanella: the Po River transports woody materials which are then deposited on the banks of the river delta by sea waves. This phenomenon concerns the beach of Albarella and Caleri. From an ecological point of view, this is energy which gradually nourishes the dune system (underneath this wood, the soil becomes relatively dark and rich in organic matter, photo on the right). We would like to leave these dead woods in place in areas of the island with a more natural use.

https://doi.org/10.1371/journal.pclm.0000418.g005

make the climate [65,66], a climate we are still unable to manage. Finally, all higher life forms are dependent on the activity of microorganisms [64].

Considering the enormous quantities of greenhouse gases accumulated in the atmosphere, the only solution seems to be CO2 capture and storage. These are called Direct Air Carbon Capture and Storage (DACCS) technologies. Several problems remain to be solved [67].

A note on PNR (point of no return) [68]. PNR corresponds in 2100 to a maximum of 2˚C of average air temperature above the temperature of the pre-industrial era. Beyond this threshold, there will be a sharp decrease in arable land (sea level rise and drought) and consequent accentuation of human migrations with what we can imagine as disease [69]. The planet's climate is endowed with a certain inertia (delay in the manifestation of the taken actions), and recent models predict that with a growth in renewable energy production of 2% per year, the PNR will be reached in 2035; if, on the other hand, the growth of renewable energy reaches 5%, it will be touched in 2042. In the Albarella models, we suggested growth of renewable energy of 10% per year. If such a ratio were carried out at the planet level, the PNR would move away to 2050. We know that the temperature increases by one degree centigrade for every 1000 Gt of CO_2 added to the air. If the whole Earth planet acted like an Albarella-like planet (a growth of 500 Gt in 10 years, which means an increase of 0.5˚C: Fig A, Table A in S1 Text), the temperature would stabilize below the 2˚C limit (actual level 1.5˚C + 0.5˚C).

Remember the economic shutdown due to COVID 19? Well, a continuous reduction in emissions of that magnitude (10-20%) [70] and for the next 30 years would be capable of bringing us in 2050 within the 2˚ C limit. Recent published data says that we are far from this goal [71].

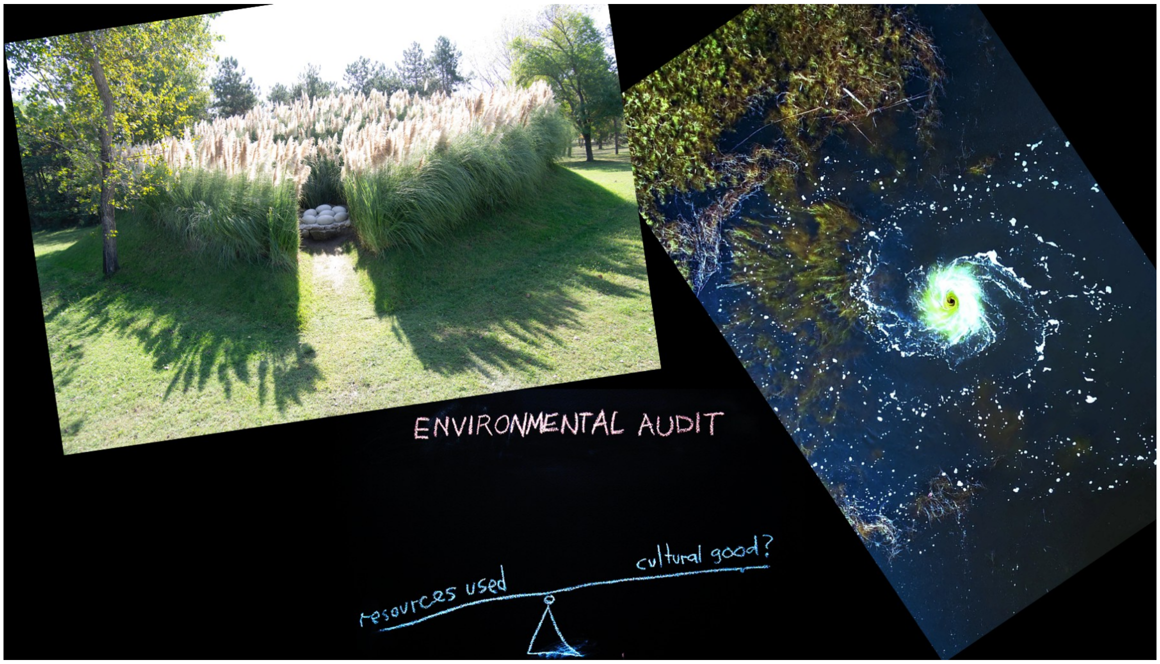

Fig 6. Artistic views. Left: "White Sea" by Nils Udo, German artist. Carrara marble eggs in a nest surrounded by an artificial hill 27 meters long and 4 meters high, covered with pampas grass, which shows a white panicle that resembles the foaming of a sea wave. Right: "The Big Ear", a sound installation by Officinadidue, the art collective Vera Bonaventura & Roberto Mainardi, Italian artists. Lengh min. 5.11". Performing every day at 10 am and 7 pm, on Albarella lake Palancana. Sound here: https://www.officinadidue.it/the-big-ear, visited on March 25 2024. Bottom: Environmental Audit, Historical balance, resources used and cultural good. How the effects and costs of human culture can be measured? More information in a graphical publication about the project in Ihlein 2010 [55].

