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EMBRACING UNCERTAINTIES IN CLIMATE CHANGE EDUCATION: DESIGN AND IMPLEMENTATION OF A FUTURE-ORIENTED SCIENCE EDUCATION APPROACH TO DEVELOP SUSTAINABILITY COMPETENCES

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Abstract

Climate change is a complex phenomenon that demands an interdisciplinary approach to understanding its scientific, social, economic, and political dimensions. The inherent complexity of climate systems, characterised by nonlinear causality and uncertainties, complicates efforts to predict, educate, and act on climate-related issues. This doctoral research explores how climate change education can address these challenges by fostering sustainability competences, emphasising sustainability, uncertainty, and future thinking.

Guided by the European framework for sustainability competences, the GreenComp, the research is structured into two parts. The first examines the context and background of climate change education and includes three case studies. The first case study analyses the role of uncertainties in climate science using risk-based and storyline approaches, assessing their potential to develop sustainability competences. The second investigates sustainability education within a six-month collaboration with the National Consortium of Packaging (CONAI), highlighting the complexity of stakeholder engagement in sustainability discourse. The third focuses on interdisciplinary approaches to uncertainty through an activity at a European summer school for pre-service teachers in STEM disciplines.

Building on these insights, the second part presents a novel educational approach integrating sustainability, uncertainty, and futures studies to address climate change. This approach culminated in the course "Towards New Future Scenarios: The Role of Physics in Dealing with Climate Change Challenges," involving high school students. The course was evaluated using qualitative methods, focusing on learning outcomes related to climate concepts, sustainability competences, and decision-making in uncertain scenarios.

Further investigations explored students' responses to personal climate-related experiences and their influence on learning, integrating insights from disaster education during a research visit to the University of Southampton. The research findings, disseminated through publications and collaborations, contribute to advancing climate change education as a tool for fostering critical competences and future-oriented action. The dissertation concludes with recommendations for further research and implementation in educational settings.

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There are so many things I do not understand
There's a world within me that I cannot explain

Within – Daft Punk

“The unknown,” said Faxe’s soft voice in the forest, “the unforetold, the unproven, that is what life is based on. Ignorance is the ground of thought. Unproof is the ground of action. If it were proven that there is no God there would be no religion. No Handdara, no Yomesh, no hearthgods, nothing. But also if it were proven that there is a God, there would be no religion… Tell me, Genry, what is known? What is sure, predictable, inevitable - the one certain thing you know concerning your future, and mine?”

“That we shall die.”

“Yes. There’s really only one question that can be answered, Genry, and we already know the answer… The only thing that makes life possible is permanent, intolerable uncertainty: not knowing what comes next.”

The Left Hand of Darkness - Ursula Kroeber Le Guin (1969)

Introduction

Climate change represents a one-of-a-kind phenomenon that is so big, so diffuse, and so difficult to study that it could be treated as an entire field of study.
From the scientific aspect, the climate is a complex system composed of many different elements operating at a scale of times and lengths very different from each other. The complexity of climate cannot be addressed by linear scientific reasoning, in that the cause-effect process is replaced by a circular type of causality, in which the element's interaction can't be avoided to understand the phenomena.
Another issue of climate change is connected to its dimensions and impacts. It is known that climate change impacts act on several different levels, such as social, economic, and political. For this reason, it is not easy to determine who should be the expert in this case. There is a need to build an interdisciplinary approach that trespasses the borders between the different disciplines and creates a boundary zone where knowledge can be shared and re-organised. At the same time, this interdisciplinary approach needs to be intertwined with sustainability in all its aspects, considering sustainability a multi-folded concept that needs to be taught at all levels.
Moreover, the scale of the phenomena, both for dimensions and for time, makes it difficult to understand how, where and when we should act to face the problem. We can't create replicas of our planet to run; therefore, simulations are much needed in this case. Depending on the level of accuracy, we can look at different aspects of our world, but we can't reach total accuracy in these future predictions if we want to take into account all the dimensions of the issue. Scenario-making activities, coming from the futures studies field, can help in dealing with these uncertainties.

From an educational point of view, these aspects create an enormous challenge in understanding how to bring climate change into class. How should we talk about it? Who should talk about it? What discipline should focus on what aspect? In which part of the curriculum is it appropriate to talk about climate change? What should be the main aim of climate change education?

My doctoral work aims to understand how to deal with these difficulties by designing an educational path to discuss climate change as a space to develop sustainability competences. The path revolves around three main themes – sustainability, uncertainty, and future – and uses GreenComp (Bianchi et al., 2022), the European framework for sustainability competences, as a reference framework.

The thesis is divided into two main parts.
In the first part, I start by describing the context, background, and research in which my work is positioned (Chapter 1). This positioning has been the focus of a study conducted in collaboration with Prof. Antti Laherto, Dr Tapio Rasa, Prof. Olivia Levrini, and Prof. Sibel Erduran and published in the book Science for the Anthropocene, vol. 2" (Laherto et al., 2023a).

I then present three case studies in which sustainability, uncertainty and future are used in different ways and contexts in education.
The first case study (Chapter 2) regards the relationship between sustainability and uncertainties. This study has been conducted by exploring two different approaches to uncertainties in the field of Detection and Attribution in Climate Change: the Risk-based approach and the Storyline approach. In particular, the chapter presents and explores the differences between the two approaches using GreenComp as an analysis tool to explore the potential of developing sustainability competences of each approach. This study has been presented at the GIREP22 Conference and has been selected by the Editors and the GIREP Board for inclusion in the Springer book of the Challenges in Physics Education series, titled "Effective Learning in Physics: from Contemporary Physics to Remote Settings", published in December 2024 (Miani & Levrini, 2024).

The second case study (Chapter 3) concerns the theme of education for sustainability. The focus of the chapter is a 6-months collaboration with the National Consortium of Packaging (CONAI) in which I've analysed the formation activities they organised, using GreenComp as an assessment tool to confront the different activities. This study serves as a starting point to explore the complexity of talking about sustainability and the need to shape the information to consider all the stakeholders, using GreenComp as a lens to explore each activity's sustainability dimensions. It has been presented at the International Scientific Workshop on Challenges of Sustainable Education, held in Trento in June 2024, and submitted as a proceeding for the relative proceedings.

The third case study (Chapter 4) focuses on uncertainty's role in discussing climate change in an interdisciplinary environment. The study describes the implementation and analysis of an activity realised in the context of an international summer school of the European project IDENTITIES together with the research group in Science Education of the University of Crete. The activity revolved around the concepts of complexity and uncertainty, and it included the participation of 14 pre-service teachers from the fields of physics, computer science, mathematics, biology, and natural sciences. This study has been submitted as a paper to the "Science & Education" journal and is currently under major revisions (Miani, Bitsaki, Metaxas, Stavrou & Levrini, under review).

In the second part of the thesis, I present the approach created starting from the experiences collected through these case studies, and the main outcome of this thesis, which is a course on climate change that revolves around the concept of uncertainty.

In Chapter 5, I present the main aspects of the approach, describing how it is possible to merge sustainability, uncertainty and futures studies to talk about climate change and outlining the design principles that led me to shape and create a course to implement the approach. In the second part of this chapter, I present the design and the implementation of the course "Towards New Future Scenarios: The Role of Physics in Dealing with Climate Change Challenges". The course has seen the participation of 34 high-school students and has been designed and taught together with my colleague Dr Francesco De Zuani Cassina.
The course has been used to test the approach's potential. During the course, data were collected using questionnaires, recordings, and interviews and analysed using qualitative methods such as thematic analysis.

Finally, in Chapter 6, I present the methodology of data collection and analysis used to evaluate what happened during the course in terms of learning fundamental concepts for the study of climate change, repositioning with respect to the future, developing sustainability competences, and managing the inherent uncertainty of complex systems in order to take action. These analyses have been discussed and presented in three papers, currently under review, focusing on the aspects of decision-making in mitigation and adaptation for climate change(Miani, De Zuani, Levrini, under review), harmful hope in exploring sustainable futures (De Zuani, Miani, Levrini, under review), and the role of digital artefacts in a future-oriented science education framework (Miani, De Zuani, Levrini, under review).

Moreover, in Chapter 7, I focused on the role that personal experience with climate-related extreme events played in students' reactions to the course. I explored this aspect in detail by studying the aspects connected to the field of Disaster Education during my visiting period at the University of Southampton, under the supervision of Prof. Wonyong Park. This collaboration led to the publication of a post on the blog of the United Nations Disaster Risk Reduction (UNDRR) website.

The final chapter (Chapter 8) presents the conclusions of this work and possible follow-ups.

Part 1 – Background, positioning and case studies

Chapter 1. Positioning towards Climate Change Education

The field of Climate Change Education (CCE) has expanded rapidly in recent years (Monroe et al., 2017), driven by increased interest from students and society (Anderson, 2013; Rodrigues & Shepherd, 2022), the rising frequency of climate-related events (IPCC, 2014, 2022), and institutional pressure to promote sustainability and environmental responsibility (https://sdgs.un.org/2030agenda). There is an urgent need to look for effective ways to address Climate Change in school curricula and communicate it (Andrey & Mortsch, 2000), in that Climate Change Education can play a crucial role in promoting a shift in students' ways of dealing with complex issues to make them future citizens capable of occupying pivotal roles towards a green transition (Grayson, 2022). Climate Change Education "can be a strategic and meaningful entry point for promoting the principles and practice of sustainable development through education" (Mochizuki & Bryan, 2015, p. 5). Kumar et al. (2023) argue for its inclusion in school curricula due to its importance, while Lee et al. (2015) stress the need for enhanced climate literacy and public understanding to foster greater climate action and support.

Given the complexity and interdisciplinary nature of climate change, determining where it should be taught and who should teach it is challenging. Climate Change Education must extend beyond traditional curricula to include informal and hybrid spaces like school-community partnerships, which can facilitate new learning opportunities and actions (Stevenson et al., 2017).

Climate Change Education involves several challenges, from curricular content and teaching practices to social implications. The inherent complexity of climate science can obscure public understanding and engagement, making effective science communication critical to advancing informed climate action (Sterman, 2011; Wibeck, 2014). As Mochizuki and Bryan (2015) observe, the scale and complexity of climate change often hinder people's understanding of their role in the crisis. Chen (2011) highlights that grasping climate processes requires understanding the non-linear and time-delayed characteristics of phenomena like carbon cycles and heat exchange between the atmosphere and oceans.

Since climate change spans numerous disciplines, integrating it into the curriculum presents difficulties for both students and teachers (Stevenson et al., 2017). Many teachers feel unprepared to address climate issues, and resources on teacher training remain limited (Greer et al., 2023; Tolppanen & Aksela, 2018). Mochizuki and Bryan (2015) emphasise that a holistic, interdisciplinary approach is essential for fully understanding climate change's scientific, ecological, political, and social dimensions.

Monroe et al. (2017) propose that effective Climate Change Education must resonate personally with learners. Engaging activities, such as discussions with experts, hands-on scientific processes, and school-based projects, are instrumental in moving beyond basic climate science. The authors highlighted two primary themes in environmental education: emphasising personally relevant and significant information and employing active, engaging teaching methods. In addition, they developed four themes related to climate change in participating in deliberative discussions, collaborating with scientists, correcting misconceptions, and executing school or community projects.

Additionally, Rousell and Cutter-Mackenzie-Knowles (2020) suggest that participatory, interdisciplinary, and creative methods are more impactful in shifting attitudes and behaviours toward climate issues. Climate change education should aim to drive social transformation by utilising teaching methods that inspire creativity, empower students, and equip them with the knowledge and skills to take meaningful action (Lotz-Sisitka, 2010).

Busch and colleagues (2019) discovered that understanding the causes and effects of climate change was only a weak predictor of behaviour. In contrast, social norms that support climate change, along with the effects of these norms through efficacy and certainty, emerged as strong behaviour predictors. Certainty regarding human attribution and efficacy were also weak predictors, mediating the impact of knowledge and norms. Factors such as students' grade level, club participation, and the number of science classes significantly influenced both knowledge and social norms. This suggests that if climate change education aims to encourage action, learning activities must focus on enhancing efficacy and fostering supportive social norms.

Often, climate change is discussed together with sustainability, both considered pressing global challenges that require comprehensive educational approaches to prepare the next generation for effective decision-making (UNESCO, 2017a). Science education can play a pivotal role in equipping students with the necessary skills to navigate these complex issues (OECD, 2023). In this context, the integration of hope, agency, and action competence into educational frameworks has gained increasing attention. Scholars such as Ojala (2017) and Finnegan (2022) have emphasised the importance of transforming students' eco-anxiety and sense of hopelessness into driving forces for action. This aligns with the concept of "critical hope", which encourages science educators to promote an active disposition for students to build equitable and sustainable futures (Freire, 1992; Torres Olave et al., 2023).

In a historical period marked by the possibility of reaching information almost immediately and instabilities throughout the world, many young people share a loss of hope towards the future, a feeling that pushes them to live mainly in the present (Giddens, 1991; Rosa, 2013) and to perceive the global future as hopeless and out of their influence (Cook, 2016; Levrini et al., 2021; Heikkilä et al., 2019). At the same time, young people may perceive their personal future as positive and in their own hands (Levrini et al., 2021).
This phenomenon, according to Leahy and colleagues (2010) and Threadgold (2012), resembles the so-called "two-track thinking" observed in the context of the climate crisis, where the "global long-term future is conceptualised separately from one's own personal future" (Levrini et al., 2021, p. 2).

According to Dillon (2022), students persist in advocating for significantly enhanced climate change education, and their efforts are beginning to influence policymakers. The connection between this and the role of sustainability education in the curriculum remains uncertain, yet "climate change education without sustainability education would seem to be missing an obvious synergy" (Dillon, 2022, p. 70).

What emerges is that, to address the specific aspects of climate change in terms of drivers, impacts, adaptation, and mitigation, it is necessary to unpack the issue and examine its different dimensions through different lenses, always considering sustainability at its core. From an educational standpoint, this involves embracing a cross-disciplinary approach that seeks to deepen our understanding of reality instead of oversimplifying it to prevent excessive linearity. It is essential to equip students with the right tools to comprehend the complex realities they face, enabling them to make relevant decisions for a future in which they would like to live in.

Following these aspects, I present in more detail the theoretical framework for this thesis and the research background for my PhD, the Research Group of Physics Education of the University of Bologna.

Section 1.1 describes the main reference for sustainability, i.e. GreenComp, the European Sustainability Competence Framework published by the JRC in 2022 (Bianchi et al., 2022).
In Section 1.2, I describe the reference framework used to conceptualise the relationship between different disciplines and their connections, i.e. the Boundary Framework (Akkermann & Bakker, 2011).
In section 1.3, I briefly present how I approached the theme of the future by describing the main characteristics of a specific positioning, that is, the one used in the field of futures studies. I discuss its origins and different epistemologies and methodologies here. All these dimensions are integrated into

the Future-Oriented Science Education model, developed by the Research Group of Physics Education of the University of Bologna in the last years and presented in Section 1.4. This model has been fundamental to the development of my thesis, as it brings together all the dimensions outlined in the previous sections and underpins all the reasoning produced within my PhD.

1.1 GreenComp as a reference framework for sustainability

Defining sustainability is not easy, as it has become one of the most used and abused catchwords in many fields, from economy to education.
I would like to start by quoting a piece from Italo Calvino from the Invisible Cities (1972). In this book, Calvino, through the narrative expedient of Marco Polo coming back from his trips, shows us many different invisible cities, which are cities that are, might have been, will be, or will never be.
Each of these cities is connected to an idea that lays the foundations around which the city is built. The tradition of using Calvino's works is not new in our research group, as many different invisible cities have been used as a starting point for several reasonings and projects.
In this case, I would like to use the city of Ottavia, which I report in its original version in Italian and then in English.

> Se volete credermi, bene. Ora dirò come è fatta Ottavia, città-ragnatela. C'è un precipizio in mezzo a due montagne scoscese: la città è sul vuoto, legata alle due creste con funi e catene e passerelle. Si cammina sulle traversine di legno, attenti a non mettere il piede negli intervalli, o ci si aggrappa alle maglie di canapa. Sotto non c'è niente per centinaia e centinaia di metri: qualche nuvola scorre; s'intravede più in basso il fondo del burrone. Questa è la base della città: una rete che serve da passaggio e da sostegno. Tutto il resto, invece d'elevarsi sopra, sta appeso sotto: scale di corda, amache, case fatte a sacco, attaccapanni, terrazzi come navicelle, otri d'acqua, becchi del gas, girarrosti, cesti appesi a spaghi, montacarichi, docce, trapezi e anelli per i giochi, teleferiche, lampadari, vasi con piante dal fogliame pendulo. Sospesa sull'abisso, la vita degli abitanti d'Ottavia è meno incerta che in altre città. Sanno che più di tanto la rete non regge.
>
> Italo Calvino, 1972. Ottavia. Le città invisibili.
>
> If you choose to believe me, good. Now I will tell how Ottavia, the spider-web city, is made. There is a precipice between two steep mountains: the city is over the void, bound to the two crests with ropes and chains and catwalks. You walk on the little wooden ties, careful not to set your foot in the open spaces, or you cling to the hempen strands. Below, there is nothing for hundreds and hundreds of meters: a few clouds glide past; farther down, you can glimpse the chasm's bed. This is the foundation of the city: a net which serves as passage and as support. All the rest, instead of rising up, is hung below: rope ladders, hammocks, houses made like sacks, clothes hangers, terraces like gondolas, skins of water, gas jets, spits, baskets on strings, dumb-waiters, showers, trapezes and rings for children's games, cable cars, chandeliers, pots with trailing plants. Suspended over the abyss, the life of Ottavia's inhabitants is less uncertain than in other cities. They know the net cannot hold too much.
>
> Italo Calvino, 1974. Octavia. The invisible cities. Translation by William Weaver.

The city of Octavia can be read as a fitting metaphor for sustainability. The limits of the web are clear, and nobody in the city would risk abusing them, as the end of the story would be clear to everybody. In our case, even if we are aware of the limits of our net, we're continuing to stress it above and beyond its limits.

The inquiry that emerges from this discourse revolves then around the object of sustainability, as it is not easy to define what we mean by sustainability. In other words, answering the question "sustainable for whom" is necessary to clarify what should be done or how to tackle the issue. Numerous programs and projects have employed the term "sustainable" without adequately specifying what should be sustained or maintained. Thinking about how our society has progressed in its history, we are aware that a model of perennial development is not “sustainable” from a societal, economic and environmental point of view (Purvis et al., 2019). Therefore, it is important to understand what I consider for sustainability, and with what goal.

Rockstrom and colleagues identified in 2009 nine “planetary boundaries” (Rockstrom et al., 2009), i.e. some specific thresholds that can be used to identify a “safe operating space for humanity with respect to the Earth system […] associated with the planet’s biophysical subsystems or processes” (Rockstrom et al., 2009, p. 472). These boundaries are Biodiversity loss, Atmospheric aerosol loading, Chemical pollution, Climate change, Ocean acidification, Stratospheric ozone depletion, Nitrogen cycle, Phosphorus cycle, Global freshwater use, and Change in land use. The concept of safe operating space can be seen as a broader definition of sustainability, in that to act sustainably would mean moving in the direction of respecting the thresholds for such boundaries. In this way, we can think about sustainability as a way to respect and live according to the planet's limits.

From an educational perspective, it is necessary, therefore, to understand which are the competences needed to include sustainable behaviours and ways of reasoning in everyday aspects.
In this thesis, I use GreenComp as a reference framework for sustainability competences. GreenComp puts together several works that focus on defining a set of sustainability competences for educational purposes (see for example Wiek et al., 2011).

GreenComp is the European Sustainability Competence Framework (Bianchi et al., 2022). It has been developed by the Joint Research Centre (JRC) of the European Commission after a long process of analysis with experts, policymakers and stakeholders to understand the most comprehensive way to talk about sustainability in the field of education. The framework follows other policy initiatives issued by the European Community in recent years, in particular, the “European Green Deal” (European Commission, 2019), the “European Skills Agenda for Sustainable Competitiveness, Social Fairness and Resilience” (European Commission, 2020a), the EU biodiversity strategy for 2030 “Bringing Nature Back into our Lives” (European Commission, 2020b), and “Achieving the European Education Area by 2025” (European Commission, 2020c).

The methodology used to produce GreenComp has been already tested and validated by the JRC in the production of several competence frameworks, like DigComp 2.2 (Vuorikari et al., 2022), EntreComp (Bacigalupo et al., 2016) and LifeComp (Sala et al., 2020).

GreenComp's objective is to "cultivate a sustainability mindset by enabling individuals to develop the knowledge, skills, and attitudes necessary to think, plan, and act with empathy, responsibility, and care for our planet" (Bianchi et al., 2022, p. 2). This framework offers a comprehensive guide for creating activities focused on building sustainability competences and tracking progress in educational and training contexts, adaptable to all lifelong learners. GreenComp aims to establish a shared foundation for learners and educators in framing sustainability as a set of competences. Here, sustainability is described as "prioritizing the needs of all life forms and of the planet by ensuring that human activities do not exceed planetary boundaries" (p. 12).

GreenComp identifies a series of sub-competences, or sustainability competences, encouraging learners to embrace complexity and make choices grounded in sustainability principles. The framework also emphasises the core of sustainability education, termed "learning for environmental sustainability," defined as "fostering a sustainability mindset from childhood to adulthood, grounded in the understanding of humanity's interdependence with nature" (p. 13).

1.1.1 Competence Areas

GreenComp is composed of 4 competence areas, each one subdivided into 3 competences. The four areas are ‘Embodying sustainability values’ (Valuing sustainability, Supporting fairness, Promoting nature), ‘Embracing complexity in sustainability’ (Systems thinking, Critical thinking, Problem framing), ‘Envisioning sustainable futures’ (Futures literacy, Adaptability, Exploratory thinking), and ‘Acting for sustainability’ (Political agency, Collective action, Individual initiative).

As presented in Laherto et al., (2023), the four areas can be described in the following way.

- “Embodying sustainability values” encourages individuals to examine their personal values and biases within a societal context, supporting principles of fairness and justice for both current and future generations as a foundation for a more sustainable society.
- “Embracing complexity in sustainability” promotes a systemic approach to analysing societal and environmental issues, helping individuals recognize connections and feedback loops in systems. This approach allows problems to be addressed from a sustainable point of view, such as examining the link between environmental degradation and income inequality.
- “Envisioning sustainable futures” highlights the value of imagining possible future scenarios, allowing individuals to consider actions today that could lead to preferred, sustainable outcomes. This mindset involves recognizing uncertainty, identifying probable and alternative futures, and actively shaping circumstances to achieve desired results.
- “Acting for sustainability” emphasizes the role of individual and collective actions in advancing sustainability goals. It encourages activities that influence the priorities of stakeholders and legislators, while also recognizing individual contributions, such as voting, volunteering, career, and consumer choices, alongside broader cultural, social, and policy changes needed for sustainable transformation.

The GreenComp framework outlines the 12 competences as interconnected, and to so uses a bee pollination metaphor to convey the interdependence between the areas: bees symbolize “acting for sustainability,” flowers represent “envisioning sustainable futures,” the beehive stands for “embodying sustainability values,” and pollen and nectar embody “embracing complexity”. (Figure 1.1).

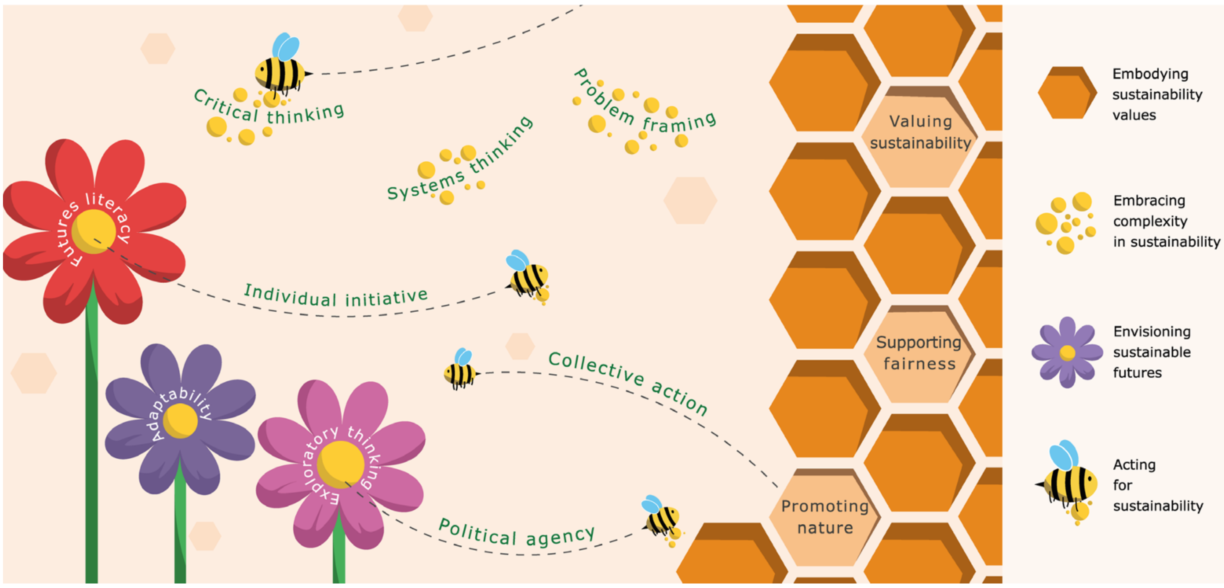


Figure 1.1 The representation of GreenComp through the metaphor of bee pollination (from Bianchi et al., 2022).

This representation emphasises how each competence supports the sustainability "ecosystem."
Each competence is then described according to the ensemble of Knowledge, Skills and Attitude (KSA). Two fictional cases demonstrate practical applications of these competences: one about a teacher restoring a local river with her students and another about a student promoting waste reduction in school. These examples show that applying sustainability competences can be natural and impactful when everyday issues are reframed through a sustainability lens.

1.2 Interdisciplinarity

To address complex issues such as climate change, an approach that tries to bring together the different aspects that characterise the problem must be adopted. This approach must adopt a plural vision and exploit the potential and expertise linked to the specificities of the problem.
As presented above, different disciplines are involved in climate change education, from hard sciences like climatology, physics, or engineering to social sciences like economics, psychology, or political sciences. To this extent, an approach that avoids and overcomes the limits of monodisciplinarity but focuses on the strengths of disciplines, such as methods, epistemologies, and established specific areas of expertise, is needed.

As for Krishnan (2009, p. 9):

1) disciplines have a particular research object (e.g. law, society, politics), even though the research object may be shared with another discipline;
2) disciplines have an accumulated body of specialised knowledge that relates to their object of research, which is specific to them and not generally shared with another discipline;
3) disciplines have theories and concepts that can effectively organise accumulated specialist knowledge;
4) The disciplines use specific terminologies or specific technical language adapted to their subject matter;
5) Disciplines have developed specific research methods according to their specific research needs;
6) Disciplines must have some institutional manifestation in the form of subjects taught in universities or colleges, respective academic departments and related professional associations.

Recent decades' cultural and scientific evolution has led from the definition of discipline to the concepts of multidisciplinarity, transdisciplinarity, and interdisciplinarity, demonstrating that certain topics and themes cannot be addressed from a single point of view within well-established boundaries.
As for Klein (2010):

- Multidisciplinarity is defined as "an approach that juxtaposes disciplines. Juxtaposition fosters wider knowledge, information, and methods. Yet, disciplines remain separate, disciplinary elements retain their original identity, and the existing structure of knowledge is not questioned" (p. 17).
- Interdisciplinarity is defined as an approach that promotes proactive integration and interaction between disciplines. There are several ways in which interdisciplinarity manifests itself; the differences between these ways are due to the relationship between the interacting disciplines, whether they share methodologies, paradigms, or epistemologies (pp. 18-19).
- Transdisciplinarity is defined as "a common system of axioms that transcends the narrow scope of disciplinary worldviews through an overarching synthesis" (p. 24).

The interdisciplinary approach has been considered more suitable based on the experience gained in my master's thesis (Miani, 2022; Miani, Modica & Levrini, 2023) and the collaboration within the IDENTITIES project.

The IDENTITIES project (Integrate Disciplines to Elaborate Novel Teaching approaches to InTerdisciplinarity and Innovate pre-service teacher Education for STEM challenges, https://identitiesproject.eu/) is an Erasmus+ project, coordinated by the University of Bologna with the collaboration of 4 other universities (Barcelona, Crete, Montpellier and Parma), whose main objective was to develop teaching modules for pre-service teachers on both curricular and extra-curricular STEM topics. The project ran from 2019 until 2022. IDENTITIES, through the development of teaching modules, materials and pedagogies, sought to show how interdisciplinarity can be valorised as a source to develop the skills needed to cope with a world that is changing very fast.

The IDENTITIES project considers interdisciplinarity as the best way to take advantage of the potentialities of disciplines and, at the same time, overcome the limitations imposed by their division. As Klein (2000) states:

> "The relationship between disciplinarity and interdisciplinarity is not a paradox but a productive tension characterised by complexity and hybridity." (p.7)

The project's main theoretical reference is the "Boundary crossing and boundary objects" framework developed by Akkerman and Bakker in 2011.
Focusing on education, we can think about disciplines as spaces separated by boundaries. In this case, the boundaries have a multiple nature: they are imaginary limits drawn in the broad panorama of knowledge to allow a deeper understanding of the specificities of each area. We are accustomed to distinguishing the various areas of knowledge according to which starting points, which methodologies and procedures and which objectives are chosen to answer certain questions.

The boundary framework takes the definition of boundary objects from Star and Griesemer (1989) and opens up to a definition of what boundary crossing is, when it can happen and, more importantly, what are the different ways in which it is possible to cross a certain boundary. Boundary objects are defined as objects "plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites" (Star & Griesemer, 1989, p. 393).

Boundaries are usually seen as limits, separating a certain zone from another. At the same time, boundaries are shared by the same two zones that should be separated by it. Therefore, a boundary can have a double nature, depending on the aim of the discussion. In our case, we consider boundaries as possibilities, where different actors can share their commonalities and confront their differences. Following the definition of the Italian dictionary, a boundary can be defined as a "transition zone in which the identifying characteristics of a region disappear and the differentiating ones begin." (https://www.treccani.it/vocabolario/confine/).

In their review of boundary crossing and boundary objects, Akkerman and Bakker (2011) highlighted four potential boundary learning mechanisms: Identification, Coordination, Reflection and Transformation (see Figure 1.2).

- Identification: comparing differences between practices. The line between the two disciplines is not clear-cut, so comparing them leads to questions about the identities of the various sites participating in the exchange and a renewed vision of the sites and their respective practices.
- Coordination: creating cooperative and routinised exchanges between practices. Movement and dialogue between practices are encouraged in order to keep the flow of work between all

participants in the joint work. The processes inside this mechanism use common instrumentalities, i.e., Boundary Objects, to connect and coordinate the different sites involved in the process

- Reflection involves expanding perspectives on and between practices. By expanding one's perspectives on the practices, one can understand their differences and discover more about the practices involved. Through this mechanism, people can look into the world in an enriched way, enriching the various identities involved in the process.
- Transformation: collaboration and Co-development of (new) practices. This mechanism unites all the others, as it represents a profound change that has occurred as a result of the sharing of practices and methods. This can lead to the creation of new, in-between practices, sometimes called boundary practices.

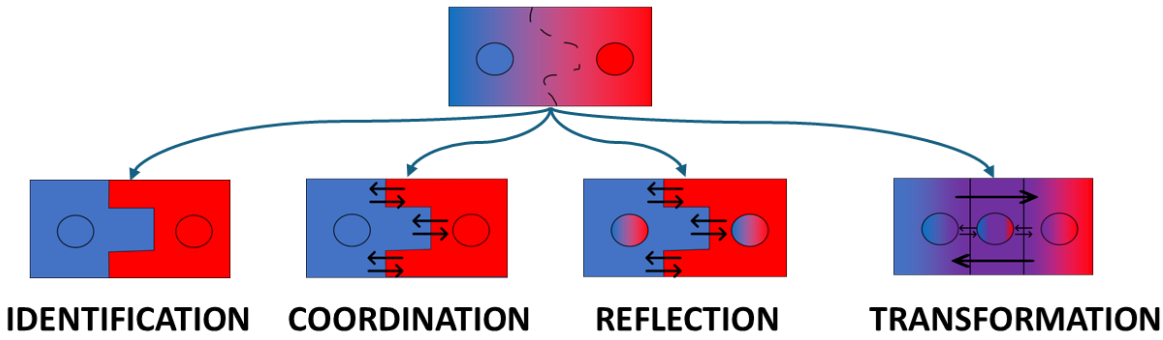


Figure 1.2 Boundary crossing mechanisms. Circles represent the epistemic core of disciplines, coloured areas around them the areas of influence, connected to the practices, the languages, and the methods of research.

1.2.1 Adopting and employing interdisciplinary strategies in science education

In recent years, there has been an increase both in literature and in practice regarding the application of interdisciplinarity in science education. This is due to the growing recognition that traditional, discipline-bound models of science education are insufficient to prepare learners for the complex, interdependent challenges that define contemporary global issues (Weingart & Stehr, 2000). When dealing with climate change, as in the case of this work, there is a need to adopt educational approaches that transcend disciplinary boundaries. Climate change involves not only the understanding of scientific principles such as the greenhouse effect, carbon cycles, and energy balance but also requires an appreciation of economic systems, political frameworks, ethical considerations, and cultural perspectives. While interdisciplinary approaches offer significant pedagogical benefits, they also encounter structural, epistemological, and practical constraints that must be addressed in order to achieve meaningful implementation. I explore here some pros and cons from the literature.

Interdisciplinary instruction is ideally suited for tackling "wicked problems" such as climate change, sustainability, and public health, which cannot be resolved through a single discipline (Zeidler, 2016). These challenges demand that students integrate various types of knowledge while managing complexity, uncertainty, and value-laden decisions. As Weingart and Stehr (2000) suggest, collaborative efforts across disciplines promote a more comprehensive understanding of these issues. In the context of science education, this approach allows students to relate scientific concepts like the greenhouse effect, carbon cycles, or ecosystem dynamics to broader societal contexts, such as political structures, economic theories, and ethical considerations (Tolppanen & Aksela, 2018).

One of the key outcomes of interdisciplinary strategies is the promotion of systems thinking, considered here as the ability to understand interrelationships and feedback loops within complex systems. Research by Assaraf and Orion (2005) shows that students engaged in interdisciplinary learning better conceptualize environmental issues as interconnected, rather than isolated, events. As discussed also in GreenComp (Bianchi et al., 2022), this skill is vital for tackling multifaceted problems like climate change. Moreover, interdisciplinarity fosters

epistemological pluralism, allowing students to evaluate knowledge claims from multiple perspectives and appreciate the contingent nature of scientific understanding (Aikenhead, 2006).
Research indicates that integrative approaches can significantly boost student motivation and engagement by linking science to personal, local, or global issues (Ivanitskaya et al., 200w). Context-based and culturally relevant teaching methods, which are often interdisciplinary, effectively connect students' real-life experiences with academic science (Aikenhead, 2006; Barton & Tan, 2009). For example, merging environmental science with indigenous knowledge or artistic expression can create a more inclusive and impactful learning experience, especially for students from marginalised communities.
Modern frameworks such as the Next Generation Science Standards (NGSS) and the GreenComp sustainability competence model highlight the significance of skills like systems thinking, collaboration, and problem-solving, competences are supported by interdisciplinary teaching (Toma et al., 2024). Additionally, current scientific research frequently takes place at the intersections of disciplines. Involving students in interdisciplinary inquiry reflects genuine scientific practice, which improves the authenticity and relevance of classroom experiences (Lederman & Niess, 1997).

Despite its benefits, implementing interdisciplinary frameworks in science education can be hindered by several structural, pedagogical, epistemological, and assessment-related challenges.
Education systems are typically organised around subject-specific curricula, timetables, and assessment structures. This compartmentalisation inhibits interdisciplinary collaboration among teachers and restricts opportunities for project-based or co-taught models (Venville et al., 2002). Standardised exams further pressure educators to prioritise content coverage over exploratory, integrative learning (Fortus et al., 2016).
Effective interdisciplinary teaching requires proficiency across multiple domains as well as pedagogical competences in integrating diverse concepts. Many educators feel unprepared to teach outside their disciplinary expertise (Ivanitskaya et al., 2002). In addition, the scarcity of suitable teaching materials and the lack of sustained professional development undermine the feasibility of implementing interdisciplinary instruction at scale.
Interdisciplinarity may result in conceptual fragmentation if not carefully designed. Simply juxtaposing topics from different fields without coherent integration can lead to cognitive overload or shallow understanding (Lederman & Niess, 1997). As Weingart and Stehr (2000) note, interdisciplinary synthesis is a complex task that requires navigating the epistemic assumptions and methodological norms of distinct disciplines. Moreover, traditional assessment tools are not made for measuring competences such as critical reasoning, systems thinking, or future envisioning. While alternative assessments like performance tasks, debates, and portfolios have been proposed (Reynolds et al., 2012), these remain difficult to standardise, scale, or align with existing accountability systems (Woodin et al., 2010).

Thus, it is evident that interdisciplinary approaches in science education provide significant pedagogical opportunities, especially in fostering systems thinking, ethical reasoning, civic engagement, and practical problem-solving skills. These methods assist students in managing the complexity and unpredictability associated with today's socioscientific challenges. However, effective integration of interdisciplinary frameworks goes beyond just conceptual support; it necessitates structural changes, teacher assistance, careful curriculum planning, and creative assessment strategies.

As proposed by Weingart and Stehr (2000), practising interdisciplinarity requires intentionality, reflexivity, and institutional support to prevent superficial efforts. In science education, this means equipping students to think beyond disciplinary boundaries and rethinking educational frameworks to facilitate this kind of thinking while maintaining disciplinary integrity.

1.3 Futures literacy and futures studies

The field of futures studies developed mostly in the last Century to respond to the need to plan and create possible scenarios after the Second World War. At the same time, the ability to think about the future has shaped humankind's development from its beginnings (Masini, 2006) and still influences it today (Miller, 2007).

The main aim of the field was to consider the long-term possibilities of policies and actions and to forecast different possibilities of continuation for the society of the time (Kuosa, 2011). Many institutions formed and started to produce knowledge connected to these aspects, such as the Association Internationale de Futuribles, the Club of Rome and the World Futures Studies Federation (WSFS) (Bishop, 2010). An important aspect of this field of research is that it has been related since its beginnings to policymaking by sharing findings and discussions with governments, corporations, and think tanks (Slaughter & Hines, 2020).

I now present some of the most used terminology to deal with the future, in order to position myself with respect to the field of futures studies.
I start by presenting the concept of futures literacy, which is also one of GreenComp's fundamental competences, before moving on to the different methods and approaches used in the field.

In the GreenComp, futures literacy is described as the competence "to envision alternative sustainable futures by imagining and developing alternative scenarios and identifying the steps needed to achieve a preferred sustainable future" (Bianchi et al., 2022, p. 15)
In the field of futures studies, according to Miller (2007), "futures literacy is the capacity to explore the potential of the present to give rise to the future" (p. 347).

Different approaches and methods can be used to deal with the future, such as forecasting, foresight, scenario making (Bishop et al., 2007), backcasting and more, all tools used to develop critical thinking towards the possible types of future, although with important differences in terms of what we think future is, or, more precisely, what we can say about it.

In the field of futures studies, three main viewpoints can be considered: forecasting, foresight and anticipation (Poli, 2017).

Forecasting is a data-based method of analysis that assumes the possibility of predicting future, by stating that the future will follow the main trends that we can see in our past and present. The forecasting method is used mainly in predictive approaches and research fields such as meteorology or economy. This method can be reliable in short time windows and in very long ones.

Foresight is a systematic participatory process (Störmer et al., 2020) that focuses on intermediate time windows, from medium to long time frames. This method of analysis starts from the premise that the future cannot be predicted but imagined and built, and is usually used in policymaking. Foresight includes several approaches, like horizon scanning, megatrends monitoring and analysis, scenario building, speculative design and serious games.

Anticipation can be considered a way to stress, as in foresight, the different ontological nature of the future with respect to the present and past (Poli, 2017) and, at the same time, deeply connected futures with agency. For this approach, anticipating means influencing actions in the present or behaviours according to visions of what might happen in the future.
According to Poli, one of the main authors of the field, "anticipation concerns the capacity exhibited by some systems to tune their behaviour according to a model of the future evolution of the environment in which they are embedded" (Poli, 2010, p. 770).
Therefore, we can consider anticipation as the emphasis on transforming foresight into action through decisions. Implementing anticipatory behaviour into education is necessary to imagine possible futures and prepare for changes. This goal can be achieved through back-casting activities, so as to "return to the present to design possible actions that can foster the achievement of a desirable scenario" (Branchetti et al., 2018, p. 10).

Foresight and anticipation viewpoints differ from forecasting from epistemological and ontological perspectives with respect to the idea of futures. In forecasting, one assumes predictability from the past anyway, even if the predictions are probabilistic. In foresight and anticipation, one assumes that the future is neither predictable nor knowable, but one can imagine it using a 'what if' approach and consequently construct from that.

Research indicates that parameters associated with the past, heavily utilised in forecasting, frequently neglect crucial turning points related to long-term transformational changes (Miller, 2007). Another often overlooked risk is that an excessive focus on probable outcomes can hide possibilities that, although improbable, may be more favourable. This can hold us back in making strategic decisions because we might not think enough about unexpected outcomes and the paths to achieve them (Miller, 2007).

Due to their diverse epistemological and ontological stances, techniques like forecasting, foresight and scenario-making offer a great space for exploration and reflection. Different approaches with different epistemologies coexist when dealing with the future, leading to many definitions and classifications of the methods connected to the field.
For example, we can consider the distinction made by Muiderman and colleagues (2020) between four approaches to futures literacy, depending on their aims and scope:

- predictive approach: futures can be considered as partially knowable by using mechanisms and models “to determine the probabilities of certain futures unfolding” (Mangnus et al., 2021, p. 3), such as forecasting;
- plausible approach: futures are fundamentally uncertain, so is necessary to explore and test adaptive capacities in multiple plausible future pathways. This approach considers quantitative techniques like strategic planning and participatory scenario development;
- experimental approach: different futures can be explored and imagined with a focus on how they are built in the present. Scenario-building techniques connected to foresight like design and gaming are used in this approach;
- critical approach: visions and imaginaries of futures are scrutinized focusing on the societal and political implications.

As said above, some of these approaches can coexist, although they are defined from very different epistemological and ontological perspectives.

The work presented in this thesis is aligned with the last two approaches (experimental and critical), therefore using the foresight viewpoint.

As for foresight, Poli (2018) distinguishes between different methods, which can focus on:

- the present, like environmental scanning, strategic interviews, Causal Layered Analysis, weak signals, and wild cards;
- the link from the past/present to the future, like scenarios, futures wheel, morphological analysis, visioning, or three horizons;
- the link from the future to the present/past, like backcasting.

To distinguish and orient scenario thinking and scenario-making, we can distinguish between different typologies of futures (Voros, 2003):

- Possible futures: all the futures we can imagine, even if very far from the status quo. They answer to the question “what might happen?”;
- Plausible futures: all futures that could happen based on our current knowledge. They answer the question “what could happen?”;

- Probable futures: all futures that have a high probability of happening. They answer the question "what is likely to happen?";
- Preferable futures: the class of futures we want to happen. They answer the question "what do we want to happen?";
- Wildcards: low-probability events that may have high impacts, and may be imaginable or unimaginable.

This distinction can allow us to unpack the perception of the future as a monolithic concept and serves as a first-level lens to explore different possible futures, moving out of the linear perspective and into a paradigm of possibility and complexity (Funtowicz & Ravetz, 1993).

The linear thinking usually presented in science and science education does not allow us to embrace this paradigm. It is necessary to break out of Laplace's chains (Levrini et al., 2019; Levrini et al., 2024) to expand our perspectives and abandon all prerogatives of thinking of the future as a simple development of what we have today, and avoid thinking of the future as 'business as usual' because the past tells us so.

To close up on this brief presentation of the field, it is useful to present what are defined as "Dator's laws of future" (Dator, 2019, p. 3-4):

1) "The future" cannot be "predicted" because "the future" does not exist.
    a. "The future" cannot be "predicted", but "alternative futures" can, and should be "forecast".
    b. "The future" cannot be "predicted", but "preferred futures" can and should be envisioned, invented, implemented, continuously evaluated, revised, and re-envisioned.
    c. To be useful, futures studies needs to precede, and then be linked to strategic planning, and thence to administration.
2) Any useful idea about the futures should appear to be ridiculous.
3) We shape our tools and thereafter our tools shape us.

These laws are relevant to the work presented in this thesis, as they represent the epistemological positioning of my work with respect to what I mean by "future." As I will show in the second part of the thesis, in order to promote meaningful agency with respect to the climate crisis, I consider it necessary to embrace the idea that different futures are imaginable and, therefore, possible.

These needs are shared by the research group and have led them to develop an approach to science education that explicitly focuses on the role of the future and on the perception we build of it through science. Therefore, a future-oriented science education approach has been designed, in which different aspects from the field of futures studies (Bishop, 2010) have been included in the design of modules and teaching activities. The approach is discussed in section 1.4.

For a more extensive picture of futures studies, see, for example, the five volumes collection "The Knowledge Base of Futures Studies 2020" edited by Richard Slaughter and Andy Hines (2020), and the book "Introduction to anticipation studies" by Poli (2019).

1.4 Future-Oriented Science Education

Future-Oriented Science Education, or FOSE (Levrini et al., 2019, 2021; Laherto et al., 2023; Rasa, 2024; Rasa & Laherto, 2022), is a model that focuses on the role of the future in science. Although the role of futures literacy occupies a central role in the discussion regarding science education, this approach considers the future not only as a topic but as a core concept that shapes many aspects of the relationships we have with science and our society.

The FOSE model has been developed inside the European Union funded projects I SEE (2016-2019, https://iseeproject.eu/) and FEDORA (2019-2022, https://www.fedora-project.eu/), both led by the research group in Physics Education of the University of Bologna and participated by other partners in Europe.

The I SEE (Inclusive STEM Education to Enhance the capacity to aspire and imagine future careers) project aimed to "design innovative approaches and teaching modules to foster students' capacities to imagine the future and aspire to STEM careers" (Branchetti et al., 2018, p. 13). The project aimed to work on developing skills needed to deal with modern societal issues and to foster students' identities to become citizens and active actors in society (Figure 1.3).

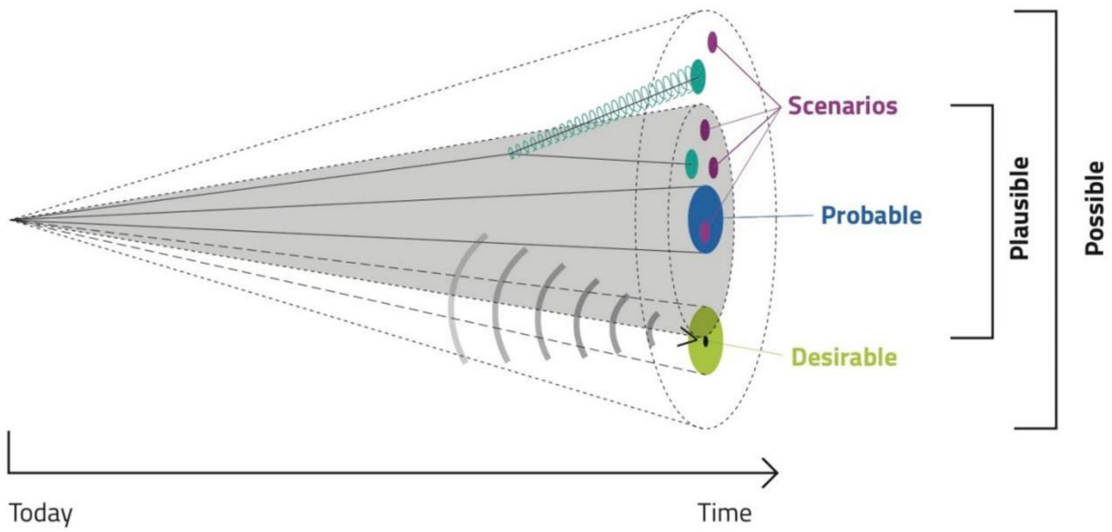


Figure 1.3 Representation of the future's cone, adapted from Voros (2003) in the I SEE project.

The FEDORA (Future-oriented Science Education to enhance Responsibility and Engagement in the society of acceleration and uncertainty) project grounded on three main blind spots in Science Education: the clash between the structure of society and schools, the need to explore new languages and narratives to enable future generations to deal with complexity, and the need to futurize science education by providing students with future-scaffolding skills (Levrini et al., 2021; Levrini et al., 2023). The project produced many relevant documents that oriented the research field and produced a manifesto to regenerate science education (Bol et al., 2023).

All these projects focused on the role that future has in science education, and show the main idea behind the research group activities, i.e. to enrich scientific contents with "epistemological and cognitive elements that foster processes that make sense to the learners" (Levrini et al., 2023, p. 3). Ioannidou and Erduran (2022) highlighted the importance of integrating problem-solving and critical thinking into science education to effectively tackle future uncertainties, including environmental challenges. Consequently, policymakers appear to acknowledge the need to shift from traditional teacher-centred methods to promote future-oriented skills.

The model has been developed over the years to address young people's and students' shared feelings about the future. It aims to regenerate science teaching so as to make it relevant for our society and capable of offering support and means for critical analysis, problem framing and mechanisms for identifying possible strategies to tackle complex and wicked problems.

The model shares many commonalities with the GreenComp framework (Bianchi et al., 2022), as it has been shown in the chapter "Future-Oriented Science Education Building Sustainability Competences: An Approach to the European GreenComp Framework" (Laherto et al., 2023) of the book "Science Curriculum for the Anthropocene, Volume 2" (Fazio, 2023).
The chapter shows the potential of science education, and in particular of the FOSE model, to "address the sustainability competences defined in GreenComp" (Laherto et al., 2023, p. 85).
The objectives of the chapter were:
- to show that all areas of GreenComp are important and relevant for science education and there are already studies for each area;
- the area connected to the field of futures studies is the newest, but it is expanding.
- all GreenComp areas are closely connected, and FOSE can identify an entry point to deal with them all.

My intervention in this chapter was to describe in detail the areas and competences presented in GreenComp, giving a summary of the background and objectives, the competence areas and their interconnection. The interconnection between the different areas can be discussed following a FOSE perspective.

The model is shaped around the "*envisioning futures*" area. Scenario-thinking activities and construction and exploration of possible pathways stay at the core of the model. Students are asked to reflect on the difference between possible, plausible and preferable futures, to discuss the potential of science and technology to be drivers of potential change. At the same time, the interdisciplinary nature of the model opens the space to discuss the need for a systematic approach that not only focuses on technology but expands to other areas of knowledge, to avoid simplistic technofixing solutions to address complex and wicked issues.

By discussing the feasibility and limits of desirable futures, the model offers a way to discuss sustainability from many perspectives, starting from the values lying in classic approaches to science (embodying sustainable values) to the need to open to non-linear and complex ways of reasoning (*embracing complexity*).
Students actively contribute to shaping potential futures by engaging with sustainability issues within a complex society that includes diverse factors, stakeholders, and interests. For example, in a "backcasting" exercise, students are tasked with envisioning a desirable future and then mapping a pathway to achieve it. This involves discussing the complexities of the situation, identifying key leverage points to create impactful change, and integrating various perspectives to build a shared vision (*acting for sustainability*) (Laherto et al., 2023).

1.5 Case studies

In the next three chapters, I present three case studies conducted in the first part of my PhD.
These case studies served as the basis for the approach to Climate Change Education in Physics Education built in my PhD and presented starting from Chapter 5.