https://doi.org/10.1371/journal.pclm.0000418.g006

The ecological crisis we are currently experiencing [72] can end if transformations similar to the one presented here take shape on the planet. These may begin on an individual scale, at home, or in small areas, and become more and more numerous over vast areas, villages or towns, then regions, until they cover the entire Earth. That would be great, right? That's why we started to believe in it.

6. Conclusions

The initial questions: in a 5 km^2 controlled territory, is it possible to bring equivalent CO_2 emissions to zero? No, it's not possible. Can the calculation performed for a small territory help to understand a global reality? Yes, it can.

Ultimately, to maintain the tourist activity of this modernized island, at least 1/4 of the initial emissions cannot be avoided. These residual emissions essentially depend on human nutrition (85%) and on the implementation and recycling of solar panels that replace fossil energy sources (15%). Although some differences remain in the perception of the problem and spending possibilities of the island's inhabitants, current data indicates that the change planned over 10 years for Albarella (75% reduction in emissions) could be achieved. The inhabitants and managers of the island are sensitive to global warming and willing to take the challenge; public funding intervenes to encourage the transition from fossil to solar energy. However, without the part of the planet outside the island there is no solution. This part must produce the food and panels consumed on the island and could also buy any surplus electricity produced with more sophisticated, possible tools on the island.

At the planetary level, the project size is 5 million times larger than in Albarella (in Supporting information, S1 Text). Reducing socio-economic disparities by promoting consciousness of belonging to a common survival plan is essential to mitigate the climate change. Emissions cannot be eliminated. Roughly 1/4 - 1/5 of the current ones remain present in the current technological planet. Half of these are due to the human food chain, and the other half mainly to the means of energy production. There is no part outside the planet that could compensate for this still unfavourable balance. Our estimates show that we need to double the increase of the planet's organic carbon sink (a sink today close to half of what it should be to offset all emissions) to be able to reduce current emissions to 1/4. Warning: we have not considered the oceanic part of the planet, which is roughly a sink of similar size to the terrestrial one. We have not considered possible artificial carbon sinking techniques, which could become important in the future. The living natural part of the planet, made up of macro and micro-organisms in systems that regulate the important balance between production and consumption of CO2, deserves more attention and could certainly fill, if brought back to a higher and more respected biodiversity, the deficit that we also noted in this study.

Finally, scientific discoveries have not yet established which and how much part of the living system is necessary to keep our species alive on the planet. It follows that natural resources are limited and must be shared among us and with the other indispensable co-evolving species, to preserve as much intelligence (conscious ability to adapt) as possible.

Supporting information

S1 Text. From Albarella to planet Earth. S1.1. A scenario of hope. Fig A. Emissions and storage on an Albarella-like planet Earth 8 billion people (density on land: 50 people per km^2). Table A in S1 Text. Albarella-like planet Earth scenario estimated for 2023 and 2032; calculated in linear progression from one to the other over the years. S1.2. Detail of the calculations that allowed Albarella values to be extended to planet Earth. Table B in S1 Text. Estimation of Diet, Transport and Wastes emissions on an Albarella-like Planet Earth.
(DOCX)

S2 Text. Questionnaire template.
(DOCX)

S3 Text. A more effective solar system.
(DOCX)

S4 Text. Other Uni-Impresa project issues. S4.1. Work packages of the Uni-Impresa project. Fig A. Work packages of the Uni-Impresa project. Relationship diagram between the activities. S4.2. Punctual ecological investigations. S4.3. Publications relating to the Uni-Impresa project.
(DOCX)

Acknowledgments

We thank the inhabitants of the island of Albarella for their trust in the university and for their concrete help in the realization of the questionnaires and for the hospitality shown to the students and the research team. We also thank the Management of the Porto Caleri Botanical Garden for having allowed the necessary surveys and for having believed in our project. Concerned about how the climate is changing, Jeanelle Sutton-Yeomans asked to participate by carefully re-reading the article, finding several imperfections, and raising the morale of the troops.

Our friend Allan Yeomans died recently at 92. Dynamic inventive man, creator of the Yeomans Carbon Still used for soil carbon testing on Albarella (and in many other country of the world), Allan had a long and illustrious career as a significant contributor to sustainable agriculture and published some important books about climate change. Thank you, Allan, for your help in our research and for your constant effort at the service of agriculture and our planet.

Preprint v2 (Europe PMC): https://doi.org/10.21203/rs.3.rs-1865024/v2

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