The first case study is mainly theoretical, and focuses on the differences between two different approaches coming from the field of Detection and Attribution of Extreme Events, the risk-based approach and the storyline approach.

This case study has been chosen in that recently IPCC changed the approach used to present data for researchers and policymakers in terms of new approaches to addressing uncertainties and creating future scenarios, a discussion that stems from recent debates within the detection and attribution (D&A) of extreme weather events (Shepherd, 2016; Shepherd et al., 2018; Shepherd, 2019; Stott et al., 2004, 2013, 2016; Trenberth et al., 2015).
Extreme events are among the most invasive and dangerous aspects of climate change, so they emerged as an interesting way to enter the conversation about climate change.

The introduction of the storyline approach has sparked lively debates among climate scientists, as it rests on different assumptions and reflects distinct views about science and the role of probability in climate events. Given its socio-political importance, policymakers and philosophers of science have also joined the discussion (Lloyd & Oreskes, 2018). This chapter aims to engage with the debate from an educational angle, exploring its implications for science teaching and communication.
In the chapter, I present a way to use GreenComp as an analytical tool to assess the potential of the two different approaches to developing sustainability competences. From this study, I was able to develop a framework to describe and differentiate between the different types of uncertainties connected to climate change, an aspect that has played a key role in the development of my PhD project.
The case study presented in this chapter was presented at the 2022 GIREP Conference and published as a selected contribution in the "Challenges in Physics Education" volume edited by Springer as a chapter titled "Analysing the storyline approach's competence-developing potential for Climate Change in Science Education" (Miani & Levrini, 2024).

The second case study presents an analysis conducted on the formation activities of the Italian Packaging Consortium (CONAI, Consorzio Nazionale Imballaggi), a non-profit consortium working in the field of sustainability. The study was made possible by the nature of my PhD, for which I needed to collaborate with a company for six months.
In the chapter, I present the methodology of the study, which is an in-depth study of the materials produced by the consortium associated with two rounds of interviews to collect data. The analysis is qualitative, and has been conducted using the same tool developed in the previous chapter starting from GreenComp to map the different activities. This mapping led me to think about two possible new activities to focus on those areas that were less present in CONAI's work.
The work presented in this chapter has been presented to the company as a report in June 2024.

The third case study is a small module I created for the second Summer School of the IDENTITIES project. In it, I presented the differences between the different types of uncertainties connected to climate change and then led a group activity in which participants reasoned about the role that aspects like uncertainties and complexity play in their discipline, in their studies, and in climate change.
The chapter presents the school's setting, the activity's design and the qualitative analysis of the data collected through artefacts and recordings.
The case study described in this chapter has been presented at the 2023 ESERA Summer School and has been submitted to the Science & Education Journal in October 2024 as a paper with the title "Teaching about climate change using complexity and uncertainty: design and implementation of an interdisciplinary STEM approach" (Miani, Bitsaki, Metaxas, Stavrou & Levrini, under review).

Chapter 2. Case study 1: Analysing the storyline approach's competence-developing potential for Climate Change in Science Education

2.1 IPCC: brief history and development

The research and communication on Anthropogenic Climate Change developed mainly in the second part of the twentieth century, when global climate change started to be considered a problem. After the first hypotheses of a potential human-induced greenhouse effect by Arrhenius in 1986 (Bolin, 2007), the first relevant scientific discoveries were made in the second half of the 20th century, when different international and intergovernmental organizations started to form to assess the status of global climate (Skodvin, 2022). Between these results, the first and most relevant report to declare the role of humankind in affecting the climate is the Charney report (Charney et al., 1979), which affirmed that "we now have incontrovertible evidence that the atmosphere is indeed changing and that we ourselves contribute to that change" (p. vii), and that "if carbon dioxide continues to increase, the study group finds no reason to doubt that climate changes will result and no reason to believe that these changes will be negligible" (p. viii).

From this point on, many organizations started to plan conferences to work on this issue, like the World Climate Conference in 1979 and the Villach Conference in 1985, in which the UN Environment Programme (UNEP), the World Meteorological Organisation (WMO) and the International Council of Scientific Unions (ICSU) decided to set up an Advisory Group on Greenhouse Gases (AGGG) in 1986. Due to the composition (only six members) and the status of AGGG, some relevant actors decided to create a player that would be able to face emerging issues (Bolin, 2007). This led to the resolution of the 1987 WMO Executive Council to "establish an *intergovernmental* mechanism to carry out internationally coordinated scientific assessments of the magnitude, impact and potential timing of climate change" (Agrawala, 1998, p. 611, emphasis in the original version). This resolution led to the formation, in 1988, of the IPCC, the Intergovernmental Panel on Climate Change.

The UN General Assembly endorsed the establishment of the IPCC in 1988. As specified in UN General Assembly Resolution 43/53 on December 6, 1988, its primary task was to conduct a thorough review of climate science, assess the social and economic impacts of climate change, and propose response strategies, including elements for a potential international climate agreement (Agrawala, 1998). Since then, the IPCC has completed six assessment cycles, each culminating in an Assessment Report, which represents the world's most comprehensive scientific evaluation of climate change. Each report is composed of the results of three Working Groups: the physical science basis (WGI); impacts, adaptation and vulnerability (WGII); and mitigation of climate change (WGIII).

Additionally, it has published various Methodology Reports, Special Reports, and Technical Papers in response to requests from the United Nations Framework Convention on Climate Change (UNFCCC), governments, and international organizations for information on specific scientific and technical topics.

2.1.1 IPCC and uncertainty

The role of IPCC shifted during the years, from the need to create certainty around the question "Is climate change real and how do we know?" in its early years to the transformation of that knowledge into actual policies to understand "how do we act, who acts and how fast" (De Pryck & Hulme, 2022). To communicate their results, IPCC scientists need to use the language of uncertainty, due to the intrinsic nature of climate and its unpredictability. Many CC contrarians have used this necessity to underscore the knowledge around the issue, in that "action cannot be taken until knowledge is complete"

(O'Reilly, 2023, p. 160). At the same time, due to the incumbency and dimension of climate change, it is fundamental to deal with this uncertainty and navigate it
to prevent disastrous consequences.

The IPCC developed a specific way of using uncertainty-related terms through the years and produced a specific approach common to all Working Groups to promote a more consistent and transparent application of the concept of risk (Reisinger et al., 2020). In the official document used during the sixth assessment cycle (Reisinger et al., 2020), they define the words risk and risk management as follows.

> RISK: The potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. (p.4)
>
> RISK MANAGEMENT: Plans, actions, strategies or policies to reduce the likelihood and/or magnitude of adverse potential consequences, based on assessed or perceived risks (see also risk assessment, risk perception, risk transfer). (p.5)

In terms of uncertainties, the IPCC released a "Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties" (Mastrandrea et al., 2010), a document in which specific terms and windows of confidence are defined to uniformly present the results between the different working groups.
As described in the Guidance Note, the AR5 relied on two parameters to communicate the degree of certainty of key findings:

- the confidence in the validity of a result, based on the type, quantity, quality and consistency of evidence (e.g. mechanistic understanding, theory, data, models, expert judgement) and the degree of agreement.
- a quantified measure of the uncertainty of an outcome, expressed in probabilistic terms (based on statistical analysis of observations or model results, or expert judgement).

To describe different levels of quantified uncertainty, the IPCC uses terms such as virtually certain, very likely, likely, about as likely as not, unlikely, very unlikely, and exceptionally unlikely, each connected to a specific level of probability (Tab 2.1).

Term	Likelihood of the Outcome
Virtually certain	99-100% probability
Very likely	90-100% probability
Likely	66-100% probability
About as likely as not	33 to 66% probability
Unlikely	0-33% probability
Very unlikely	0-10% probability
Exceptionally unlikely	0-1% probability

Table 2.1 Likelihood scale used during the 5th cycle of IPCC Assessment (from Mastrandrea et al., 2010, p. 3).

2.1.2 Scenarios

One of the most used methods to explore uncertainty in future developments and climate change is the construction of long-term global scenarios (Jones et al., 2014; O'Neill et al., 2017). These scenarios are usually constituted by qualitative and quantitative components. Quantitative components are, for example, population, economic growth, or rates of technological development (O'Neill et al., 2017), while qualitative ones relate to those aspects that can't be projected quantitatively, such as political stability, people's values, or environmental awareness.

In recent years, the community around the IPCC created a first set of scenarios, the representative concentration pathways (RCPs), representing alternative trajectories for the concentration of relevant greenhouse gases in the atmosphere (Van Vuuren et al., 2011). At the same time, other researchers started to produce a new set of alternative pathways of future societal development called shared socioeconomic pathways (SSPs), to use together with integrated assessment models (IAMs) to produce more quantitative data starting from those pathways (O'Neill et al., 2017). SSPs make different use of uncertainties, as they merge qualitative and quantitative elements to create alternative future worlds.

SSP narratives combine qualitative descriptions of regional trends with quantitative data on key variables, facilitating the integration of various models for assessment and vulnerability analysis (O'Neill et al., 2017). They are designed as representations of plausible future conditions, serving as a foundation for generating diverse scenarios (Nikoleris et al., 2017). These narratives aim to support policymakers and stakeholders in exploring varying levels of sustainable behaviours for the future. This objective aligns closely with the efforts of Science Education researchers to create classroom practices and approaches that effectively educate about climate change and foster sustainability competences.

2.2 Detection and attribution of extreme events

This study examines two key approaches in the study of extreme weather events, the risk-based approach and the storyline approach, which have sparked debate about the foundations of the scientific method and the role of research in society. These approaches are particularly relevant for educational purposes due to their potential to enhance understanding of complex phenomena. The risk-based approach focuses on evaluating the impact of specific factors across a range of possibilities and is rooted in the concept of risk (Allen, 2003, 2011; Stott et al., 2004, 2013, 2016). In contrast, the storyline approach emphasizes constructing narratives to explain events (Hoerling et al., 2013; Shepherd, 2016; Shepherd et al., 2018; Shepherd, 2019; Trenberth, 2011; Trenberth et al., 2015). We can see here an alignment with the different ways in which the IPCC narrates its results.

These approaches have often been positioned as opposing methodologies due to their apparently divergent ways of addressing questions related to the detection and attribution of extreme weather events (Allen, 2003; Lloyd & Oreskes, 2018; Trenberth, 2011). I present here the approaches and their characteristics.

2.2.1 Risk-based approach

The risk-based approach aims to estimate the change in the likelihood of a certain effect in the presence of a specific factor. "Event attribution assessments seek to quantify to what extent anthropogenic or natural influences have altered the probability or magnitude of a particular type of event having occurred" (Stott et al., 2016, p. 25). There are three phases needed to obtain relevant data through the use of this approach: defining the event, constructing a factual likelihood distribution for that event using a model, and then constructing a counterfactual distribution with which to compare the factual distribution (Shepherd, 2016, pp. 30-31). The factual distribution is the one with the activities of humans, while the counterfactual is the one in which our contributions in terms of pollution and changes at the environmental level are deleted.

The effects of anthropologic climate change (ACC) are then calculated by comparing the altered frequency of a class of events of a specific magnitude or the altered magnitude of a class of events having the same frequency in the factual world. This approach, in which the event attribution is estimated by calculating the *fraction of attributable risk* (FAR) of climate extremes, was introduced in 2003 and used to address the European heat wave of 2003 (Allen, 2003; Stott et al., 2004). The method has developed over the years as the main way in the field of D&A of extreme weather events. The FAR model is composed of two different probabilities:

- *p1*: the estimated probability of a certain class of events related to the factual world, i.e. the world as we see it today.
- *p0:* the estimated probability of the same class of events in a counterfactual world, where the estimated role of humankind in contributing to climate change (ACC) is removed.

The ratio of *p1* to *p0* (Risk Ratio, RR=p1/p0) expresses the possibility of the class of events taken into consideration of being more or less likely interpreted as the result of human forcing. Because FAR is defined as *1-p0/p1*, the threshold above which an actual human contribution to climate change can be evidenced is 0.5 (Stott et al., 2016).

This method is reliable at a global scale regarding thermodynamic aspects like temperature changes or sea surface temperatures (SST). At the same time, when moving to regional scales there is the need to consider also dynamic aspects, as the thermodynamic aspects are strongly influenced (Shepherd, 2016) like in atmospheric or oceanic circulation. Therefore, when studying classes of events of this kind it is possible to encounter high levels of uncertainties.

2.2.2 Storyline approach

The storyline approach has been introduced recently in the D&A field, and has been used for the first time in assessing the Texas drought of 2011 by Hoerling and colleagues (2013). Trenberth and colleagues (2015) explained the reasons behind this choice. Storylines are defined as "physically self-consistent unfolding of past events, or plausible future events or pathways" (Shepherd, 2016, p. 2). Storylines "can raise risk awareness by framing risk in an event-oriented rather than a probabilistic manner" (Shepherd et al., 2018, p. 566).

A storyline-based approach identifies the causal chain of factors leading to a certain event, assessing their roles and their links. To make a storyline of an extreme weather event, it is necessary to take the data of a certain extreme event and perform an "autopsy" of the event (Lloyd & Oreskes, 2018). The approach makes it possible to qualitatively attribute the causes of a certain event when it is caused by a combination of not well-known dynamic factors and thermodynamic ones (Shepherd, 2016). Through a Bayesian method, and thus the identification of causal links between events, it is possible to construct a causal network capable of highlighting those areas in which actions can be taken (Shepherd, 2019).

The most relevant aspect of storylines is that they provide a mechanism to improve decision-making by analysing vulnerability points and partitioning probability factors, combining regional aspects and factors related to climate change risk (Shepherd et al., 2018). According to Trenberth and colleagues (2015), in those situations where a risk-based approach brings high-uncertainty results, it can be useful to physically investigate the unfolding of the events, trying to determine how each factor may have been affected by known thermodynamic aspects of climate change (Shepherd, 2016). Tracing the succession of certain events by determining their causes can help predict and prevent that event from occurring again with the same consequences and results. The storyline-based approach does not address the potential change in the probability of the dynamic situation that resulted in the event but can tie attribution directly to the observed event, rather than just being probabilistic in a frequentist sense (Shepherd, 2016; Trenberth et al., 2015). "The direct confrontation with data as an essential component of the attribution is a very attractive feature of this approach, as is its emphasis on a physically based causal narrative" (Shepherd, 2016, p. 34). Examples of this approach can be found in the literature (Hazeleger et al., 2015; Hoerling et al., 2013; Trenberth et al., 2015).

An important aspect of the storyline approach lies in the distinction made between the different types of uncertainty present in the study of climate. As explained in detail by Shepherd (2019) and Dessai and Hulme (2004), climate phenomena are marked by three different types of uncertainty.

The first type of uncertainty, called reflexive uncertainty, is connected to the future climate forcing, which is the dimension of climate that directly depends on humans, like the mitigation and adaptation measures. This uncertainty is usually studied with the creation of scenarios, realised to predict different types of futures, (Dessai & Hulme, 2004). A second type of uncertainty is due to the climate response to future climate forcing, which is known as epistemic uncertainty. This uncertainty is connected to our level of knowledge, and our capability of building reliable and accurate models of how climate works and will respond to possible future measures. The third type of uncertainty stays in the actual realization of climate in a certain time window, and it's generally called aleatoric uncertainty (Shepherd, 2019). This third type of uncertainty is connected to the internal variability of the system, its complexity and inner natural randomness.

2.3 Methodology

In this study, GreenComp is used as a reference framework to confront the different methods usually used to detect and study extreme events and compare their educational potential for sustainability training and decision-making development.

The analysis presented aims to compare the risk-based approach and the storyline approach through the lenses of GreenComp and evaluate whether and how these approaches can be used in an educational setting. In particular, the analysis aimed at detecting whether and how each competence was present, addressed, and promoted.
To realise the analysis I focused on the papers that used the approaches directly (Allen, 2003; Hoerling et al., 2013; Shepherd, 2016; Shepherd et al., 2018; Shepherd, 2019; Stott et al., 2004; Stott et al., 2013; Stott et al., 2016; Trenberth et al., 2011; Trenberth et al., 2015) and on the papers that discussed the philosophical, societal and ethical implications of the approaches (Allen, 2011; Curry, 2011; Lloyd & Oreskes, 2018; Mann et al., 2017).
To conduct the analysis, I constructed a grid by reformulating each competence into a targeted guiding question (Table 2.2). The guiding questions have been used to navigate both the original papers and those that alimented the debate between the approaches. To conduct this focused reading, I looked for some particular keywords inside the papers mentioned above. For some of the competences, the keyword is the name of the competence itself, while for others I choose particular words considered representative of the competence. The keywords used for the analysis are also reported in Table 2.2 and are taken from the definitions given in the GreenComp. Both singular and plural versions were considered for the analysis. The analysis does not aim to provide a count of the number of times a particular keyword appears in a paper but rather to discuss if and how specific keywords are considered in the papers when discussing the approach. The results of this confrontation are used to present in detail the different points of view of the debate between the approaches.

Areas	Competences	Guiding questions	Keywords
Embodying sustainability values	Valuing sustainability	What kind of values are promoted? How do they align with sustainability values and ethics?	Values, sustainability, ethics
	Supporting fairness	Does the approach support equity and justice for all?	Fairness, equity, justice
	Promoting nature	Is the approach capable of promoting respect towards other species and nature itself to restore and regenerate healthy ecosystems?	Respect, nature
Embracing complexity in sustainability	Systems thinking	Does the approach help in tackling sustainability problems from all sides and focusing on how the elements interact within and between systems?	System thinking
	Critical thinking	Is the approach useful for promoting reflections about information, assumptions and the influence of social and personal backgrounds?	Critical thinking
	Problem framing	Does the approach help to formulate challenges as sustainability problems based on social, economic and territorial aspects to anticipate and prevent present and future challenges?	Problem framing
Envisioning sustainable futures	Futures literacy	Is the approach capable of generating alternative sustainable futures through imagination and the development of scenarios?	Futures literacy
	Adaptability	Does the approach help in managing transitions and challenges and in making future decisions in the face of uncertainty, risk and ambiguity?	Adaptability
	Exploratory thinking	Does the approach facilitate the adoption of a relational way of thinking by using creativity and experimentation?	Exploratory thinking, creativity
Acting for sustainability	Political agency	Does the approach help in identifying political responsibility and accountability?	Political agency, decision making
	Collective action	Is the approach useful for promoting action for change in collaboration with others?	Collaboration
	Individual initiative	Does the approach contribute to identifying one own potential to actively improve one's role in the community?	Initiative, attitude

Table 2.2 Guiding questions from GreenComp (Miani & Levrini, 2024)

2.4 Results of the analysis

The results are presented by discussing how each competence can be addressed by using the two approaches from an educational perspective. This section is directly taken from the paper published in the chapter “Analysing the storyline approach’s competence-developing potential for Climate Change in Science Education” (Miani & Levrini, 2024) with some minor adjustments.

Regarding the competences “sustainability values” and “supporting fairness”, the papers analysed do not directly address the values promoted by each approach. However, Lloyd and Oreskes (2018) showed how the two approaches differentiate themselves in terms of type I (i.e. false positive) or type II (i.e. false negative) errors, and therefore, taking decisions of preferentially guarding against one or another is a question of values rather than a scientific one. Committing a type II error, i.e., a false negative, allows researchers to avoid exposure in the case of wrong predictions and to avoid unnecessary expenses and costs to prevent and prepare for extreme events that may never happen (Lloyd & Oreskes, 2018). But at the same time, this choice puts at risk those exposed to extreme events who have not done adequate prevention and mitigation. According to Lloyd and Oreskes (2018), by drawing parallels with the research that is carried out in the medical field for testing medicines and vaccines, it would be more appropriate from an ethical point of view to change the perspective and put the mantra of "do no harm" first. In the case of medical research, scientists need to verify that the drug is effective and that it does not cause unwanted effects (Lloyd & Oreskes, 2018). It then becomes necessary to understand which harm is most desired to be avoided in the case of D&A of extreme weather events. It has been shown that people are more forgiving when false alarms are made, rather than missed warning calls (Economou et al., 2016).
No related keywords were found in the papers regarding “promoting nature.” Nonetheless, both approaches aim to improve the D&A process and better describe extreme weather events to help society deal with them. The preservation of our ecosystem is a specific purpose of the detection and attribution process without distinction between the approaches, as understanding the human role in influencing the climate is necessary to identify activities that foster this influence.

Regarding “systems thinking”, the possibility of constructing causal networks to establish the role of each particular event as in the storyline approach can be useful for developing connections across systems. Since the climate is a complex system, facing extreme weather events using a frequentist approach (as in the risk-based approach) based on many factors could lead to an unclear definition of the interaction between different elements. The frequentist approach is widespread in the scientific community. However, it does not have deep roots (Mann et al., 2017), leading many scientists to re-examine the appropriateness of such an approach for hypothesis testing (Nuzzo, 2014).

> “The result of bad and misleading statements about attribution, of which there have been many, is to grossly underestimate the role of humans in climate events of note in recent times to the detriment of perceptions about Climate Change and subsequent policy debates” (Trenberth, 2011, p. 929).

A Bayesian approach instead assumes, starting from many considerations on climate change (Trenberth et al., 2015), that “climate change is likely to be impacting extreme weather events” (Mann et al., 2017, p. 133) as a prior. This approach proves much more helpful in cases where there are aspects of the problem detectable with a certain high probability (e.g., thermodynamic aspects) and others much more uncertain (e.g., dynamic aspects) (Mann et al., 2017). However, it may lead to type I errors (Lloyd & Oreskes, 2018). This could also be because the fundamental use of simulations and models requested by the risk-based approach can generate a black-box effect hiding important systems relations. Through the Bayesian approach and the assumption of the specific dynamics related to a particular event (past or future), the storyline approach helps generate connections between factors (Shepherd, 2019) and understand the role of each one of those.

Working with complexity has been shown to have a great potential to provide citizenship skills to navigate society (Barelli, 2017, 2022; Barelli et al., 2018; Cilliers, 1998; Morin, 1999).
As for critical thinking and problem framing, there is a distinction between the two approaches regarding ways of treating uncertainties. In the storyline approach, unlike the risk-based approach, a distinction is made between different types of uncertainty related to climate phenomena and extreme weather events. In dividing the factors that led to a specific event, the storyline approach makes explicit distinctions between the aspects connected to science, those connected to nature and those connected to humans. To promote action, an approach such as the storyline approach is more suitable than a risk-based one. In the storyline approach, much distinction is made between epistemic and aleatoric uncertainty, whereas in the risk-based approach, these uncertainties are often considered together (Shepherd, 2016). This distinction can help address the different responsibilities that each one can have in preventing or facilitating a specific event and, therefore, in framing extreme weather events in a different light based on the related type of uncertainty.

The competences presented in the "envisioning sustainable futures" area are also strictly related to the different ways of treating uncertainties in decision-making. The distinction between the two approaches stays in the difference between the concepts of forecast and foresight. Recalling the differences between these concepts presented in section 1.2 and applying them to this specific case study, forecasting is the process of making predictions using past and present data, as in the risk-based approach. Foresight explores the range of plausible futures starting from a certain point to identify preferable scenarios to reach (Cuhls, 2003), as in the storyline approach. Foresight is also tied with backcasting, where the task is to figure out a way to a particular plausible or preferred future, as Laherto and colleagues showed (2023b). The possibility of imagining different future scenarios can, therefore, help in promoting creativity and experimentation for decision-making, two main aspects of "exploratory thinking". For example, a Future-Oriented Science Education approach that has been produced in recent years (Branchetti et al., 2018; Rasa & Laherto, 2022; Laherto et al., 2023a) ties together complexity and future imagination with values through the development of different possible futures.

Regarding the "acting for sustainability" area, the distinction between the two approaches can be analysed through the lens of the three spheres of change model proposed by O'Brien and Sygna (2013). This model expresses the need to work simultaneously on three distinct levels (practical, political, and personal) to promote a profound transformation for achieving the necessary sustainability goals for our society. When facing a wicked problem such as climate change or others demanding socio-scientific issues, there is a tendency to extremise the dichotomy between the individual and the collective dimension of problems (Barelli et al., 2022). The possibility given by the storyline approach of distinguishing between the several factors that are tied to a specific extreme event, and therefore the possibility of generating a causal network to separate the different levels of intervention (Shepherd, 2019), can be a strong incentive for promoting action both at the individual and collective level. Also, stakeholders, policymakers and scientists may respond to different types of information. This aspect is tied to the possibility of the storyline approach focusing more on local events and, therefore, facilitating the decision-making process. The storyline approach is case-specific, referring to well-defined events that have already had local consequences, and thus, it succeeds in being more effective at the time when decisions need to be made to prevent the event from recurring with worse consequences. As Shepherd noted, "it may be difficult to convince people to invest in defences against a hypothetical risk, but easier to do so if an event has previously occurred so clearly could occur again, but potentially with more impact" (Shepherd, 2016, p. 33). In the case of risk-based, on the other hand, there is a focus on classes of events, which can be categorised as unlikely or very likely within ranges that are too wide to allow an effective decision to be made (e.g. unlikely corresponds to a 33% chance) (Mastrandrea et al., 2010; Shepherd, 2019).

In light of these differences, several researchers inferred that the two approaches are incompatible and that the storyline approach challenges what the scientific community assumed was right in the past, i.e., preferring type II to type I errors (Allen, 2011; Curry, 2011; Lloyd & Oreskes, 2018). This debate can be seen in detail in Lloyd and Oreskes (2018), in which the authors analyse the debate, showing how the two approaches are compatible and complementary as they answer two different research questions: if the FAR methodology's research question is "What are the odds or probabilities of a particular class of events, given changes in climate compared to historical pre-industrial or counterfactual climate?" (Lloyd & Oreskes, 2018, p. 313), the research question the storyline approach tries to answer is "given the atmospheric dynamics about the event, how did climate change alter it?" (Lloyd & Oreskes, 2018, p. 313). According to the authors, the choice of one approach over another lies in the preference and the decision that needs to be made about which risk is of greater concern. This discussion is based on several aspects, namely, the role of scientists in research, the role scientists have in society, the kind of information that needs to be passed on to the public, and the values tied to this information passage. In cases where information needs to be passed to other researchers, local stakeholders, policymakers or laypeople, it is crucial to understand what kind of information to present and for what purpose. Likewise, from an educational perspective, it is necessary to understand which approach is most effective in enabling a more adequate understanding of the phenomenon of climate change and the training competences necessary for sustainable development.

2.5 The potential of the storyline approach for science education to deal with extreme events

As stated by Lotz-Sisitka and colleagues (2015) and UNESCO (2017a), there is a request for a rethinking of values and purposes to develop transformation in individuals and society. Sjöström and colleagues (2017) expressed the need for science education to directly support value-based transformative agency. As discussed above, the two approaches offer different stances and positions about the four competence areas. On the value level, the two approaches are both useful in promoting awareness toward sustainability issues, with the storyline more focused on the safety of people while the risk-based focuses more on the accuracy of statements and assumptions. Regarding complexity, the storyline looks closer to the requests coming from the Science Education literature on developing skills for reading complexity in everyday life. The complexity of climate systems is fully addressed within the storyline approach, allowing the reconstruction of the links between the different factors that led to the occurrence of a certain event, while in the risk-based approach, this possibility is limited by the extensive use of models and simulations that can prevent a clear view of the mechanisms at play unless specific advanced knowledge is available. Regarding the future, the distinction between forecast and foresight helps in creating plausible scenarios rather than making predictions, leading to a possible enhanced capacity for making decisions and creating policy plans. To promote action, an approach such as the storyline approach is more suitable than a risk-based one, in that the clear division between the different types of uncertainty present within the storyline approach, along with the reconstruction of causal networks, allows for clear identification of which aspects can be acted upon. In this way, one goes to act on aspects of systemic thinking that are not touched upon in the risk-based approach.
Building on these methodological and epistemological differences, I infer that the storyline approach is better suited to developing the sustainability competences presented in GreenComp when used in an educational setting.

This result served as a starting point for the development of the uncertainty-centred approach to climate change education, presented in the following chapters. In particular, an important research question used to guide the development of the approach and the design of the course was to see if and how the epistemological assumptions underlying the storyline approach could be implemented and exploited for developing teaching courses and modules, as climate change touches on deep underlying epistemological and ontological issues about the concept of causality, temporality and prediction. An approach such as the storyline allows one to focus on process characteristics, the actual causes that lead to certain consequences, and possible actions that can be taken to prevent and adapt. The idea behind this case study is that bringing a similar approach into the classroom and re-reading storylines from an educational perspective might be a way to foster action and enable the development of knowledge, skills and attitudes needed to promote sustainability.

2.6 Further insights on the storyline approach

After the publication of the chapter mentioned above (Miani & Levrini, 2024), Prof Ted Shepherd reached out to inform us of its interest for our analysis, and as the conversation went on, we continued the study connected to the storyline. Specifically, Prof. Shepherd visited our research group in March 2025 to explore the epistemological basis of storylines and the role that probability has in this field. In this opportunity, organised together with the research group in Atmospheric Physics of the University of Bologna led by Prof. Di Sabatino, Ted presented two seminars for both students and researchers in the field of Physics Education and Atmospheric Physics, with a high participation of our department.

The exchange of emails had with Prof. Shepherd led to the discovery of new insights on the different connections and implications of the storyline approach. I present here a brief summary of two works considered relevant for this work and for possible future collaborations (Rodrigues & Shepherd, 2022; Shepherd & Lloyd, 2021).

2.6.1 Meaningful climate science

In their 2021 paper "Meaningful Climate Science," Shepherd and Lloyd (2021) offer a critical reflection on the current state of climate science and call for a fundamental reorientation in how climate knowledge is produced, communicated, and used. Their argument centres on the premise that while climate science has achieved remarkable technical sophistication, its societal relevance often remains limited due to its persistent emphasis on objectivity, prediction, and probabilistic certainty. The authors contend that such a paradigm, rooted in traditional scientific ideals, is increasingly inadequate in addressing the complex, value-laden, and context-specific nature of the climate crisis.

Shepherd and Lloyd frame their critique within a broader philosophical and epistemological discussion regarding the function of science in society. They highlight the constraints of what they call "normal science", defined as the science that follows standardised methods, emphasises detachment, and seeks generalisable laws and predictive capabilities. Although this methodology has produced significant insights, particularly in the physical sciences, the authors contend that it is inadequate for the complex realities of climate change, where uncertainty is inherent, social implications are significant, and decisions must be made with incomplete information. In this context, the quest for increased precision or certainty through intricate modelling and simulation can unintentionally mask the crucial issues that matter most to stakeholders' ground.

The notion of "meaningful climate science" entails, therefore, moving beyond a purely objective and reductionist framing of climate knowledge to one that is reflexive, participatory, and attuned to the concerns and experiences of diverse communities. Rather than positioning scientific knowledge as neutral or apolitical, Shepherd and Lloyd emphasise the importance of acknowledging the normative dimensions of climate science: the values, assumptions, and interests that shape research agendas, model construction, and communication strategies. The goal is not to diminish scientific rigour but to enhance its relevance by recognising and engaging with the sociopolitical contexts in which science operates.

The authors advocate for a shift towards post-normal science, the framework developed by Funtowicz and Ravetz (1993), which is especially applicable in situations characterised by deep uncertainty, high stakes, contested values, and urgent decision-making. Post-normal science challenges the conventional separation of facts and values and calls for an extended peer community that includes not only scientists but also policymakers, stakeholders, and the public. In this perspective, the validity and value of scientific knowledge rely not just on its internal coherence or empirical correctness, but also on its willingness to undergo scrutiny, its clarity about uncertainties, and its ability to address social needs.

Shepherd and Lloyd illustrate their arguments with examples from high-profile climate science efforts, including the IPCC and national climate assessments. They show how even subtle choices in framing - such as the decision to emphasise probabilistic projections over narrative scenarios - can have significant implications for how climate risks are understood and acted upon. They also highlight the limitations of current practices in communicating uncertainty, noting that excessive reliance on technical language and statistical thresholds can alienate non-expert audiences and impede public engagement. Instead, the authors propose approaches prioritising intelligibility, relevance, and inclusiveness. This includes integrating qualitative and narrative methods, such as climate storylines, that foreground causal mechanisms and context, enabling decision-makers to explore plausible futures without being constrained by probabilistic precision.

The role of scientists, in this reimagined climate science, shifts from that of detached experts to engaged interlocutors or "honest brokers" who facilitate dialogue between different ways of knowing and help navigate complex choices. This requires humility, openness to alternative perspectives, and a willingness to co-produce knowledge with those affected by climate risks. Institutions, too, must adapt by fostering interdisciplinary collaboration, supporting participatory methods, and creating spaces where diverse voices can be heard and valued.

An interesting aspect of this work is the use of the boundary object framework, presented in Chapter 1. Specifically, Lloyd and Shepherd discuss how climate storylines serve as tools to bridge disciplinary divides by drawing on the concept of boundary objects, described by the authors in this case as entities flexible enough to be interpreted differently across disciplines, yet stable enough to maintain a shared identity. This makes them ideal for facilitating cooperation among diverse "social worlds," such as climate scientists, ecologists, policymakers, and local communities.
Storylines, the authors argue, fulfil this role by accommodating different scientific norms. For example, in an Arctic case study, storylines linked the forensic focus of ecosystem researchers with the statistical approach typical in climate science. Through tools like branching diagrams and causal networks, findings could be translated across disciplines. The authors also highlight how storylines can incorporate various knowledge sources - including indigenous knowledge and formal scientific data - while remaining adaptable. This adaptability allows scientists to revise or simplify storylines without undermining their coherence, as seen in their reinterpretation of Pisaric and colleagues (2011), where less relevant or contestable claims were downplayed.

Moreover, storylines enable locally grounded applications of climate knowledge. In Namibia, for instance, researchers used storylines to translate regional climate trends into meaningful insights about food security and household income, incorporating trusted local knowledge. The authors conclude then that storylines function as effective boundary objects by facilitating shared understanding and co-produced knowledge across disciplines, thereby supporting more actionable and socially relevant responses to climate change.

2.6.2 Climate change as if people mattered

In their work titled “Climate Change as if People Mattered” (2022), Rodrigues and Shepherd acknowledge the rising urgency of the climate crisis and the extensive, intricate scientific systems deployed to comprehend and tackle it. In doing so, they critique the technocratic and often hierarchical approach of mainstream climate science, arguing that it is influenced by dominant institutions, global models, and abstract metrics that can obscure local contexts and personal experiences.
The authors contend that the dominant model of climate science tends to prioritise quantitative data, large-scale projections, and standardised indicators of vulnerability and risk. This “view from nowhere,” while valuable for international negotiations and high-level planning, often marginalises indigenous knowledge systems, grassroots experiences, and the social, political, and cultural dimensions of climate change. It fails, in essence, to ask the fundamental question: science for whom, and for what purpose?

Drawing on Schumacher’s ideas of “appropriate technology” and “economics as if people mattered,” the authors advocate for a climate science that is similarly grounded in human-scale ethics and practical relevance. They argue for a reframing of climate research and action around values of justice, equity, humility, and care. This entails not only listening to the voices of those most affected by climate change but also co-producing knowledge with them. Local communities, especially in vulnerable regions, must not be treated merely as data points or passive recipients of scientific knowledge—they must be active participants and co-creators in shaping solutions.

The work critiques the epistemic authority of international scientific bodies such as the IPCC, suggesting that while their assessments are influential and well-intentioned, they often privilege perspectives from the Global North and reinforce a narrow conception of objectivity. The homogenising frameworks used to measure climate vulnerability, for example, may neglect how climate change intersects with pre-existing inequalities, histories of colonisation, and power structures. The authors point out that such frameworks risk universalising a particular worldview, erasing the heterogeneity of climate impacts and responses. The paper also highlights the need for a pluralistic and democratic approach to knowledge production. This would involve integrating different epistemologies—scientific, local, traditional, and experiential—into climate discourse. Rather than assuming that technical solutions alone will solve the climate crisis, the authors stress the importance of political will, moral clarity, and context-specific adaptation strategies.

Rodrigues and Shepherd call for a radical reorientation of climate change science - away from abstraction and technocracy, and toward a science that genuinely serves people. This means rethinking not only the content of climate knowledge but also the structures through which it is produced and the purposes it is meant to serve. A climate science “as if people mattered” would prioritise dignity, justice, and participatory engagement, fostering solutions that are not only technically sound but also socially and ethically grounded. To reach so, the storyline approach seems a just way of considering local and contextual information and background to avoid generalisation and far-from-reality global averages.

Chapter 3. Case study 2: Mapping and analysing the training activities of a sustainability-centred company (CONAI)

In this chapter, I describe the analysis of the sustainability training activities conducted by CONAI, the Italian National Packaging Consortium (Consorzio Nazionale Imballaggi). The chapter aims to show a way to consider the relationship between sustainability and education. In particular, the chapter shows how GreenComp (Bianchi et al., 2022), the European sustainability framework produced by the JRC, can serve as an assessment tool to explore the potential of developing sustainability competences of a certain activity.

In section 3.1, I present the literature related to the field of sustainability education in formal, nonformal and informal settings, and then focus specifically in section 3.2 on the description of CONAI, starting with its foundation, its role in the Italian recycling system and its structure. In section 3.3, I introduce the methodology adopted to conduct the research on the company's training activities. In section 3.4, I present the results of the analysis, while in section 3.5, I describe the conclusions and possible recommendations for adopting a global perspective on sustainability education by describing two possible new activities. The specific results of the analysis are showed in the Appendix.

The materials used to conduct this analysis are mainly the reports and the documents prepared by the consortium (CONAI, 2015, 2016, 2021a, 2021b, 2021c, 2022a, 2022b; CONAI-ANCI, 2018; Ministero della Transizione Ecologica, 2022).

3.1 Education for Sustainability

As indicated by the United Nations final report on the 2005-2014 Decade of Education for Sustainable Development, it is necessary for all members of society - governments, the private sector, civil society, and people around the world - to do their part to achieve an equitable and sustainable future (UNESCO, 2017b). Talking about sustainability in a broad sense, however, can be misleading and, at times, harmful, given how widely the term has been used in recent decades. As already pointed out by Jacobs (1999) several years ago, the terms sustainability and sustainable development have been dominant in the field of environmental policies since the "Brundtland report" (Brundtland, 1987), a document produced by the United Nations Commission on Environment and Development within which the concept of sustainable development is established as the area under which it is necessary to work to achieve the goals of environmental protection and economic development. The main problem with this definition lies in its significant ability to accommodate various approaches in the field of sustainability while avoiding critical reasoning about what truly needs to be sustained (Bonnett, 2002). The concept of sustainable development, as outlined by Bonnett, risks being overly general, allowing numerous actors and stakeholders to operate within it without clearly defining how their actions promote sustainable activities, behaviours, and attitudes.

This discussion, which has been going on for several decades, finds its resonance in the field of education, as national and local directions are very deeply affected by the cultural, economic, and political climate surrounding schools. Education assumes a decisive role in educating and training future generations concerning climate and environmental issues, and how this is carried out must be aware of the real world around it. The ability to learn about the outside world is not only necessary for the introduction of subjects into the world of work, but it becomes essential in order to enable them to understand, act and change the dynamics of the system, especially those that have led to the current conditions in terms of resource consumption and pollution.

The concept of sustainability, as evident, includes several dimensions within it. We generally refer to three main dimensions, also called pillars: environmental, economic, and social. The formulation based on the three pillars does not have a clear origin, as reported by Purvis and colleagues (2019), but it is

generally used to represent the three main areas that need to be focused on in order for decisions and actions taken to be effectively sustainable.
Since its publication, the GreenComp framework (Bianchi et al., 2019) has been adopted as the main guideline for sustainability education in European project writing. Several networks and working groups are continuing the conversation to put it into practice, for example, through the Education for Climate network (https://education-for-climate.ec.europa.eu/community/).
In the study presented in this chapter, following the analysis presented in the previous chapter, GreenComp is used as an analysis tool to assess the closeness and correspondence of a range of educational and training activities to the indications of the competency framework, and thus the European community. The activities analysed here are carried out by CONAI, the National Packaging Consortium, and vary in type between formal, nonformal and informal education.

3.2 The CONAI system

CONAI, Consorzio Nazionale Imballaggi, was established in 1997 as a result of the Ronchi Decree (Legislative Decree 22/97), replaced in 2006 by the Legislative Decree "Norme in materia ambientale" (Legislative Decree 152/06 and subsequent updates). Its task is to manage the recovery and recycling of packaging in its entirety and to pursue the recycling and recovery targets set by European legislation. The operational management of packaging recovery for each individual material is entrusted to seven specific Consortia: Ricrea (steel), CiAl (aluminium), Comieco (paper), Rilegno (wood), Corepla (plastic), Biorepack (bioplastics), and CoReVe (glass). These seven Materials Consortia are joined by four other independent consortia. Therefore, the "CONAI system" is a nationwide system of consortia, which is a unique case in Europe in terms of regulations, structure, and operational and financial management.
CONAI, the seven Material Consortiums and the four independent consortiums have a four-year agreement with the Association of Italian Municipalities (ANCI), in order to ensure the coverage of costs arising from the services of separate collection, transport, sorting and other preliminary operations of packaging waste, as well as the modalities of collection of the same waste for recycling and recovery activities. It is a self-funded system that has achieved its targets at the lowest costs in Europe, while also investing considerable resources in information to the general citizens (Figure 3.1).

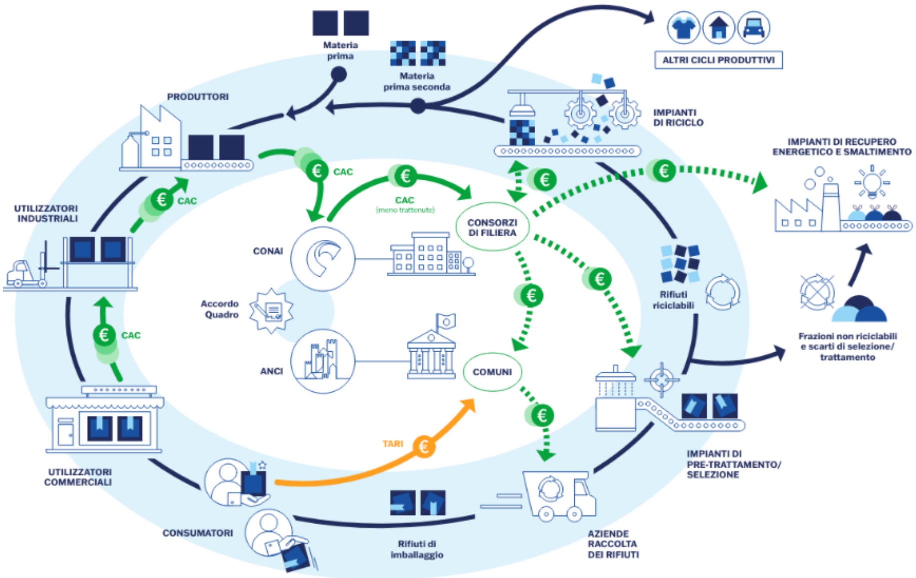


Figure 3.1 The structure and functioning of CONAI, from CONAI (2021a).

This system, established by law and entrusted to companies, has marked the transformation from landfill-based management to an integrated system based on the prevention, recycling and energy recovery of packaging waste, then extended to other waste. The overall structure works on nine different SDGs and five specific programmes (Figure 3.2)

Figure 3.2 The SDGs targeted by the consortium

At the international level, CONAI is a member of EXPRA (Extended Producer Responsibility Alliance), a European reference organisation representing waste management and packaging systems. Through EXPRA, CONAI carries out comparison activities with European institutions and references consultants of the European Commission to share know-how on EPR systems belonging to EXPRA.

CONAI moves within the European regulations of the European Green Deal (which promotes a climate-neutral, resource-efficient and competitive economy) and the New Circular Economy Action Plan (2020, which aims to preserve the value of products, materials and resources in the economy as long as possible and minimise waste production).

Since 2005 in Europe, the state that produces packaging is also responsible for its end-of-life. CONAI's packaging waste management model is among the most efficient and least costly. In Italy, there is a national policy called 'National Strategy for the Circular Economy', a National Waste Management Programme (PNGR). Following the publication of the Single Use Plastic (SUP) Directive, CONAI published the Guidelines on the implementation of the Directive with specific reference to the impact on the packaging sector in Italy. The document has been submitted for public consultation with the aim of collecting all the useful hints for the definition of a shared and complete document.
In 2021, 12 million tonnes of virgin primary material will be saved, 54 TWh of primary energy have been consumed, and 9.5 Mt CO2eq have been emitted into the atmosphere. The contribution of the consortium system is 5 mln tonnes of virgin primary material (285kt steel, 16kt aluminium, 1318kt paper, 916k wood, 519kt plastic, 1796kt glass, 140kt compostable bioplastic), 26 TWh of primary energy and the emission of 4.7 Mt CO2eq. The direct costs of the CONAI recovery chain in 2021 amounted to about 800 mln euro. The directly and indirectly related economic benefits amounted to 1.5 billion.
As far as packaging materials are concerned, CONAI's consortium management covers 24 % of the energy recovered (318 kt) against 76 % for the market and autonomous systems (1014 kt) and 50 % for recycling (5275 kt). 1332 kt are used for energy recovery, 2501 are disposed of in landfills or incinerators and 10,548 are recycled. Italy has already reached the European targets for 2025 and 2030 on packaging recycling.

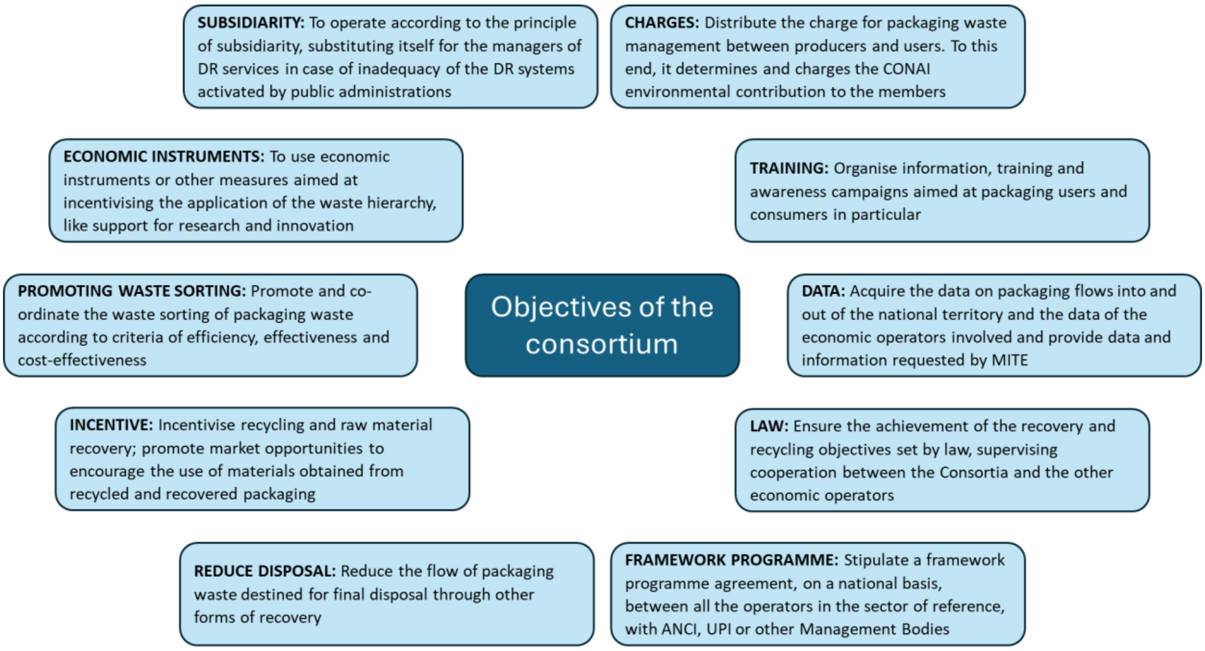


Figure 3.3 Main aims of the consortium

CONAI is organised according to a Board of Directors (BoD) consisting of 17 members: eight belong to the producers' category, eight to the users' category, while the 17th is appointed by the Minister of Ecological Transition and the Minister of Economic Development to represent consumers. The Board of Directors remains in office for three years and elects the President of the consortium from among its members. The Board of Directors may delegate certain tasks to a President's Committee composed of the President and 2 Vice-Presidents with the participation of the Mayors and the General Manager. The president and vice presidents are elected among users and producers. The Board of Statutory Auditors expresses its opinion on the regularity of the consortium's accounting management and consists of 7 full members plus two alternates. Three members are appointed by the Ministry of the Environment, the Ministry of Economic Development and the Ministry of Economy and Finance. There is an EPR coordination committee and a technical commission: the committee expresses opinions and proposals to be examined by the Board of Directors and can open working tables to deal with specific issues, while the technical commissions serve to ensure discussion with the association representatives of packaging producing and user companies, public administrations and supply chain operators.
As described above, one of the aims of CONAI is to train stakeholders, technicians and more, in general citizens, to know and respect the latest European directions in terms of waste disposal and recycling (Figure 3.3). To do so; the consortium has developed several activities over the years to reach these goals. In the next section, I will show in what way the context of the consortium has proved to become an interesting case to introduce the relationship between education and sustainability.

3.3 Research work

The study reported in this article is based on a six-month study period conducted together with the CONAI Consortium. The research conducted aimed to study how the training activities carried out by the consortium's various experts together with territorial realities, companies and schools can contribute developing sustainability skills and promoting values related to sustainability. All the work was carried out paying attention to the interdisciplinary dimension of the activities analysed and their context.

The work was divided into three phases. In the first phase, I gathered information on the orientation, training and communication activities implemented by the Consortium on environmental sustainability issues through interviews, document analysis and direct observation of practices. The interviews were conducted with representatives from the main areas of the Consortium, with the aim of mapping the activities implemented in the context of sustainability training. The semi-structured interviews were conducted online. After asking some introductory questions, such as each interviewee's background and role within the company, I moved on to focus on questions regarding change, skills, practices, and activities, with the following questions:

- What kind of change does your area intend to promote in relation to different goals?
- In opinion, what are the skills that need to be promoted and developed in your target group to achieve the change you are aiming for?
- How do you work to build and develop these kinds of skills?
- What activities do you carry out in your projects to promote these skills?
- What values do you seek to promote through the implementation of these activities?
- Are these values, in your opinion, typical of the areas or are they across the ?

In this phase I interviewed 8 company members, respectively Simona Fontana and Ilaria Barbisotti from the Centro Studi per l'Economia Circolare, Alessandro Bizzotto for the journalist area, Luca Brivio and Chiara Morbidini for the Communication and Formation area, Amanda Fuso Nerini for the international area, Luca Piatto and Fabio Costarella for the local land services.
During this phase, we noticed that we could attend some of the activities personally and conduct two more interviews, one with Irene Piscopo for the consortium partners area and one with Donata Gammino for the green jobs area.
Finally, a total of 10 interviews were conducted, each lasting about 50 minutes.

In the second phase, I proceeded to systematise and categorise all educational activities by target, topic, and primary objective. This process was necessary because the first round of interviews and reading of the transcripts showed how the consortium was moving on different fronts and levels to pursue its sustainability education. However, neither the reports nor the interviews revealed a systemic view of all the activities carried out. Accordingly, I identified four main targets: schools and universities, stakeholders and partners, technicians and public officials, and journalists. A total of 8 main activities were surveyed (Figure 1).

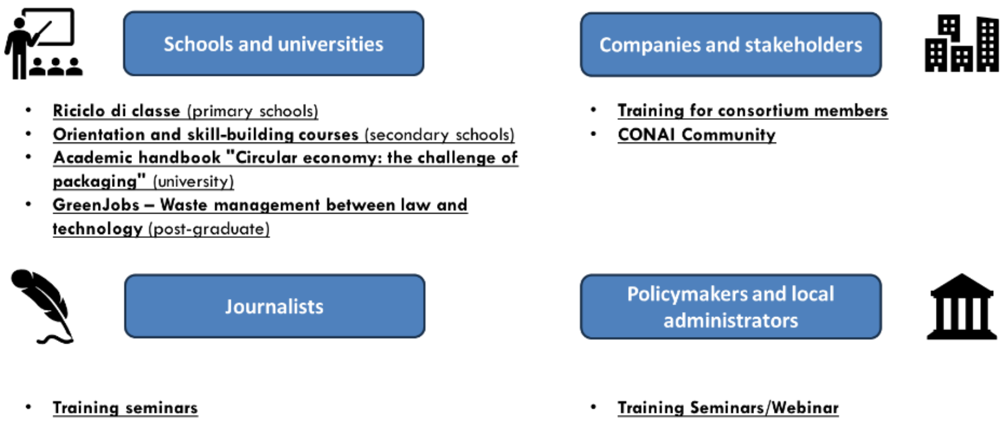


Fig. 3.4 List of training activities carried out by CONAI, broken down by target audience.

This analysis was guided by three main questions:
- Are the training activities presented by CONAI aligned with the European reports in terms of sustainability competences?
- Are the activities designed to develop the core competences for green transitions?

- Is the development of GreenComp competences already made explicit as an objective within the activities?

In order to answer the research questions, I created a guiding tool based on the one presented in Chapter 2, in which I rephrased the competences definitions used in GreenComp and turned each definition into a guiding question. This was intended to create an assessment tool close enough to the GreenComp definitions and flexible enough to be declined depending on the topic being assessed.
I report here the complete list of guiding questions produced to conduct the analysis (Table 3.1).

Embodying sustainability values	
Valuing sustainability: To reflect on personal values; identify and explain how values vary among people and over time, while critically evaluating how they align with sustainability values	**Valuing sustainability:** What kind of values are promoted? How do they align with sustainability values and ethics?
Supporting fairness: To support equity and justice for current and future generations and learn from previous generations for sustainability	**Supporting fairness:** Do the CONAI training activities support equity and justice for all generations?
Promoting nature: To acknowledge that humans are part of nature; and to respect the needs and rights of other species and of nature itself in order to restore and regenerate healthy and resilient ecosystems	**Promoting nature:** Are the CONAI training activities capable of promoting respect toward other species and nature itself to restore and regenerate healthy ecosystems?
Embracing complexity in sustainability	
Systems thinking: To approach a sustainability problem from all sides; to consider time, space and context in order to understand how elements interact within and between systems	**Systems thinking:** Do CONAI training activities help tackle sustainability problems from all sides and focus on how the elements interact within and between systems?
Critical thinking: To assess information and arguments, identify assumptions, challenge the status quo, and reflect on how personal, social and cultural backgrounds influence thinking and conclusions	**Critical thinking:** Are CONAI training activities useful for promoting reflections about information, assumptions and the influence of social and personal backgrounds on thinking and conclusions?
Problem framing: To formulate current or potential challenges as a sustainability problem in terms of difficulty, people involved, time and geographical scope, in order to identify suitable approaches to anticipating and preventing problems, and to mitigating and adapting to already existing problems.	**Problem framing:** Do CONAI training activities help to formulate challenges as sustainability problems based on social, economic and territorial aspects to anticipate and prevent present and future challenges?
Envisioning sustainable futures	
Futures literacy: To envision alternative sustainable futures by imagining and developing alternative scenarios and identifying the steps needed to achieve a preferred sustainable future	**Futures literacy:** Are CONAI training activities capable of generating alternatives sustainable futures through imagination and the development of scenarios?
Adaptability: To manage transitions and challenges in complex sustainability situations and make decisions related to the future in the face of uncertainty, ambiguity and risk	**Adaptability:** Do CONAI training activities help in managing transitions and challenges and in making future decisions in the face of uncertainty, risk and ambiguity?
Exploratory thinking: To adopt a relational way of thinking by exploring and linking different disciplines, using creativity and experimentation with novel ideas or methods	**Exploratory thinking:** Do CONAI training activities facilitate the adoption of a relational way of thinking by using creativity and experimentation?
Acting for sustainability	
Political agency: To navigate the political system, identify political responsibility and accountability for unsustainable behavior, and demand effective policies for sustainability	**Political agency:** Do CONAI training activities help in identifying political responsibility and accountability?
Collective action: To act for change in collaboration with others	**Collective action:** Are CONAI training activities useful for promoting action for change in collaboration with others?
Individual initiative: To identify own potential for sustainability and to actively contribute to improving prospects for the community and the planet	**Individual initiative:** Do CONAI training activities contribute to identify one's own potential to actively improve one's role in the community?

Table 3.1 GreenComp sustainability competences definitions (left); TASC CONAI version (right)

The ensemble of the guiding question has been named TASC (Tool for Assessing Sustainable Competences).
The TASC can be seen as a multifield polyvalent instrument, and can be used in different contexts. The questions refer to a common root but can be modified very easily in case they need to be

recontextualised. In this case, they have been applied to CONAI formative activities, while it has been used in Chapter 2 in the field of Detection and Attribution of extreme events.

The TASC has been used to explore and analyse the eight activities. The activities are presented through the creation of summative tables, accessible in the Appendix. These tables are divided into two main parts. In the first part, the table describes the name of the activity, the area responsible inside CONAI that organises it, the target of the activity, the type of activity, and the objectives of the activity. In the second part, there is a description of the competences the activity aims to develop in the relative target.

To represent more rapidly what kind of aspects were more emphasised by each activity, I created a simple graph that summarises the four main competence areas and the 12 competences of GreenComp (Figure 3.5).

Figure 3.5 A different representation of GreenComp competence areas, used in the TASC to highlight which competences is activated but which activity.

This image has been used to represent which competences were activated by each specific activity.

The third phase of the work focused on co-designing possible instructional modules for formal or nonformal education contexts aimed at more directly and effectively linking school and social and local contexts. These proposals are suggested at the end of the next section.

3.4 Results

In this section, I present the outcome of the analysis of the eight activities made through the use of TASC. For each activity, I present a brief description of the activity, the target, the main theme and content, the materials and the competences activated. In the Appendix is then attached the summative card.

Class Recycling (Riciclo di Classe)

The first project described is called "Riciclo di Classe," and it is a significant example of sustainability education aimed at Italian elementary school. Created with the aim of bringing children closer to the themes of recycling and separate waste collection, the project adopts an educational approach that combines didactics, creativity and active participation. Included in the School Regeneration Plan and linked to the teaching of Civic Education, the educational path consists of a series of activities that combine moments of classroom reflection with artistic and narrative experiences. Over the years, the project has used different languages to communicate the value of environmental sustainability to young children. Initially, an illustrated story set in the fictional town of "Recycling" allowed students to discover the ideal functioning of a recycling collection system and to address, through storytelling, the challenges of environmental education. Next, the focus shifted to theatre, with the creation of the play "It Depends on Us," a work that tells the story of a family engaged in defending an old country house threatened by building speculation. In this context, students discover the "characters" of the scene - seven packaging materials (Steel, Aluminium, Bioplastic, Paper, Wood, Plastic and Glass) - that symbolically represent the possibilities of transformation recycling offers.

Through an educational experience that integrates play, storytelling and group work, the project promotes the adoption of responsible behaviour and encourages the building of active environmental citizenship. Children are called upon not only to understand the principles of recycling collection, but also to put them into practice concretely, developing skills related to sustainability, cooperation and creativity.

From the perspective of the European competencies for sustainability outlined in the GreenComp Framework, "Recycle Class" is placed primarily in the areas dedicated to embodying sustainability values (A1), imagining sustainable futures (A3) and acting for sustainability (A4). In particular, the activity stimulates the development of skills such as valuing environmental sustainability, promoting nature, exploratory thinking, individual initiative, and collective action. Theatre, as an inclusive form of expression, allows students to confront and collaborate, but also to critically reflect on their own daily behaviours, turning environmental education into a concrete, engaging and transformative experience.

PCTO Project

The PCTO (Pathways Transversal Skills and Orientation) project, designed for secondary students, is configured as a training opportunity to bring young people closer to professions related to sustainability and the circular economy, with a specific focus on packaging recycling. This is a 40-hour online course, developed in collaboration with CONAI and supply chain consortia, which aims to offer a broad and systemic look at the environmental, economic and social dynamics related to the materials cycle.

The activity is conducted entirely on an e-learning platform and offers multidisciplinary content divided into several modules. One of the strengths is the in-depth study of so-called green jobs, the emerging professions related to the ecological transition, offering students tools to orient themselves in an ever-changing job landscape. In addition to this, the curriculum presents concrete examples of environmental communication campaigns, such as "Renaissance for the Environment," and educational projects such as "Recycling Class," to highlight how sustainability can permeate different professional fields, from communication to logistics, from environmental consulting to waste management.

Course content aims to develop in students a critical understanding of the relationships among actors and processes involved in sustainable resource management. Indeed, the strategic role that public, private and territorial stakeholders play in building effective environmental policies and practices is highlighted. The structure of the course thus allows students to approach sustainability issues not in an abstract or sectoral way, but as part of a complex system of economic, cultural and institutional interactions.

In terms of GreenComp, the project activates a wide range of skills. In addition to the area related to embodying the values of sustainability (A1), where elements such as equity and the promotion of nature are worked on, the course enables the area of embracing complexity (A2) to be particularly effective, developing skills such as systemic thinking, critical thinking, and problem framing. In addition, exposure to future scenarios and the professional dimension of sustainability also allows for strengthening the area related to imagining sustainable futures (A3), adaptability and exploratory thinking, and finally to acting for sustainability (A4), through the promotion individual initiative, collective action and political agency.
The PCTO activity thus uses a compulsory training structure as a tool to introduce crucial environmental reflections and knowledge, transforming a school fulfilment into an educational opportunity to form more aware and action-oriented sustainable citizens. The project demonstrates how education for sustainability can become an integral part school and career guidance, providing young people with a set of skills that are fundamental for facing the challenges of the future with responsibility and a critical spirit.

Handbook on Circular Economy

The academic handbook project "Circular Economy: the Packaging Challenge," edited by Alessia Acampora and Carlo Alberto Pratesi [17], was created as a publishing initiative of CONAI on the occasion of the twenty-fifth anniversary of its founding. It is a choral work, compiled with the contribution of more than thirty university professors from Italian universities of excellence, including Politecnico di Milano, Bicocca University, Scuola Superiore Sant'Anna, the University of Tuscia, Roma Tre and the University of Basilicata. The handbook represents a rigorous and up-to-date synthesis of the knowledge and practices matured in Italy on circular economy, with particular attention to the role of packaging and the recycling consortium system. Designed as a teaching tool for university students-both from technical-scientific and humanistic fields-and for professionals in the environmental sector, the volume is divided into two main sections. The first deals theoretically and normatively with the concept of circular economy, delving into its models, European policies, operational tools and the crucial role of consumers. The second part, on the other hand, goes into the specifics of the packaging sector, addressing issues such as ecological design, waste governance and the integrated management cycle. Each chapter is constructed as a stand-alone, peer-reviewed scientific contribution that combines academic soundness with CONAI's operational experience.
The perspective adopted is strongly interdisciplinary: law, economics, management, commodity sciences and engineering converge to return a systemic view of the challenges and opportunities offered by the circular transition. The handbook provides a comprehensive picture of the Italian context, and fits into the international debate through an analysis of the literature and a comparison of theory and practice. In this sense, it represents a concrete response to the growing demand for training materials that can address the complexity of the topic of packaging from a sustainable perspective.

The presentation of the manual, carried out in several Italian universities, is an integral part of the project. During these events, in addition to the authors and professors, Randstad Research was also involved, presenting the results of the research "The 200 Professions of the Circular Economy," providing a useful overview of emerging green jobs. Thus, these occasions allowed not only to promote the manual as a learning tool, but also to raise students' awareness of new professional opportunities related to sustainability.
From a GreenComp skills perspective, the activity activates all four key areas. The values dimension of sustainability (A1) is stimulated through reflection on issues of equity and environmental responsibility. The entire framework of the manual builds on the "Embracing Complexity" area (A2), promoting skills such as systems thinking, critical thinking and problem framing. To the extent that the handbook encourages thinking about future scenarios, regulations and governance models, the area "Imagining Sustainable Futures" (A3) is also activated, with emphasis on future literacy, adaptability and

exploratory thinking. Finally, the active participation of students in presentation and discussion moments stimulates the development of political action (A4), making them informed and aware protagonists of change. In summary, the academic handbook "Circular Economy: the Packaging Challenge" represents an educational tool capable of combining scientific rigor, operationalization and dissemination. It also contributes to filling a gap in academic educational pathways, promoting a culture of sustainability based on knowledge, participation and shared responsibility.

GreenJobs

The 'Green Jobs' project concerns the post-graduate training of students living in or graduated from universities in central and southern Italy. The project was developed as an advanced training course for recent graduates and was first realised in conjunction with the events related to Matera 2019 - European Capital of Culture. The course aims to promote studies and professions related to the circular economy, thus facilitating the development of so-called 'green jobs' by developing skills related to recycling and the circular economy. The focus on universities in southern Italy arises from the disparity in infrastructure and recycling rates between northern and southern Italy. To bridge this gap, it is crucial to invest in skills and training for qualified personnel, particularly in areas that are lagging behind. Achieving packaging waste recycling targets requires the cooperation of a civil society prepared to manage the life cycle of waste.
The course has also been offered in the northern part of Italy, on the occasion of 'Bergamo Brescia Italian Capital of Culture 2023'. The Green Jobs course had its seventh edition in 2023 and was previously implemented in Basilicata, Sicily, Calabria and Campania, training almost 500 new graduates in four years. During this time, it received the patronage of MITE (Ministry for Ecological Transition), currently MASE (Ministry for the Environment and Energy Security).

The course is primarily designed for recent graduates from universities in the south of Italy or who reside in the centre-south, but will also be taken to other regions in Italy. The course is organised by CONAI in cooperation with several universities and other institutional bodies and stakeholders. The course is free of charge for participants. The course is aimed at 80 participants per session, is repeated several times a year according to the different universities that request activation, and has so far trained around 500 people.

The courses are divided into two main parts, a regulatory part and a technical part. In the first part, topics such as laws for the correct disposal of waste, management, sanctions, and liability are covered. The regulatory system is of central importance since to understand the realities of the circular economy, it is necessary to know what laws and regulations govern these processes. The technical part, on the other hand, focuses on waste treatment, the biological treatment of the organic fraction, the functioning of integrated waste management systems and processes, and product certifications (e.g. eco-labels). The technical part then focuses on the actual recycling processes, to show the reality of recycling in the area today. The technical part is developed together with supply chain consortia and companies operating in the recycling sector, which specify the differences in the recycling processes of different materials and related business opportunities.
The course approach is multidisciplinary. Several experts participate as lecturers in these courses, coming from research and business environments, but also from specialised supply chain consortia. The title of these courses is 'GreenJobs: waste management between law and technology'. It is held in 4 regions of South Italy, in collaboration with the University of Basilicata, Mediterranea University of Reggio Calabria, University of Palermo and the University of Campania.

The course is developed in 24 modules, run over 12 days along four weeks, equivalent to a total of 72 hours of face-to-face teaching. The lectures are held in live webinar mode, with a final in-presence appointment for the delivery of the certificates. During the course, notions, examples of best practices, bibliographical references and useful slides are provided for studying the topics covered. It is envisaged that Reteambiente Formazione, a partner in the project, will provide participants with an online platform with study and in-depth study materials.

The GreenJobs training activity aims to develop in the participants the ability to understand the basic rules that describe the world of separate collection and recycling and, therefore, the consortium structure through the presentation of the regulations that define what the obligations, duties and rights of individuals concerning the systems in which they live are. In addition, in the technical aspects of the course, the aim is to familiarise participants with the functioning of the consortium system, the role of the various stakeholders involved in the process and the procedures required to achieve higher levels of separate collection and recycling. Therefore, the skills to be worked on are related to aspects of knowledge, system vision, critical thinking, and the legislative and political world's role.

This activity aims to develop core competencies for sustainability in line with the GreenComp framework. Specifically, the course works on sustaining equity, systems thinking, critical thinking, problem framing, future literacy, exploratory thinking, and the ability to act at the policy level. Thus, the course is intended as a practical tool to train new skilled professionals who can actively contribute to the country's ecological transition, with a focus on the territorial rebalancing between North and South.

Consortium training

This training activity is aimed primarily at members of the CONAI consortium system, i.e., businesses, companies and trade associations that are members of the National Packaging Consortium. The objective is to provide concrete and up-to-date tools for understanding and correctly applying regulatory obligations related to packaging management and environmental contribution, as well as to enhance the opportunities offered by membership in the consortium.
Training is conducted through in-person seminars, thematic webinars and the production operational guidelines. Training events vary in duration - from one to four hours - and involve technical and administrative staff from consortium companies, as well as managers and association representatives, depending on the relevance of the subject matter.
Topics covered include the application of the CONAI Environmental Contribution (CAC), regulatory updates such as mandatory environmental labelling (effective in 2023), and implementation of the European SUP Directive on single-use plastics.
As far as the environmental contribution is concerned, CONAI is committed to specific training on how to collect the contribution. CONAI's environmental contribution (CAC) is an economic contribution that producers (those who produce the packaging) add at the time of first transfer to users of this packaging. This contribution is then collected and transferred to CONAI, which in turn transfers it to the sector consortia that use it for their recycling processes. Furthermore, part of this contribution is given to the municipalities as provided for in the ANCI-CONAI agreement to support municipalities in the separate collection process. The guidelines on the operation of the application of the contribution change very often, which obliges the consortium to carry out training seminars and webinars where these changes are presented.
In the case of the directive on compulsory labelling, various measures were produced: webinars with association representatives to inform and train, and to address critical issues raised by stakeholders thanks to previously collected questions; sector webinars open to companies and promoted with the associations and focused on the presentation of contents and moments of exchange and comparison; production of FAQs on the site and guidelines for sectoral application; publication of results on the community; participation in events promoted by associations and confederations of industry as experts.
In the case of the UAS Directive on single-use plastics, guidelines were produced to facilitate the interpretation of the standard, providing multiple practical examples of the types of packaging involved,

as well as a FAQ section structured through interaction and questions from companies and stakeholders. These guidelines were produced through the instrument of public consultation. The guidelines are divided into a presentation of the chronology, the regulatory aspects and subject measures of the directive, sanctions, and a description of the packaging articles covered.

The support provided by CONAI aims to clarify the procedures to be followed, the penalties, the actors, and the packaging items affected by the new regulations. The approach integrated regulatory and value aspects, promoting participants' technical knowledge and awareness of the role played by the consortium system in the ecological transition. The skills developed through this activity can be traced to several areas of the European GreenComp framework, specifically valuing sustainability, equity, systems thinking, problem framing, political agency, and collective action.
The strength of this activity is its ubiquity: by spreading the events throughout the country and publishing the materials online, it is possible to reach a very wide audience, facilitating the sharing of best practices, discussion among professionals and the continuous updating of companies with respect to a constantly changing regulatory environment.

CONAI community

The CONAI Community is a digital platform created to offer support, updates and opportunities for discussion to all players in the packaging supply chain interested in issues of separate collection, environmental contribution and circular economy. Officially active since 2022, the platform represents a professional networking environment where companies, trade associations, consultants and even citizens can interact, share experiences and find useful information related to the CONAI world.
Organized in a form similar to a social network, the Community allows users to create a personal profile, comment, publish posts and actively participate in the life of the network. It is therefore a dynamic space that aims to foster dialogue and the collective construction of knowledge and best practices. The content, in fact, is published following a Digital Editorial Plan updated every two weeks, with the support of a graphic team that also takes care of the visual part of the posts and videos.
Topics include: environmental packaging labeling, regulatory news, environmental contribution, circular economy projects, eco-design tools, ANCI-CONAI agreement, international events, green jobs, and more. For some documents in particular, such as the vademecum for the digital environmental labelling of packaging or the guidance on the UAS directive, public consultation of the document was used via the community. Users (companies, consultants, consortia and member companies) in this way can access the document, read it, comment on it and leave suggestions for changes or suggestions for doing so. The topics to be posted on the community are decided through a PED (Digital Editorial Plan), in which the topics to be covered are entered bi-weekly. A graphics support company then handles the construction of the posts/videos to be uploaded to the platform.
The Community fits within the CONAI Academy training ecosystem, serving as an interactive and collaborative space that complements more traditional training activities. Its added value lies in its ability to unite members of the CONAI network in a participatory environment, fostering the emergence of transversal skills related to system vision, collaborative approach and the ability to act responsibly within a circular economy model.
From a skills perspective, the platform supports the development of systems thinking, problem framing, exploratory thinking, collective action and individual initiative, in line with GreenComp's "Embracing Complexity" (A2), "Imagining Sustainable Futures" (A3) and "Acting for Sustainability" (A4) areas.

Municipal technician training

CONAI, in collaboration with the National Association of Italian Municipalities (ANCI), has launched a targeted training program for municipal technicians as part of the four-year agreement governing the

management of packaging waste. This agreement allows municipalities to collaborate with supply chain consortia for waste take-back and recycling, thus providing structured support to ensure efficient management of recyclable materials.
The training plan developed by CONAI spans two years and consists of various educational activities designed to involve not only municipal technicians, but also other stakeholders in the sector, such as collection companies and citizens. Each year, training seminars are organized in all Italian regions, one for each capital city, whose main objective is to provide detailed information on the ANCI-CONAI agreement and its practical applications. During these seminars, which are held both in-person and online, central topics such as how the agreements work, the management of separate collection, and the opportunities offered to municipalities are covered. In addition, specific topics such as waste legislation, the Single Use Plastics (SUP) directive and procurement management are explored in depth each year. An important event is the annual Circular Economy event, which provides an opportunity for updates on current issues related to sustainability. Each year, in fact, the event addresses a central theme, such as the Deposit Return System (DRS), which deals with the deposit return bottles and containers, or other innovations related to the circular economy. This event also provides an opportunity to hear from local experts and administrators on how different municipalities are addressing and implementing innovative solutions in waste management. Alongside these, thematic webinars are also organized on individual packaging materials, such as plastic, metal, glass, and paper, to learn more about techniques and regulations related to their recycling. These webinars, run in collaboration with experts in the field, also provide spaces for participants to exchange views, answering frequently asked questions and promoting a greater understanding of the challenges and adoptable solutions waste management.
For areas in Southern Italy that are experiencing difficulties in managing separate waste collection, CONAI has provided special seminars designed support municipalities in these areas by helping them develop more efficient collection systems. In addition, as part of the National Recovery and Resilience Plan (NRP), local communities are offering support to help South municipalities intercept funds and plan waste management improvement projects.
The main objective of all these activities is to inform and educate municipal technicians, particularly those responsible for waste collection services, on how separate collection and recycling processes work, what regulations are in place, and how to optimise services to make the entire system more efficient. The information offered during the seminars and webinars helps participants understand not only the regulatory aspects, but also the practical challenges faced in the waste collection and recycling process. The training materials, such as slides, are available online and can be accessed even after the events, allowing participants to have a continuous point of reference. In this training context, a variety of skills are developed, ranging from systems thinking, which helps to understand how each action in waste management impacts the overall system, to collective action, which emphasises the importance of collaboration among various actors, including citizens, local governments, and businesses. It also aims to raise awareness of the need to promote equity and sustainability in waste management policies by encouraging responsible and participatory engagement by all stakeholders.
In conclusion, CONAI's training program for municipal technicians provides an important opportunity to update and raise awareness for those responsible for waste collection services, promoting more efficient waste management and contributing to the achievement of Italy's circular economy goals. Through this type of training, municipalities are able to implement more effective and sustainable solutions, environmental impact and improving the quality of waste collection.

Journalist training

In recent years, CONAI has developed training activities dedicated to members of the Journalists' Association, designed to contribute to achievement of continuing professional education credits required by law. These seminars, held in different regions of Italy, provide an opportunity for journalists to learn more about issues related to packaging waste management and recycling, and to acquire skills necessary to properly communicate these issues to the public. Each seminar lasts four hours and

involves several speakers, both internal and external to CONAI, who provide a detailed overview of how the separate collection system works in Italy.
The meetings are also enriched by the participation of experts from the institutional and academic worlds, who share their knowledge on the role that CONAI and the various supply chain consortia play in the waste collection and recycling process. The seminars are organized in different Italian cities, and previous events were held in Palermo and Milan, with intention of reaching all journalists registered with the regional orders. The main objective of these seminars is to provide a clear and comprehensive view of the waste management system in Italy, the results obtained, and European policies in the area of recycling.
An example of such meetings the one held in Florence April 2023, where the seminar, entitled "Recycling and Circular Economy. The Italian model that sets the standard in Europe: how it works and how it is communicated," covered the Italian waste management model, analyzing the data and results obtained by CONAI and the recycling supply chains. During the event, participants had the opportunity to engage in discussions with consortium executives and external experts, gaining useful information both recycling processes and for the proper dissemination of that information in the media.
These training activities are designed to provide theoretical information and to train journalists on how to effectively communicate how the separate collection and recycling system works, avoiding inaccuracies and misinformation. In this way, the seminar helps to ensure proper dissemination of knowledge related to environmental sustainability and waste management, which are essential elements in raising public awareness of circular economy issues.
From a skills perspective, these workshops enable journalists to develop a solid understanding of recycling processes and current regulations, activating skills in sustainability, systems thinking and collective action. In addition, the training gives them the tools they need to deal with complex environmental issues with a critical and informed approach, contributing to better information on how the management system works of waste. In particular, the seminar stimulates skills such as critical thinking, systems thinking, and the ability to communicate complex information clearly and effectively.
Ultimately, these seminars represent an important opportunity for professional updating for journalists, providing them not only with a detailed overview of Italian and European environmental policies, but also with the tools needed to communicate responsibly and effectively on issues related to recycling and sustainability. With this initiative, CONAI aims to strengthen the dissemination of correct and quality information on collection issues, fostering greater awareness among the public and compliance with environmental regulations.

3.5 General Report and Description of Prototype Activities

As can be seen from the image below (Figure 3.6), in general, the eight training activities manage to intercept and activate all the competences described in GreenComp. Some competences are present in almost all activities, such as Systems thinking, Problem framing and Political agency. Slightly less present are Supporting fairness, Exploratory thinking and Individual initiative. Collective action and Critical thinking are present in half or slightly more of the activities. Valuing sustainability, Promoting nature, Futures literacy and Adaptability, on the other hand, are scarcely present, i.e. they are activated in about a third or a quarter of the activities.
This overview can also be observed in the figure below, which shows the GreenComp competence activation indicators of each activity. From this overview, it can be observed that the orange zone

(Embodying sustainability values) and the green zone (Envisioning sustainable Future) are the least activated.

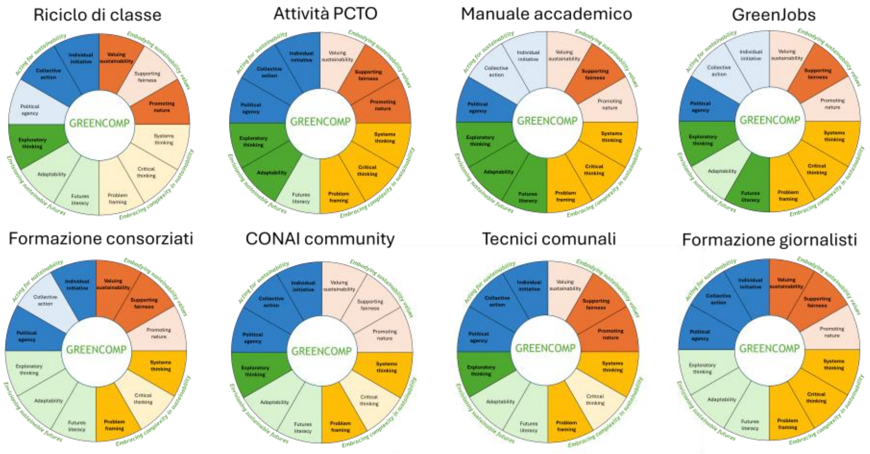


Figure 3.6 TASC indicators for every training activity realised by CONAI

In this regard, I designed two prototype activities to focus on the least activated skills among the various CONAI training activities. These activities are the *CONAI Future Lab* and the *CONAI Natura initiative*. Both activities are presented below.

CONAI FUTURELAB

Keywords: future; alternative scenarios; preferred sustainable future; manage transitions; decision making; dealing with uncertainty, ambiguity and risk

The CONAI Future Lab is a course/workshop dedicated to secondary school students that combines sustainability, climate science education, and future visioning topics. The course/workshop is designed to include meetings in which students are introduced to the knowledge needed to understand the basic functioning of separate waste collection processes, the influence these processes can have regarding environmental impact, and the consequences these choices could have in possible future scenarios. Students will be asked to participate actively during the meetings through group work, readings, feedback, and moments of shared reflection.
The course/workshop can be offered as part of the civic education and citizenship hours made compulsory by current legislation or as an extracurricular training opportunity.

The course/workshop has a profoundly interdisciplinary nature. The organisational structure of the course is based on the collaboration between technical experts in the sector and CONAI communication experts, researchers in science education and climate change education, and practitioners of future languages and scenario building. The course can be divided into three main phases: understand, reflect, and imagine. The understanding part is necessary to know what the current realities are, the potential and limits, the functioning of the basic processes, and the constraints that need to be respected.
The reflection part allows students to analyse these processes and their impact, look at the problem from a different perspective based on a scientific vision, and activate the reflection mechanisms necessary to think critically about it. The imagination part is designed to help students go beyond the current problems and overcome the anxieties and fears linked to concepts such as risk and uncertainty by constructing future scenarios where sustainability takes on a central and leading role.

The course/workshop will touch on topics such as environmental risk and uncertainty, the nature of recycling processes and how they work together, the importance of sorting to compensate for the lack

of raw materials, the need to make a sustainable ecological transition in many aspects of our daily lives, and techniques for constructing and narrating future scenarios.
The course/workshop includes specially prepared slides, extracts from scientific papers, textbook references, suggested readings to expand on the topic, and videos and/or films to watch and discuss in groups.

The course/workshop primarily aims to develop skills in future visioning, futures literacy, adaptability and exploratory thinking. The collaboration between technical experts, researchers and future scenario building practitioners might enable students to look at the future as a space of imagination and possible scenarios, capable of guiding choices in the present. This type of future-oriented thinking aims to help students deal with the concepts of risk and uncertainty by providing useful tools for analysing the complexity of a situation and finding criteria for making decisions and choices. Critical thinking assumes a central position in order to be able to think critically about current aspects of reality and to imagine future realities (Figure 3.7).

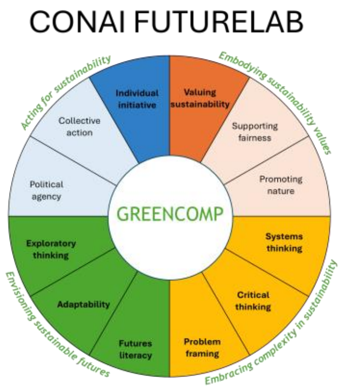


Figure 3.7 Graphic representation of GreenComp competence areas activated in the CONAI FUTURELAB activity.

CONAI NATURA

Keywords: values; choices; consequences; nature; regeneration of healthy ecosystems.

The CONAI NATURA initiative would consist of organising meetings for citizens to present the effects of separate waste collection and recycling on their surrounding nature, which they encounter daily.
The meetings could be organised as part of the communication plan under the ANCI-CONAI agreement, i.e. the agreement drawn up between CONAI and the National Association of Italian Municipalities.
The designed meetings might last about three hours and would see the attendance of CONAI representatives, local municipal technicians and representatives of local associations working in the field of sustainability.
The primary goal is to explain the importance of waste separation, the specific methods of collection, its effect on the environment, and the repercussions of our current decisions for the future.
This initiative's target group is very diverse, as it aims to reach the widest number of inhabitants of the area concerned. The meetings should be organised to be understandable for an age group that starts at 12 and has no upper limit.

The activity would see the collaboration between CONAI representatives, municipal technicians and representatives of local associations, helping in this way in the development of discussions on topics such as respect for nature, the influence of a good collection on the health of the surrounding

environment, the economic possibilities and use of the separate collection and recycling system, and the cost of such interventions.
In addition, a part of each meeting can be reserved for the exchange of ideas between residents and the local administration, to allow for the improvement of critical situations or suggestions on the optimisation of services already in place.

Meetings can be recorded and made available on the municipalities' websites. In addition, guides can be prepared on how separate collection works at the local level and how to optimise the way materials are delivered, with a focus on the local impacts of these processes.

This activity aims to develop skills related to the values of sustainability and respect for nature as a system. In particular, the aim is to foster a sense of awareness regarding our everyday actions and their consequences over the short, medium, and long term. Understanding the weight of our daily actions can help in the development of an internal feeling of sustainability, a necessary feeling that can be applied to all daily actions.

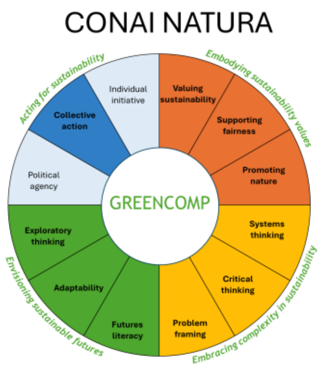


Figure 3.8 Graphic representation of GreenComp competence areas activated in the CONAI NATURA activity.

3.6 Conclusions

The aim of this chapter and of the work described was to show how the GreenComp sustainability competence framework can be used as an analysis tool to make a qualitative assessment of training activities. In particular, the chapter shows how the tool, consisting of the guiding questions obtained from the definitions of the various competences, can succeed in reporting an overall view of the potential to develop sustainability competences of that particular activity. The main objective of this analysis was, therefore, not only to carry out an assessment of CONAI's activities to see in what way they were able to activate the various competences but also to develop a useful tool for the design and construction of training and educational paths that would activate all of GreenComp's competence areas at the same time.

What emerges from the analysis is that the educational and training activities conducted by CONAI are very nice examples of possible ways of raising awareness by training and educating all those involved in the waste management and packaging recycling process. Through lectures, courses, events, seminars, and webinars aimed at students, graduates, professionals, municipal technicians, journalists, and other professional categories, CONAI is committed to disseminating a thorough understanding of the consortium system and current regulations, with the goal of improving the efficiency and the effectiveness of separate waste collection and recycling in Italy. These initiatives not only provide essential information for operational waste management but also help promote greater collective awareness of sustainability, the circular economy and the key role each actor plays in achieving environmental goals. CONAI's integrated approach, involving both local governments and information, is an example of how continuing education can foster more informed, effective and responsible management of the waste cycle while helping to build a more sustainable future.

The relationship between training and education in the activities conducted by CONAI is configured as complementary and synergistic, with a clear distinction between the two concepts, but with an integration that enhances the final results. In this context, training is strongly oriented toward providing practical and specific skills. Training activities, such as seminars and webinars, are intended for professionals, technicians and journalists, and aim to convey operational knowledge, updated regulations and best practices related to waste management and the circular economy. The main objective is to make participants more competent and prepared to face the daily challenges of their work by improving the effectiveness of separate collection and recycling systems. For example, seminars for municipal technicians offer targeted instruction on how ANCI-CONAI conventions work, how to manage procurement, and how to implement specific technical solutions, while seminars equip journalists with the knowledge they need to communicate sustainability and recycling issues correctly and accurately.

On the other hand, the educational aspects refer to a broader and longer-term process that aims to promote widespread awareness and a sustainable culture. The educational aspect of CONAI's activities goes beyond the transmission of specific knowledge and seeks to raise participants' awareness of the importance of responsible behaviour toward the environment. CONAI's community platform, as well as the GreenJobs course, for example, is not only a place for professional exchange but also an environment that stimulates collective reflection on sustainable futures, helping all stakeholders understand how their actions can influence the entire waste management system. In this sense, education is seen as the process of building a shared mindset about sustainability that goes beyond technical updates and is rooted in everyday choices.

Thus, while training focuses on providing concrete tools and technical information, education has a broader scope, seeking to form a collective mindset and consciousness focused on respect for the environment and the importance of the transition to a circular economy model. The two types of activities complement each other, creating a continuous cycle: training enables the correct application of acquired knowledge, while education stimulates the desire to continue learning and improving, making the overall system more dynamic and responsive to future challenges.

Chapter 4. Case study 3: Teaching about climate change using complexity and uncertainty: design and implementation of an interdisciplinary STEM approach

In this chapter, I present the design and implementation of an activity in which students are asked to reflect on and reason about climate change using the three types of uncertainty – reflexive , epistemic, and aleatoric.
The activity was implemented in the context of the European project IDENTITIES during the second summer school held in Barcelona in the summer of 2022.
14 pre-service teachers with backgrounds spanning physics, mathematics, computer science, biotechnology and natural sciences participated in the activity.
Data have been collected by recording the lesson and the group activities. Together with the colleagues of the University of Crete we conducted a thematic analysis of the transcriptions, in order to explore the potential of discussing climate change through the different types of uncertainty.
The activity showed how students activated different ways of reasoning depending on what type of uncertainty they reflected upon. Also, it is worth noticing how the activity, thanks to the setting and the design of the environment, led students to investigate the epistemological aspects of the different disciplines and overall to open a space of confrontation on the nature of science.
This activity can be considered a prototype for the course design presented in the next chapters. The design principles highlighted in the previous chapter have been implemented and tested.

4.1 Summer school and climate change module

The summer school is the result of the cooperation of the different project partners. 28 students from the five universities took part in the proposed activities. The summer school included collective moments, generally linked to the introduction of the activities, the presentation of the theoretical frameworks and the overall sharing, and moments in which the students were divided into two macro-groups to follow the modules, both on curricular and extra-curricular topics. In total, four modules were offered, two on curricular topics such as parabolic motion and linguistics and epistemology, and two on extracurricular topics such as climate change and COVID-19.

The activity presented in this chapter is part of the module on climate change, prepared in collaboration between colleagues from the University of Crete and the University of Bologna. The climate change module is part of the STEM advanced interdisciplinary topics, that have been designed to implement the principles of the IDENTITIES project (Miani et al., submitted):

- DP1) Value "authentic" forms of interdisciplinarity, basing the module on important intrinsically interdisciplinary boundary concepts (like the concepts of complexity and uncertainty for the module on climate change)
- DP2) Introduce and articulate the metaphor of the boundary as it is conceptualised by Akkerman and Bakker (2011) to share a common language for interdisciplinarity.
- DP3) Make "Disciplines matter", to value background sources of resources to deal with interdisciplinary issues to ground new explorations on a solid basis and protect from the insecurity given by the uncertainty and ambiguity of a new experience.
- DP4) Activate an epistemological reflection that problematises the classical image of science and regenerates science's capacity to deal with advanced STEM topics.

The module was shaped according to an adaptation of the "Study and Research Path to Teacher Education" (SRP-TE model) developed by Barquero and colleagues (2018). The model is framed within the Anthropological Theory of Didactics (ATD) developed by Chevallard and colleagues (Bosch & Gascon, 2006; Chevallard, 1985).

The SRP-TE model structures activities to guide participants through different roles: explorers, students, and analysts. As explorers, participants investigate a topic, sharing and expanding their knowledge under the guidance of educators. In the student role, participants engage in interdisciplinary activities, learn new content, and actively participate in their learning process. As analysts, they apply the acquired knowledge to evaluate experiences, reflecting on various dimensions like epistemology and education. The model originally included a designer role, where participants would design classroom projects, though this was often omitted due to practical challenges with differing school contexts.

The first part of the module, prepared by Eleonora Barelli, aimed to introduce the macro-theme of climate change, opening up to the concepts of complexity and uncertainty as ways of staying within the problem, understanding its internal dynamics, and understanding its scale.
The second part of the module, run by Giulia Tasquier, focused on the idea that climate is a complex system, and as such, it is not possible to study it without taking into account the characteristics of complex systems, such as circularity, emergent phenomena, uncertainty and feedback mechanisms. In the module, students conducted a multi-stage activity on the topic of biodiesels, exploring possible feedback mechanisms and their consequences.
The third part of the module was run by a team of researchers from the University of Crete consisting of Chara Bitsaki, Ioannis Metaxas and Prof. Dimitris Stavrou. In this part of the module, students had the opportunity to work hands-on with specific experiments related to complex phenomena, such as weather forecasting, magnetic pendulum analysis, and Benard cells. In the fourth part, organised jointly by the two groups and run by me, students explored the issues of complexity and uncertainty in the context of climate change from an epistemological perspective, focusing on the role these concepts can play in the study of climate change when approached from an interdisciplinary perspective. In this part, PSTs participated actively in the lesson. Most of the activity was developed to allow the different groups to discuss, analyse and reason in detail about questions on the epistemological aspect, the impact on curricular topics of complexity, and the role that uncertainty can have in climate change discussions from a disciplinary and interdisciplinary perspective. PSTs were asked to fill the analyst role, focusing on the epistemological aspects. Complexity and uncertainty can be seen here as epistemological activators that bring together the different disciplinary views in the groups.

In this chapter, I focus on the second activity of the latter part, as it was generated directly from the analysis presented in the previous chapter.

The specific research questions that led to the construction of the activity were:
SRQ1. How do students deal with different types of uncertainties in the context of climate change?
SRQ2. What are the possible outcomes of working on the different uncertainties of climate change in an interdisciplinary environment on an epistemological level?

4.2 Design of the activity

The activity focused on exploring three types of uncertainty in climate studies—reflexive, epistemological, and aleatoric—drawing from Shepherd (2019), Dessai & Hulme (2004), and Kahneman & Tversky (1982). Pre-service teachers (PSTs) analysed these uncertainties in their disciplines and their relation to complex systems and climate studies. Each group tackled three key questions connected to a specific type of uncertainty, one for each group:

- Which examples of this type of uncertainty can you identify in your discipline of expertise?
- How can this type of uncertainty be related to the complexity and/or properties of complex systems?
- How can this type of uncertainty be related to the study of climate?

Each group had around 40 minutes to answer this set of questions. Each group produced a poster using sticky notes and markers to represent their answers. Each group's discussions have been recorded separately, and the analysis focuses mostly on these discussions.

After this individual work, the PSTs engaged in a meta-reflection exercise, prompted by the instructor, to consider the broader implications of these uncertainties.
In this exercise, PSTs were asked to take the sticky notes used to create the posters and collocate them on a whiteboard with the image of three intersecting circles, one for each type of uncertainty (Figure 4.1). This exercise aimed to get students from different groups to talk to each other and allow them to extend the discussion previously held on a specific type of uncertainty to all the others. Students spent around 15 minutes working on this last part of the activity.

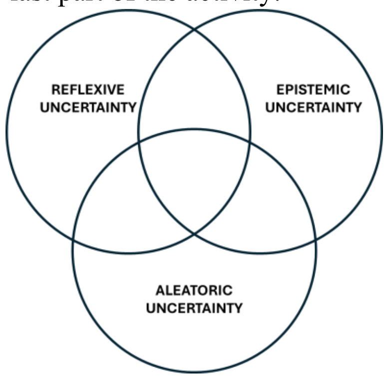


Figure 4.1 Scheme of the final activity.

Once the groups answered all the questions, they presented their work to the other groups. The conversation has been guided by me, together with Prof. Stavrou and Chara Bitsaki.

The design principles emphasised an epistemological and ontological approach (DP4), encouraging PSTs to understand the role of uncertainty and complexity in teaching climate change. The activity promoted exploratory dialogue between disciplines (DP2) and encouraged perspective-making and perspective-taking (DP1). It aimed to foster critical reasoning and systematic thinking, guiding PSTs to view uncertainty not as a limitation, but as an essential aspect of the scientific process (DP4). Ultimately, the activity helped PSTs appreciate interdisciplinary perspectives (DP3) and engage proactively with different viewpoints, broadening their understanding of the scientific process and its role in addressing climate change.

4.3 Data analysis

The aim of the analysis was to explore the different ways in which students would reason and discuss when working with uncertainties in climate change. Moreover, we designed the context and environment to give students the possibility of overcoming the boundaries of their own discipline and, therefore, applying the different mechanisms of boundary crossing.

Data has been collected by recording the students' discussions during the group activities and overall discussions. We recorded each group through their discussions and then collected the artefacts created during the activity (i.e. the sticky notes and the posters).

The data collected do not express personal information or private data on students' identities. They have been anonymised so as not to reveal the students' identities, but we kept the information on the discipline in which the students were doing their master's studies. This information is important to explore the specific research question 2 (SRQ2) and investigate what type of epistemologies were brought to the surface when dealing with the different types of uncertainty in the interdisciplinary context of climate change.

The analysis conducted is a qualitative thematic analysis (Braun & Clarke, 2006, 2012), as it has been selected as the most suitable type of analysis to answer the research questions with these types of data, i.e., mainly textual. It follows partly the steps described by Castleberry and Nolen (2018): compiling, disassembling, reassembling, interpreting, and concluding.
I first transcribed the recordings of the whole activity, using the software NVivo. The transcription consisted of 404 rows in Excel. The most relevant part of the data is the one in which students discussed in their groups (around 40 minutes), while three other parts are dedicated to the overall discussion (around 1 hour).
The disassembling (coding) and reassembling (themes) processes have been conducted to explore what approaches students used to answer the questions and what reasoning they adopted during the activity (SRQ1). In this case, I used a deductive procedure to explore what words and reasonings were used for each type of uncertainty.
These results are reported in the next paragraph by presenting the excerpts and their interpretation.

Together with the thematic analysis of the transcriptions I took into account the answers produced by each student and the different ways in which each group proceeded with the creation of their artefacts.

4.4 Results

What emerges from the analysis is that the activity revealed some interesting aspects related to the ability of each type of uncertainty to activate different forms of reasoning and to stimulate different ways of approaching the problem discussed and the activity itself. Also, data revealed how students from different disciplines reacted differently to the different types of uncertainties.
I present here the results of the thematic analysis of the conversations and approaches that each group adopted in their discussions, with details on the boundary mechanisms used by students.

4.4.1 Uncertainty on human behaviour (or reflexive uncertainty)

The first group discussed the role that the "uncertainty on human behaviour", also called "reflexive uncertainty", can have in their disciplines when dealing with complexity and climate change. Regarding the connection of reflexive uncertainty with their discipline, the students expressed great difficulty in making this connection. In particular, they emphasised several times how they could not see how the role of human beings could affect the scientific process. In this regard, it is interesting to report two excerpts in which this difficulty was explicitly described by a pre-service teacher studying computer science.

> "But the human behaviour is the thing. The human behaviour influences the knowledge, and not the other way around. Like humans reflecting on themselves. That's why I think it's very hard." (CS#1)

> "I really find it hard to see this kind of uncertainty in our fields. Because especially being a scientific figure, you want to eliminate human behaviour as much as possible, that's the

> scientific method. That's why you have experiments that are repeated many, many, many, many times so that you are sure of reality without human influence. That's why I really don't know how you can see this in our fields". (CS#1)

These transcriptions show how the student, with a computer science background, struggles to make a connection between the role of human behaviour in the scientific process. In their discussion, students differentiate between what is science and what is not, and most importantly, they do not see knowledge as a human product but rather as an abstract property detached from the rest.

Students focused more on the first question and less on the second two. When discussing the relation between reflexive uncertainty and complexity, students of this group reasoned on the difficulty of accepting complexity when dealing with problems.

> "The unwillingness of the human brain to accept sometimes complexity can lead to the oversimplification of problems, and you can see the interaction that leads to problems". (CS#1)

In the final activity, students also share how, for example, a war can be conceived as an event in which profound reflexive uncertainty occurs.

> "So I think this was connected to policies, science can be exact and everything but what you do depends on how humans react to that science, what to do with data is not easy to do, depends on human behaviour, on what humans decide, and it was kinda the definition we were given in some sense. Scientist says: CO2 will go up, are we letting it go up or will we do something to let it go up and adapt? That was the thing, it was everything based on the definition." (P#1)

Judging from the answers and the recordings of the activity, it seems that in the first part of the activity, students thought of the role of human behaviour only as related to the decision-making aspects that are made within science, and not from other spheres. In the second part, after sharing their sticky notes with the other groups on the whiteboard, they enlarged their perspective by introducing the level of personal behaviour in the discussion. This type of discussion can be ascribed to the Reflection mechanism to work at the boundary, as students opened and changed their perceptions through their discussions and confrontations.

We might infer how students refer to a deficit model, that is, a lack of knowledge or ability to know (Simis et al., 2016) when considering the role that humankind can play in dealing with issues that are marked by basic uncertainty. This type of inference, although it needs more data to be validated, is reflected in students' responses, who choose to touch on topics marked by underlying uncertainty such as "probability," "quantum revolution," and "unwillingness to accept complexity." On the other hand, it is noticeable that the responses given by students do not mention topics such as "values", "ethical aspects" or "choices", but mostly personal behaviours connected to the reaction of humans to science. Not how science can be influenced by humans, but how humans can be influenced by science.

In Figure 4.2 I reported all the answers given by the students.

Group 1 – Uncertainty in human behaviour		
Question 1: Which examples of this type of uncertainty can you identify in your disciplines of expertise?		
9) Quantum revolution forced us to choose between our old way of thinking and a completely new (and scary) one!	11) Has mathematics been invented or discovered? The way you think it affects how you approach your field of studies	12) ML DATA: The data used to train the algorithm are influenced by human behaviour and the algorithms could be use to enhance the behaviour found in the data or mitigate it
	32) Probability is the part of mathematics that concern the uncertainty the most and we can use it in other disciplines	14) Moore's law: human decided that machines will get faster with time and when the physical limit was reached, they come up with a way to keep it going anyway
Question 2: How can this kind of uncertainty be related to complexity and/or properties of complex systems?		
2) Human behaviour is a complex system 3) Sometimes you can't go back from a decision, as in Deterministic Chaos	1) Unwillingness of humans to accept complexity	33) Ukranian war
Question 3: How this kind of uncertainty can be related to the study of climate?		
4) Decisions about policies: how to act once you know the science		

Figure 4.2 Answers to the three questions made by the group that worked on reflexive uncertainty

4.4.2 Epistemic uncertainty

The second group worked on epistemic uncertainty, that is the uncertainty connected to our capability of understanding the world around us and creating models to represent and study it.
The questions related to this type of uncertainty seem to have activated the disciplinary knowledge of the group members. In answering the questions, the students referred to a broad pool of knowledge related to their study paths, with a reference to those problems that remain open but can in principle be solved through deeper knowledge.

Students engaged in a discussion connected to the differences between each discipline and the limitations that they can have in different contexts. I report here two excerpts connected to different disciplines discussed in the group.

In the first excerpt, students with backgrounds in physics, mathematics and computer science discuss on the role that epistemic uncertainty has in mathematics:

> P#2: […]I don't know if in mathematics you have any epistemic uncertainty. Because mathematics does not depend on how you understand it, it's there
> M#2: Well, I mean, there were things in math that they did it. We use for example probability, a lot, in different fields, but I'm not sure…
> P#2: But I'm not sure if it is really an uncertainty
> CS#3: In math there is some proof that is not known whether is true, but you don't know if it's not known for -
> M#2: In math everything is proven, you don't have any definition or theorem that is not proven. if they are not proven they are not used.
> M#3: Yes it's a very different approach.

In the second excerpt, students talk about the role played by epistemic uncertainty in computer science.

> P#2: Well I think that the uncertainty is given by the precision of our calculators.
> CS#3: Yes but we know. It's an uncertainty in the sense that we can do operations but they are cut down at a certain decimal point. So if you go on with calculations you have more and more errors. It's epistemological in the sense that we could improve the number of decimal points

This uncertainty seems to activate cognitive resources from disciplinary knowledge, also in questions 2 and 3, when reasoning in disciplinary terms was not directly required. Depending on their discipline of study, each student reflected differently. For some, epistemic uncertainty is deeply connected to their way of working (e.g., physics or computer science), while for others, it is not (mathematics).

The main question which students seem to have answered is: "Which are the knowledgeable limits or model limits that have been considered and faced by your discipline?". Therefore, students activated their deep knowledge by referring to the open questions that stimulated progress in the years inside the disciplines. This type of discussion is more similar to the Identification mechanisms, as students defined the differences between their disciplines and did not produce new insights on their possible connections and similarities.

This can also be observed in part by the organization of the poster, which is divided by questions (rows) and disciplines (columns) (see Figure 4.3). Each student decided to bring their particular point of view on the issue, and for this reason it is possible to recognise a certain compartmentalisation of the knowledge.

Group 2 – Epistemic uncertainty			
Question 1: Which examples of this type of uncertainty can you identify in your disciplines of expertise?			
29) Physics: - Deterministic chaos (ex Brownian motion) - Every measurement	31) Biotechnology: In nature science no knowledge is taken as perfectly defined; so, when an event/experiment arises discrepant event sciene will try to explain and therefore scientific knowledge will evolve.	16) Computer science: machine learning explainability	28) Maths: Fermat's Last Theorem -> Godel's incompleteness theorems
Question 2: How can this kind of uncertainty be related to complexity and/or properties of complex systems?			
30) Physics: Complex systems in physics are well known and studied as they one, knowing that we can't have sure answers as we develop them, so we start to take in account statistics.	10) Biotechnology: Nature is a system interrelated in many ways: as different individuals interact within and between at different levels and also with the environment. This makes nature science intrinsically related to complexity.	17) Computer science: machine learning explainability uncertainty is similar to find a complex system response to an action and what part of the system is involved to get the result	26) -Irrational behaviour - Graph theory - Spatial fractals - Ordinary differential equation
Question 3: How this kind of uncertainty can be related to the study of climate?			
27) Physics: we have to take in account that there are some things that we can't (aren't able to) predict, but we can work on the statistics to have (sometimes) a better grasp.	15) Biotechnology: The effects of the increase of certain gas emissions on radiation absorption can vary in ways is difficult to predict; because the chemicalk paths that a molecule can go through are not unique; and some can lead to harmful molecules, while others not. For instance, the molecules causing the bigger Green House effect are water in suspension, surpisingly.	18) Computer science: machine learning explainability uncertainty is the same uncertainty of climate change. Indeed we don't know what action is relevant to change the clima and what action is useless and what part of the clima is involved	13) Graph theory highlight critical areas for conservation under climate change; fractales can explain natural phenomena, and maybe they can help us predict the future?

Figure 4.3 Poster realised by group 2.

4.4.3 Aleatoric Uncertainty

The group members reasoned about uncertainty reducibility, trying to figure out which topics had inherent uncertainty specific to their disciplines, complex systems, and climate change.
In this group, students worked mainly by themselves and talked less between them with respect to the other groups. Nonetheless, it is possible to recognise some specific patterns in the discussion and in the answers given by them. They started firstly by thinking about phenomena connected to aleatoric uncertainty. Such as tsunamis, fires or earthquakes. Then, they proceeded in a discussion on the capability of predicting future phenomena in complex social issues, like climate change or the covid pandemic.

During the second part of the activity students reflected on the connections between the uncertainties, and also in this case (as for the second group) they enlarged their perspective.

> "At the beginning, I felt aleatoric uncertainty completely unlinked to the uncertainty for human behaviour, because I searched for aleatoric uncertainty on the fundamental [level]. I'm a physicist, so I search very deeply in the causes of things, but at the blackboard I realised that there are multifactorial and human behaviour can activate some very deep problems of matters for example, and we decided it to put at the intersection of human behaviour and aleatoric for example the behaviour of cells in human cancer." (P#4)

The reasoning done suggests a more reflective approach (Reflection mechanism) rather than a content approach, in which each topic is discussed and analysed to understand the origin of the type of uncertainty that characterizes it (Figure 4.4). The third kind of uncertainty seems to have activated questions such as " Which uncertainty is reducible with knowledge and which isn't?"

Group 3 – Aleatoric uncertainty			
Question 1: Which examples of this type of uncertainty can you identify in your disciplines of expertise?			
23) n-bodies problem	21) Quantum mechanics: uncertainty in quantum physics is ontological. Today we can claim that QM phenomena are inherently probabilistic; Mutation in cancer cells; Cosmic Rays; Radioactive decay; Earthquakes; Human behaviour	7) Molecules, cells behaviour (cancer...)	22) Inferencial statistics: the field of statistics that (with the use of some analytical tools) try to draw conclusions about population by examining random samples
Question 2: How can this kind of uncertainty be related to complexity and/or properties of complex systems?			
24) Deterministic Chaos	25) This type of uncertainty can be handled within the complex paradigm: by moving from prediction to scenarios and possibilities, randomness is no longer a limitation in modelling	20) Critical states	
Question 3: How this kind of uncertainty can be related to the study of climate?			
19) Clouds role	6) Study of climate must take in account these uncertainties because climate is strongly influenced by human activties that can sometimes cause chaotic "drifts" and affect climate system	5) Earthquake; Tsunami	8) Fire forest

Figure 4.4 Poster realised by group 3.

4.5 Discussion and further steps

The specific research questions that guided the analysis focused on the ways in which students dealt with different types of uncertainty in the context of climate change (SRQ1), and on the possible outcomes that this work could have when working in an interdisciplinary environment on an epistemological level (SRQ2).

Regarding the first question, the analysis highlights that different types of uncertainty can activate diverse forms of reasoning and stimulate varied approaches to the problems discussed. It also shows that students from different disciplines respond differently to each type of uncertainty, reflecting their backgrounds and ways of thinking.

In exploring reflexive uncertainty, students primarily grappled with the concept of human behaviour's influence on science. They expressed difficulty connecting this uncertainty with their fields, often distinguishing between science as an objective process and human influence as a separate factor. Their discussions suggested a tendency to view knowledge as an abstract entity detached from human involvement. However, their perspective evolved during the activity, shifting from a focus on decision-making within science to considering the role of personal behaviour and societal factors.

When addressing epistemic uncertainty, the students drew upon their disciplinary knowledge, demonstrating how their understanding varies across fields. For instance, physics and computer science students viewed epistemic uncertainty as inherent to their work, while mathematics students struggled to find such uncertainty within their discipline. This activated a deeper engagement with their respective fields, allowing them to reflect on the limitations and challenges within their domains.
Aleatoric uncertainty, on the other hand, prompted students to discuss the inherent unpredictability of phenomena such as natural disasters and complex social issues. Their discussions evolved from focusing on specific events to reflecting on the interplay between human behaviour and aleatoric uncertainty, demonstrating a more integrated and reflective approach. This type of uncertainty stimulated a broader perspective, encouraging students to question which uncertainties are reducible with knowledge and which remain fundamentally unpredictable.

Regarding the second question, the collaboration between different disciplines allowed epistemological biases related to disciplinary views on the nature of science and the ability and modalities of science to work on climate change to emerge. Students adopted different boundary mechanisms depending on the epistemological differences that emerged in the discussion. These discussions are tied to the different ideas and biases that are present between disciplines. Overall, the activity revealed how disciplinary backgrounds shape students' perceptions and responses to different types of uncertainty. It also underscored the importance of fostering interdisciplinary discussions to broaden perspectives and deepen understanding of complex issues like climate change. These insights suggest that integrating uncertainty as a central theme in educational settings could enhance students' ability to navigate and reason about multifaceted problems.
At the same time, the structure of the activity limited the possibility of exploring the commonalities and differences between the three uncertainties in the first part. Only in the final part of the activity, when they shared their sticky notes on the whiteboard, were they able to expand their perspective and elaborate a more complex connection between disciplines and their uncertainties.

Part 2 – Design and implementation of the approach, data analysis and results

The second part of the thesis builds on the results of the three case studies presented in the first part and is structured as follows.

In Chapter 5, I discuss the results of the case studies. Based on this discussion, I present an approach to Climate Change Education that focuses on the role of three main concepts: uncertainty, futures, and sustainability. The approach has been used to design a course named “Verso Nuovi Scenari Futuri: il ruolo della fisica nelle sfide dei cambiamenti climatici” (Towards New Futures Scenarios: The role of Physics in the challenges of climate change). In the second part of this chapter, I present its design and implementation.

In Chapter 6, I describe the data collection, explaining why I decided to collect certain types of data, the acquisition methods and the type of analysis carried out. The data analysis exposed two emerging themes, tied to decision-making and the concept of harmful hope.

Chapter 7 is dedicated to a third analysis of the data collected during the course. In this chapter, I focus on the relationship between climate change, extreme events, and disasters. This chapter is the fruit of the research conducted at the University of Southampton from January to April 2024 under the supervision of Prof. Wonyong Park, in which I explored the emerging field of disaster education, Prof. Park's research topic.

Chapter 8 is dedicated to the conclusions and the final comments on the thesis work.

Chapter 5. Approaching Climate Change Education through Uncertainty, Sustainability and Futures Studies

In this chapter, I present an approach to climate change education from a science education perspective, built on the case studies and research conducted in the PhD.
The approach proposes an ensemble of theoretical frameworks, different fields of expertise, and methodologies to address the main open questions in climate change education. The elements that compose the approach are diverse, as shown in the case studies presented in the first part of this thesis. They come from different fields, such as physics education, science education, climatology, futures studies, sustainability education, and sociology.

In particular, the approach revolves around three main aspects:

- Uncertainties
- Sustainability
- Future studies

The reasoning about uncertainties emerges from the case study presented in chapter two. The need to interface with the complexity of climate change led to a discussion of a fundamental aspect of science that affects individuals and society (Kampourakis & McCain, 2019): our relation to knowledge and the knowledge-building process.
The sustainability argument emerges from the need for climate change education to reason in terms of sustainability and promote a change in students' reasoning and behaviours. To address this need, I used the sustainability competence framework realised by the European Union, GreenComp (Bianchi et al., 2022), to frame the problem of climate change from a sustainability education perspective.
The reasoning behind futures studies stems from the need to orient the approach of climate change education towards imagining possible scenarios that can guide present-day decisions, through methods of foresight and anticipation.

5.1 Needs of Climate Change Education

Climate change education presents unique challenges and opportunities, intersecting with complex scientific, social, and political dimensions. The literature on Climate Change Education has seen its numbers growing in recent years and focuses on aspects connected to knowledge, teaching methods, psychological factors, political influences and social behaviours.

A recurrent theme across the literature is climate change's inherent complexity and uncertainty. Many authors emphasise that the multifaceted nature of climate change challenges conventional educational frameworks. For instance, Monroe and colleagues (2017) and Stevenson and colleagues (2017) note that the topic involves interconnected social, political, and environmental dimensions, complicating its integration into traditional curricula. The notion of "deep uncertainty" is highlighted by Funtowicz and Ravetz (1993), who describe the current era as one marked by disputes over values, high stakes, and blurred boundaries between science and policy.
Additionally, the controversial nature of climate change adds another layer of difficulty. Educators often avoid the topic due to its perceived politicisation, fearing that it may appear as advocacy rather than objective instruction (Ben Zvi Assaraf et al., 2024; Monroe et al., 2017). Rousell and Cutter-Mackenzie-Knowles (2019) underscore the impact of political and moral climate denial, further complicating the teaching process. The moral and ethical dimensions of climate change also stand out, with several authors advocating for a focus on intergenerational equity and responsibility (Moltan-Hill et al., 2019; Rousell & Cutter-Mackenzie-Knowles, 2019).

The knowledge gap among students and educators is a central concern in climate change education. Monroe and colleagues (2017) and McCaffrey and Buhr (2008) highlight a lack of foundational knowledge of climate science among students, which is exacerbated by the prevalence of misconceptions, such as confusion between weather and climate (Lombardi & Sinatra, 2012). Educators, too, are often underprepared, lacking the professional training and resources necessary to teach this complex subject effectively (Tolppanen & Aksela, 2018).
Several authors stress the importance of adopting a systems-thinking approach to overcome simplistic and linear mental models. McCright and colleagues (2013) and Tolppanen and Aksela (2018) advocate for teaching strategies that emphasise interconnections, feedback loops, and nonlinearity to better capture the dynamics of climate systems. The role of media in shaping perceptions of climate change is also significant, as it often propagates oversimplified or biased views, influencing both public and student understanding (Tolppanen & Aksela, 2018).

Climate change education inherently requires integrating socio-economic, political, environmental, and technological knowledge (Kumar et al., 2023; Stevenson et al., 2017). This approach aligns with Funtowicz and Ravetz's (1993) concept of post-normal science, where traditional disciplinary boundaries are insufficient to address problems characterised by uncertainty and high stakes.
Another key theme is education extending beyond the traditional classroom. Stevenson and colleagues (2017) argue for informal and hybrid learning spaces, such as community-based initiatives, which foster participatory and action-oriented approaches. Moltan-Hill and colleagues (2019) noted that higher education institutions must embed climate change education within broader sustainability efforts, adopting systemic strategies to prepare informed citizens and policymakers.
Finally, reflexive, inquiry-based, and creative learning methods are identified as crucial for equipping students with critical thinking skills. Stevenson and colleagues (2017) and Finnegan (2022) emphasise that these methods can inspire hope and promote a sense of agency, empowering learners to envision and work toward sustainable futures (Ojala, 2015).

In summary, the literature underscores the need for climate change education to transcend traditional educational structures, addressing its complexity and controversial nature through interdisciplinary, reflexive, and participatory approaches. By equipping both educators and students with the necessary knowledge and skills, education can play a pivotal role in addressing the urgent challenges posed by climate change.

5.2 The structure of the approach

The approach I developed throughout my PhD has been designed to address the needs of Climate Change Education emerging from literature, which can be summarised in a few points:

- Climate change is a wicked problem involving the scientific, political and social dimensions, which must be addressed simultaneously. It requires decision-making competences to move through these dimensions and act in a sustainable way;
- Climate change is an inherently uncertain issue. It is, therefore, necessary to adopt a systemic view that challenges the classical and standardised ways of perceiving science, moving from a linear and static view to a complex and dynamic one, navigating uncertainty rather than avoiding it;
- Climate change is a slow and lengthy process, with spatial and temporal scales that cannot be easily perceived through direct experience. Therefore, it becomes necessary to use methods of investigation and study that focus on the role that our perception of the future plays in our daily lives.

This approach aims to frame climate change from a future-oriented science education perspective. By doing this, I repositioned the issue from an epistemological point of view regarding core themes like uncertainty, complexity, and predictability, which are necessary for both science educators and students to deal with climate change drivers and impacts.

I now present how I articulated and framed together the three dimensions - sustainability, uncertainty, and future - to outline my approach. In doing so, I tried to be as comprehensive as possible while at the same time aiming to develop a reasoning model capable of highlighting the epistemic core of physics education.

5.2.1 The GreenComp perspective on sustainability

The GreenComp competences framework (Bianchi et al., 2022) (Figure 5.1) acted as a guide and compass for developing a strategy that addresses the needs outlined in the Climate Change Education literature. This framework outlines the goals and considers the necessary elements for a future-focused educational approach that promotes sustainability in science education.

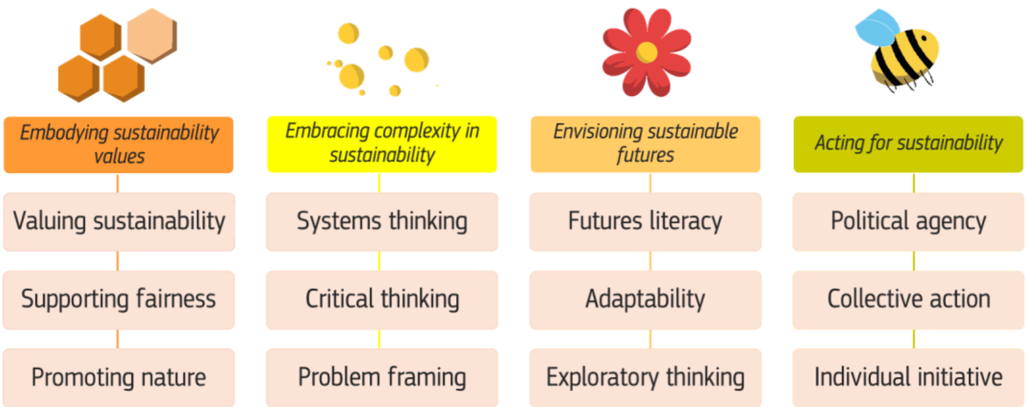


Figure 5.1 GreenComp competences

As shown in the first part of this thesis, GreenComp represents a very effective framework for addressing climate change from an educational perspective. This is due to its wide range of applicability, the foundational role that complexity and futures play in its structure and positioning towards sustainability, and its call for agency on several levels.
For our approach, grounded in the physics education culture but open to futures studies and interdisciplinarity, at least three elements of GreenComp deeply challenge the foundations of physics teaching and somehow explain why teaching climate change is so demanding for physics teachers. These aspects are also highlighted to stress why GreenComp - and sustainability education - can become a driver for reaching deep changes in science education *tout court*.

The first one is the recommendation to move from a "problem solving approach" to a "problem framing one", aiming at embracing complexity in sustainability. Problem framing incorporates problem-solving, when problems are either straightforward or complicated, in the sense that solving strategies are known or buildable. Other problems, called wicked problems, do not admit solutions and the approach to deal with them implies a multi-dimensional analysis and the activation of competences from several research fields.
Focusing on the word framing instead of solving is fundamental when facing problems that belong to the post-normal era in science (Funtowicz & Ravetz,1993), i.e., problems that have to be addressed by

the scientific community to support policy decision-making in contexts where values are in conflicts and deep uncertainties are at stake.
For physics teachers, the privileged and central role attached to "embracing complexity" can be the entry point and leverage for reshaping the curriculum and considering where and how the science of complex systems can be introduced (Barelli, 2022; Ilari, 2024).

A second aspect of GreenComp that can challenge physics teachers - and the widespread Laplacian and Newtonian culture - is the importance attached to "exploratory thinking" competence, considered as a specific type of thinking needed to envision sustainable futures. Developing an exploratory attitude towards problems means to problematise the deterministic view and to be open to the concept of possibility. It requires escaping from the idea that the future is already written and decided. Developing exploratory thinking is a necessary competence to deal with an issue like climate change, where it is necessary to be open to diverse possible outcomes or scenarios in which our idea of society, as we know it, can and should change in ways we do not yet understand.

A third aspect unusual for the physics culture is the conceptualisation of values as competences per se, articulated in knowledge, skills and attitudes. The three competences described in the "Embodying sustainability values" are required at every level of the process, as they serve as the cardinal reference point we should always strive for while working on issues connected to climate change. The positioning of values at the level of competences can be a relevant aspect of climate change education, as the changes needed for our society to cope with this problem are not only related to technological improvements and adaptation but must start from behavioural and attitudinal aspects.

5.2.2 Mapping the different roles of uncertainty

Uncertainty plays a pivotal role in science and education due to its relevance in understanding the scientific process and its broader societal implications. As an inherent aspect of science, uncertainty shapes almost every aspect of the scientific process and impacts daily choices (Dessai et al., 2007). Its study in education is essential for understanding scientific models, promoting informed decision-making, and fostering a deep comprehension of the complexity of scientific endeavours. Kampourakis and McCain (2019) emphasise that uncertainty is an "inescapable feature of science that [...] does not prevent us from gaining scientific knowledge and understanding" (p. ix-x).

Together with the research group and following a recent thread of works, we identified different levels at which uncertainty can be discussed and described.
The categorisation has four levels, starting from the scientific concept and expanding towards the role of the content in the scientific process, in its use to develop a specific way of thinking, and in its application in real-life situations. In this way, it is possible to reshape how we approach specific concepts in science education and embed them in our daily lives to make the educational process relevant, effective, and transformative.
In this case, I use this categorisation to map the different dimensions of uncertainty (Figure 5.2). This categorisation was developed in what we defined as the "uncertainty group" and has been central to several discussions and productions over the last few years. The structure of this categorisation can also be used to explore other topics, as De Zuani (2025) shows.
The structure links scientific content with educational practices and societal applications, making science education more relevant, effective, and transformative.
This discussion is presented in detail in the paper "Embracing complexity and uncertainties to deal with climate change challenges: an interdisciplinary module for preservice teacher education", which is currently under major revisions for the journal Science & Education (Miani, Bitsaki, Metaxas, Stavrou & Levrini, under review).

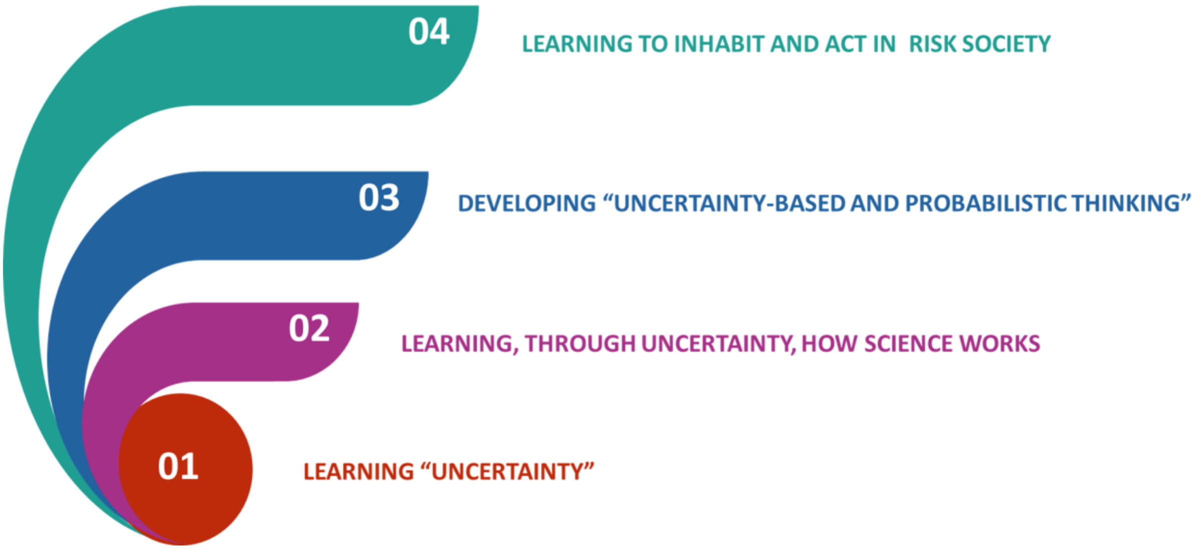


Figure 5.2 A four-scheme structure to map uncertainty through different levels, from a content-based focus to a societal one.

At the first level, uncertainty is treated as a fundamental topic in science, studied through measurement theory, statistics, and probability laws (Pollard et al., 2021). In schools, the concept is often introduced when addressing uncertainties in measurement, ensuring accuracy and reliability. Beyond this, university-level topics such as Heisenberg's uncertainty principle and statistical mechanics demonstrate how uncertainty is integral to understanding natural phenomena.
Uncertainty can be conceived as a "threshold concept" (Hall, 2006, p. 49), a concept that can transform students' understanding of a particular phenomenon, allowing them to grasp its inner aspects and change their approach to it. For the author, uncertainty can help unite many key concepts within a certain phenomenon (such as climate change) to create an overall understanding of the subject (Hall, 2006).
I will discuss later in this chapter how uncertainty, when perceived as a lack of knowledge, can hinder the appropriation process and limit agency.

On a second level, uncertainty can be perceived as a way to explore and learn how the scientific process works and how science deals with uncertainty in its epistemic practices (Chen et al., 2024; Covitt & Anderson, 2022; Tiberghien et al., 2014). Uncertainty can be considered the driving force of the scientific process, as it pushes scientists to continue their research to reach the ultimate goal of understanding nature and its functioning (Kampourakis & McCain, 2019). This perspective challenges the idea of science as flawless or infallible, promoting a nuanced understanding that avoids fundamentalist interpretations. The capability to perceive and value the role of uncertainties in science can help avoid adopting a fundamentalist approach, where science is seen as flawless and perfect with the risk of leading to unfounded conclusions (Kampourakis & McCain, 2019). Tiberghien and colleagues (2014) underscore this point, stating that "uncertainty is an essential component of the growing of knowledge, in the scientist's activity as well as in the science classroom activity" (p. 934). Such insights can help learners appreciate the provisional nature of scientific knowledge and its utility despite inherent limitations (Covitt & Anderson, 2022).

The third level brings the reasoning further, intending to develop what we can call "uncertainty-based and probabilistic thinking" by addressing its development through an engagement with uncertainty. This involves understanding the inner dynamics of uncertain and probabilistic phenomena and fostering different strategies to navigate the sense-making process. Rosenberg and colleagues (2022) argue, for example, how being able to identify biases and using a Bayesian approach can "support science learners to make sense of uncertainty […] and build trust in science" (p. 1). This perspective integrates prior knowledge with new scientific insights, facilitating a deeper understanding of phenomena and their multifaceted causes. Such thinking is crucial for dealing with complex problems where uncertainty plays a central role.

The fourth level emphasizes the application of uncertainty to real-world decision-making and societal challenges (Christensen & Fensham, 2011; Fazio, 2023; Pietrocola et al., 2022). This involves inhabiting and acting within what Beck (1992) calls the "risk society," where manufactured risks and wicked problems (Termeer et al., 2019), like climate change, demand new ways of thinking and acting. Christensen and Fensham (2011) argue that science educators must address the complexity and uncertainty underlying these grand challenges. For instance, addressing wicked problems necessitates moving beyond traditional scientific approaches, integrating societal and ethical dimensions to inform personal, societal, and political decisions (Cross & Congreve, 2021; Termeer et al., 2019; Pietrocola et al., 2022).

This four-level system maps the different ways a concept, like uncertainty, can be explored and used to promote meaningful learning and bridge the gap between schools and the real world. It also allows us to explore the content in detail and exploit its richness, discussing its ontological complexity and different dimensions.
Uncertainty lends itself well to this type of reasoning because of its omnipresence and relevance in the knowledge process.

This discussion on the concept of uncertainty becomes relevant when it is necessary to communicate the results obtained through investigation and research, as the perception that those who do science are in possession of the truth is still very much ingrained in those who do not have a complete and clear picture of the scientific process. To this extent, a deep discussion might be opened on the meaning of truth and, therefore, on the concept of trust in science. These discussions have always been central in the philosophy of science and in the community of the nature of science, as they are still today. The newly formed Special Interest Group 8 of the ESERA community, which focuses on Future-Oriented Science Education, revolves around these discussions, and aims to "discuss, from epistemological, sociological, axiological, and educational points of view, the intricate interplay between scientific advancements, new societal uncertainties, and visions of the futures." (https://www.esera.org/esera-special-interest-groups/sig8-futures-oriented-science-education/).

5.2.3 Types of uncertainty

As presented in Chapters 2 and 4, I started my study from the literature on extreme events in climate change and identified the categorisation of the three different types of uncertainty (reflexive, epistemic, and aleatoric) as useful for discussing climate changes in an educational setting.
It is necessary to notice that there is no general agreement on the uncertainty typologies proposed and used in literature (Dessai et al., 2007). According to Walker and colleagues (2003), uncertainties can be classified into three dimensions: location (where uncertainty manifests itself), level of knowledge, and nature (it is due to knowledge or inherent variability). For Hall (2006), uncertainties can be distinguished into "statistical uncertainty" (parameters that are not known with enough precision) and "structural uncertainty" (the relationship between variables may not have been defined correctly) (p.48). At the same time, for Hall it is necessary to take into account the uncertainties of the learner, as students may find science not capable of explaining or predicting phenomena in complex issues, such as climate change.
Focusing on climate models Gramelsberger and Feichter (2011) identify three main sources of uncertainty: unpredictability, structural uncertainty and value uncertainty. Schauss and Sprenger (2021) highlights three categories in deficiencies of climate models, limited knowledge of the climate system, and external influences on climate.

Chua Chow and Sarin (2002) distinguish, on a more general level, between known, unknown, and unknowable uncertainties, focusing on the subjects reactions to the availability of informations.

Although diverse categorisations of scientific uncertainties are present in literature, focused not only on climate change, I consider the one proposed in Shepherd (2019) - reflexive, epistemic, and aleatoric - simple enough to reach students and teachers straight away and at the same time capable of comprehensively mapping the different typologies of uncertainty present in literature.

The first type of uncertainty - reflexive - is directly linked to human behaviour, due to the fact that humans have the specific characteristic of reflecting critically on their actions and changing them in the light of experience (Kahneman & Tversky, 1982). Unlike other systems, human systems are the only type of system sensible to information about the future enough to change their present behaviour, for example by using anticipatory techniques (Poli, 2017). This type of uncertainty is influenced mainly by social phenomena, like politics or the economy, and cannot be reduced. Instead, the approach used to address this particular uncertainty is related to the differences between future scenarios and the actual realisation of those predictions due to the variability of human behaviour. It can be used to create future possible or plausible scenarios differing for the type of decisions taken at the political and economic levels. An example of this approach can be found in the Shared Socio-Economic Pathways used by the IPCC starting from the 5th Assessment Report (2014), where five different scenarios have been built depending on factors such as international cooperation, investments in research about renewable energies, use of fossil fuels and economic incentives for dealing with world differences and inequalities (O'Neill et al., 2017).

The second type of uncertainty, the epistemic one (Kahneman & Tversky, 1982; see Helton & Davis, 2000, for a mathematical description of this type of uncertainty) is directly connected to the knowledge level and the scientific process itself. As discussed earlier, even if we understand a certain phenomenon, our degree of knowledge might not be enough to fully comprehend it. Similarly, we may have a certain knowledge about a certain phenomenon, but future research or discoveries may change our level of understanding of it. In climate studies, this uncertainty is linked to our capability to understand and reproduce climate dynamics using climate models. As Shepherd (2019) notices, climate models are "imperfect representations of reality and share many deficiencies; they may exhibit a collective bias and fail to explore important aspects of climate change" (p. 5).
Epistemic uncertainty is tied to understanding what kind of response the climate system will realise depending on possible external forcings since we don't know how our knowledge represents the system's actual functioning.

The third type of uncertainty, the aleatoric one (Helton & Davis, 2000; Smith, 2002), is profoundly connected to the inner variability of the climate system, due to its complexity and chaotic nature (Lorenz, 1995). Climate can be described as a complex dynamic system (Dijkstra, 2013; Kirchner et al., 2021; Provenzale, 2014) due to several aspects, like nonlinearity, emergent properties, and dependence on the initial conditions. This type of uncertainty cannot be reduced because its nature is ontologically very different from the epistemic one, but it can be quantified. In the case of climatology, aleatoric uncertainty can be quantified by taking coarser spatial and temporal averages (Shepherd, 2019) using statistical analysis methods. Even if this process can be very difficult, it can help understand what kind of climate will be experienced in the future using a frequentist approach.

This distinction aims to present the complexity of climate change and unpack the different methods needed to study it. The categorisation, as discussed in Shepherd (2019), can help delimit and identify which aspects of climate change we can make a difference on and, in general, which ways to deal with and manage the uncertainty of these phenomena. Each type of uncertainty requires a different method of study, and it is therefore necessary to know the details to be able to act.

5.2.4 Future as an open set of possibilities

The third dimension of the approach relates to using methods to explore and investigate the future, as derived from the field of future studies and described in Chapter 1.

The rationale of the approach presented here for dealing with climate change lies in exploiting the space offered by uncertainty to avoid and break free from a deterministic and fatalistic view. For this reason, looking at the future through the concept of possibility becomes relevant. Following the laws of Dator (2019) and the cone of futures (Figure 5.3) (Voros, 2003), in this approach I used qualitative methods of constructing futures through exploration and scenario building.

The importance of looking to the future through scenarios lies in the fact that constructing one's own desirable vision of the future reveals the aspects that we consider fundamental to us, but also the limits to overcome.

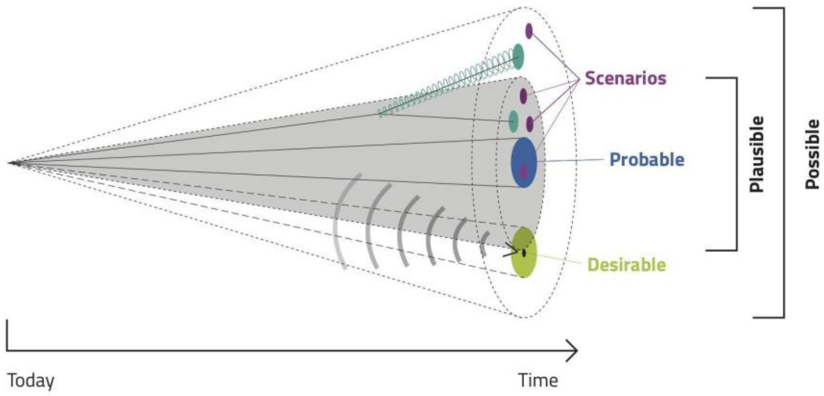


Figure 5.3 Representation of the futures cone from the I SEE project (Branchetti et al., 2018)

The ontological uncertainty connected to the future becomes, in this way, a powerful tool to strengthen our capability of making informed decisions and generate informed active hope about the possible results of those actions. In fact, because "the future" cannot be known (Dator, 2019), we need to increase our capability to explore the intrinsic possibility that the future has in itself. Therefore, by not thinking about the evolution of specific phenomena as already determined, we can prepare for different outcomes, elaborate on diverse ideas of the future and create a space for action on different levels.

5.3 The overall picture

The emerging overall picture is an approach that aims to create the space for dealing with climate change from an interdisciplinary, multilevel, and multipurpose perspective.
As will be described in detail in the next chapter, this approach can open a discussion on the specificities of disciplines and interdisciplinary aspects of the scientific process, the difficulty of sharing information, needs, and results between science and society, the connection between research and other aspects of our lives like economy and politics, and the role that we as individuals have in shaping the future.

The mechanisms of the approach can be represented through the figure below (Figure 5.4).
The figure is divided into three main parts: past, present and future.

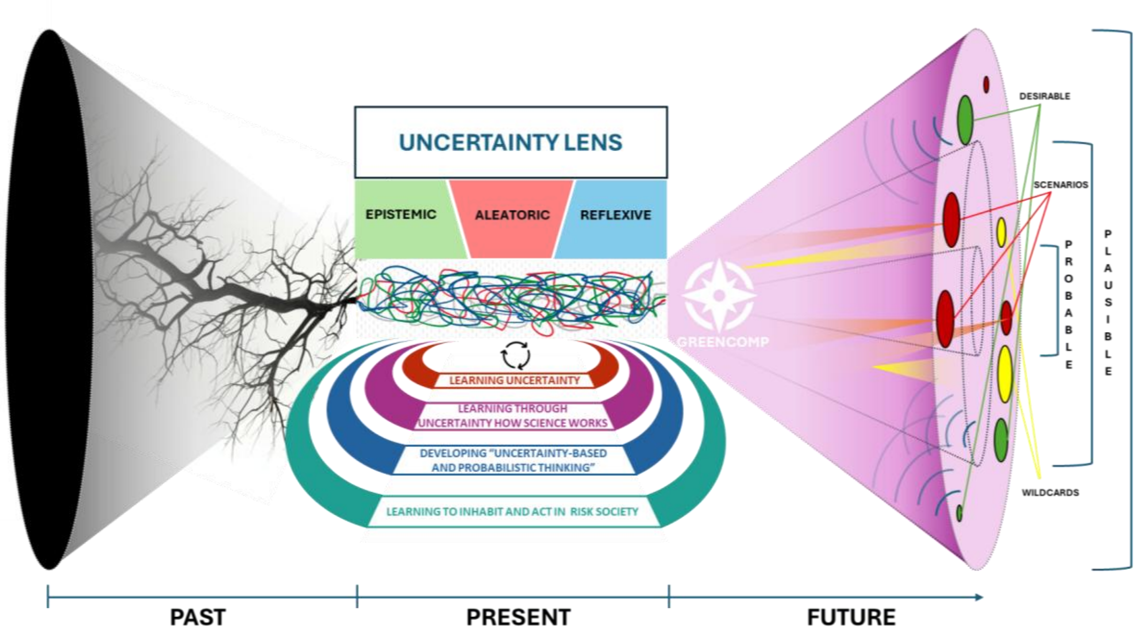


Figure 5.4 A representative scheme of the approach to climate change education presented in the thesis.

In the left part, we see a narrowing cone, where an ensemble of lines converges and flows onto a main line, representing the past. The idea behind this representation lies in the fact that the past is perceived as unique and definite, whereas reality is more complex than that and mostly due to contingencies. Therefore, the uncertainty about the exact developments cannot be resolved, especially if we go back a long way in time.
In the central part of the diagram, we have a kind of corridor in which our complex reality is analysed through the tools made available by the scientific process. In particular, here we see how analysing complexity through the lens of uncertainty and its different types allows us to distinguish the different areas in which it is possible to act and the different ways in which it is possible to do so.
The third part of this diagram represents possible future developments. This section is clearly inspired by the cone of futures depicted above (Figure 5.3), with some additions. In particular, in this case, the direction of the desirable future is indicated by following the GreenComp, which thus assumes the role of a compass. Furthermore, the representation of the future is not given by lines but by diffuse coloured strokes to indicate the inherent uncertainty of future developments.

5.4 Structure of the course

The approach presented has been used to design a 20-hour course named "Towards New Future Scenarios: The Role of Physics in the Challenges of Climate Change," aimed at students in the last years of secondary school. The course has been implemented two times, between October and November 2023 with 34 students and between November and December 2024 with another 33 students. In the first implementation, the course was co-taught with my colleague Dr Francesco De Zuani Cassina; in the second implementation, our other colleague Emma D'Orto took part in the course. I present here the structure of the first implementation.

The course has been offered as part of the "Piano Lauree Scientifiche" (Scientific Degrees Plan) (PLS). PLS is a project started in 2004 following the initiative of different organisations, the Italian Minister for Education, University and Research (MIUR), the Conference of Science and Technology Deans and Confindustria, an organisation representing companies producing goods and/or services in Italy. PLS courses are made for students and teachers, and aim to provide them with active guidance opportunities to introduce them to scientific disciplines, using innovative teaching tools and methodologies consistent with the student-centred approach to learning activities. Also, PLS courses aim to carry out self-assessment activities for upper secondary school students to verify their preparation for university access to the requirements and increase their awareness of their knowledge to choose an educational pathway. The course we describe here has been developed following the core ideas of the PLS.

Thirty-four students participated in the TNFS course. The students were all from the Emilia-Romagna region, the same as Bologna. Of the thirty-four students, thirty-one were from science high schools, two from classical high school and one from the humanities high school, for a total of eight different schools. Some students came from the same class. Twenty-one students were from the fourth grade (12th grade), and thirteen were from the fifth grade (13th grade), aged between 17 and 19. Nineteen students identified as females, while fifteen identified as males.

The course has been structured into 7 lessons (6 of 3 hours and the last one of 2 hours).
Figure 5.5 shows the course scheme, and Figure 5.6 details the contents of each lesson.

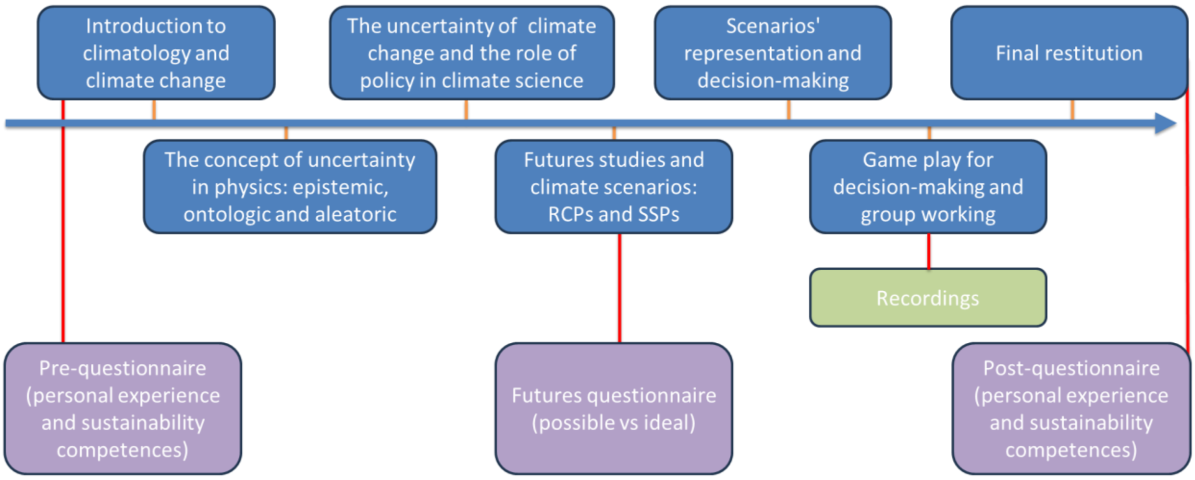


Figure 5.5 Temporal scheme of the course. The blue boxes represent the lessons, the violet the questionnaires, and in green the recordings.

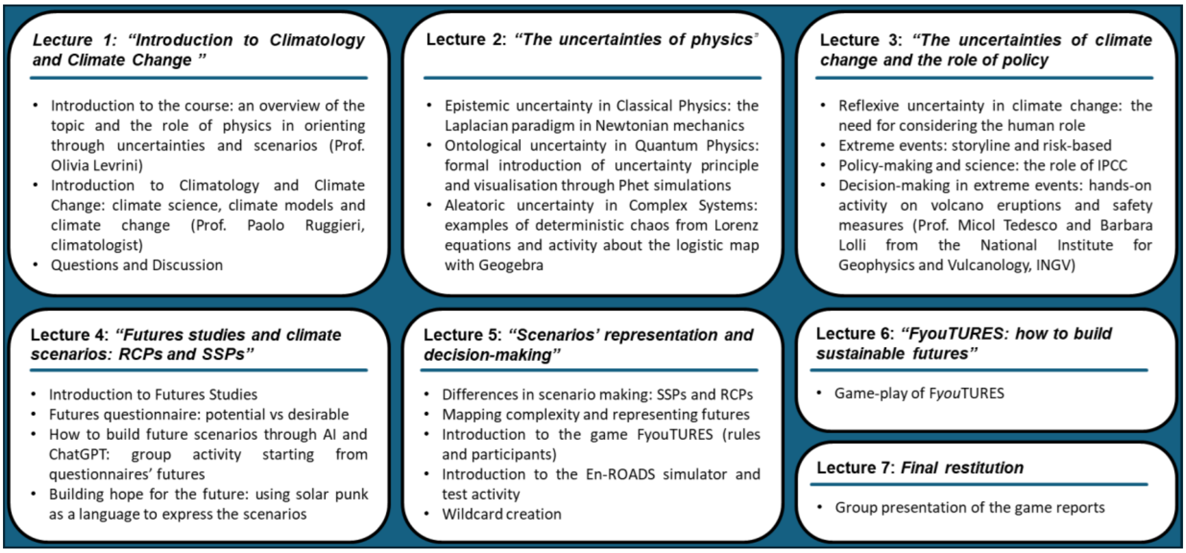


Figure 5.6 Detail of the lessons of the course.

In the course design phase, we planned diverse data collection moments (violet boxes in Figure 5.5). I now present the contents of each lesson, including the arguments discussed and the activities realised.

The discussion around the data collection and analysis is part of Chapter 6.

5.4.1 Lesson 1: Introduction to climatology and climate change

The first lesson opened with an introduction to the field of climatology and the history of research on climate change by Paolo Ruggieri, a climatologist at the Department of Physics and Astronomy of the University of Bologna. We met with Ruggieri before the course to discuss its aim and overall approach, and he prepared a very fitting presentation that addressed the topics covered in the course.
The lecture made by Paolo Ruggieri focused on four main aspects:

- Climate and the science of climate;
- Predicting the future climate;
- Uncertainty;
- Adaptation and mitigation.

The lecture started by defining climate by describing the methods used to gather present and past climate-related data, such as the Global Observing System, the study of trees' inner core or the equations used to conceptualise a general circulation model.
In the second part of the lecture, Ruggieri discussed the differences between weather and climate and introduced the first studies in which scientists started to consider the possibility of studying climate and its changes properly. Here, he presented the Charney report (1979), the first official assessment of the effect of CO_2 on our atmosphere, and the first report of the IPCC (IPCC, 1992).
Paolo Ruggieri then presented the necessity of modelling in climate science and the difficulties connected to this practice (epistemic uncertainty), opening to the concepts of chaos and chance (aleatoric uncertainty) and the uncertainty connected to future climate forcing (reflexive uncertainty).
In the last part of the lecture, Paolo Ruggieri discussed the state of the art in climate change predictions and presented the concepts of adaptation and mitigation.

Overall, the lecture introduced some specific concepts that were later discussed during the course. After the lecture, we opened a space for discussion with the students to explore their reactions and collect their questions.

In the last part of the course, we asked students to complete a questionnaire in which they shared a personal story about climate change and answered questions about GreenComp's different competences. The questionnaire aimed to collect some information on students' attitudes towards sustainability issues and their personal relationships with climate change.
The same questionnaire was given to the students again in the last lesson to collect pre and post-course data.

5.4.2 Lesson 2: The uncertainties of physics

In the second lesson, we presented the uncertainties usually associated with physics.
Francesco mainly prepared and led the lesson, which was divided into three main parts. It followed a temporal progression that opened to different types of uncertainty.

In the first part, Francesco introduced students to the first type of uncertainty, the epistemic one, by describing the deterministic perspective of classical physics and the Laplace demon.

In this part, we wanted to connect with students' experience of the concept of uncertainty by addressing the measurement process and the standard definitions of accuracy and measurement uncertainty[1].
After this, Francesco presented the Laplace Demon idea directly by reading the words of the mathematician and astronomer Pierre-Simon Laplace. The Laplace Demon is a rhetorical exercise in which the author describes how our difficulty in accurately predicting the development of future events is due to our ignorance of the laws that control the world. To demonstrate this idea, the author hypothesises the existence of a being with superhuman powers, a demon in fact, capable of knowing exactly the initial conditions of each component of the universe and the laws that control its motion. The strong assumption behind this approach is rooted in the long-held belief in the hard sciences that the world was purely deterministic, and that there was a direct causal connection between causes and effects.
After the discussion on the Laplace Demon, Francesco used the kinetic theory of gases to discuss an example of how the deterministic paradigm can be used in some cases to explain the behaviour of specific systems, although through a high level of modelling.

In the second part, Francesco introduced the world of quantum physics and the Uncertainty principle from a general perspective. In this case, the type of uncertainty is ontological, as it depends on an intrinsic peculiarity of the nature of quantum mechanics.
To present this aspect of physics, Francesco started by presenting briefly how reality is described in quantum mechanics, i.e. observables, states, operators and functions. Later on, the lesson continued with a general discussion of the two hypotheses on the nature of light made in the first part of the last century, by presenting the Compton effect and the De Broglie formulation. From this confrontation, we were then able to present the Uncertainty Principle by discussing the ontological impossibility of knowing the exact value of non-commutable observables, such as the spin on two different dimensions. Although the discussion on quantum mechanics was challenging to cover in only one hour, it opened the concept of uncertainty and provided an example of how, in specific cases, there is no possibility of knowing something, and that it does not depend on our capability of measuring.

In the third part, Francesco presented some basic aspects of the physics of complex systems and introduced the concept of aleatoric uncertainty.
To do so, we decided to start with the double pendulum, a simple example of the difficulty of making predictions when dealing with systems that are highly sensitive to initial conditions and dynamic behaviour.
Francesco then continued by describing the core elements of complex systems, focusing on the non-linear relations between the system elements, the emerging properties, and the concept of positive and negative feedback.
We then ended the lesson by introducing Edward N. Lorenz's famous "butterfly effect" (1995), the definition of chaos, and a couple of reflections from Lorenz himself and Edgar Morin (1995).

> "For a long time, many believed - and many perhaps still believe today - that the shortcoming of the human and social sciences lay in their inability to get rid of the apparent complexity of human phenomena, to elevate themselves to the dignity of the natural sciences, sciences that established simple laws, simple principles, and let the order of determinism reign. Today, we see that the biological and physical sciences are characterised by a crisis of simple explanation. And as a result, what seemed to be the non-scientific remnants of the human sciences - uncertainty, disorder, contradiction,

[1] It is interesting to notice that in Italian, the term to indicate the uncertainty on the measure is *errore,* the same word used to indicate a mistake.

plurality, etc. are now part of the problematics of scientific knowledge." (Translated from Italian, in Morin, 1995. p.26)

This last part aimed at reconnecting with some specific aspects treated in Lesson 1 by Paolo Ruggieri, specifically the difficulties of creating models to study a complex system like climate. It also laid the basis for discussing the types of uncertainties that we have to deal with in the study of climate change.

5.4.3 Lesson 3: The uncertainties of climate change and the role of policy in climate science

In Lesson 3, we continued the discussion regarding uncertainties by focusing on the specific types of uncertainty connected to climate change.
The lesson has been led mainly by me, with intervention from Micol Todesco, the director of the Bologna section of the Italian National Institute of Geophysics and Vulcanology (INGV), and her colleague Barbara Lolli.

In the first part of the lesson, I started by recalling some definitions given by Paolo Ruggieri in Lesson 1, such as the definition of climate, the different methods we can use to study it, and its complex nature. Here, I focused on the feedback mechanisms and presented the Arctic feedback, the phenomenon in which the solar radiation reflected by the ice caps (albedo) diminishes due to the increasing ice melting process accelerated by global warming, therefore increasing the temperature of the water and leading to a higher rate of ice melting. In this case, the feedback is called positive: the increase in temperature leads to an increase in the melting of the ice, so less reflection and, therefore, a consequent increase in temperature.

The discussion then went on with a description of the types of uncertainties that can be found and need to be addressed in climate change.
Together with epistemic uncertainty and aleatoric uncertainty, we introduced the concept of reflexive uncertainty, i.e., the uncertainty connected to human behaviour.
Following Shepherd's work (2019), I discussed each uncertainty in the context of climate change by showing how each type derives from different aspects of the issue and, therefore, must be treated differently (Figure 5.7).

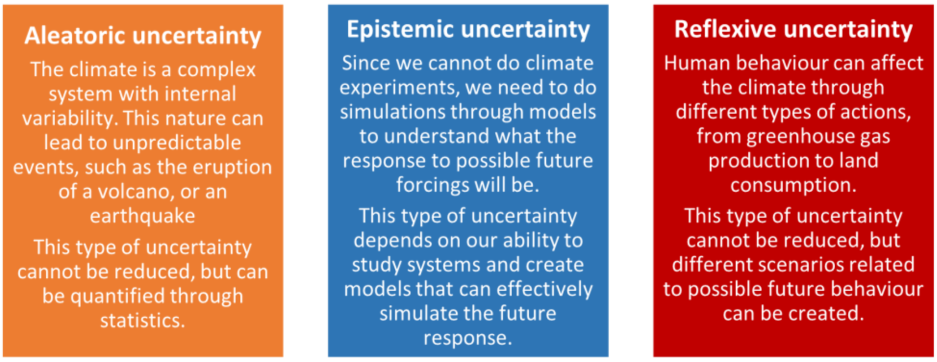


Figure 5.7 Different types of uncertainty connected to climate change, as described in Shepherd (2019).

The need to consider reflexive uncertainty, as discussed in Chapter 4, is usually neglected in the classical view of physics, which tends to consider theories and laws as absolute truths rather than as the results of the social process of science.
The discussion on reflexive uncertainty served as an entry point to explore several aspects involved in climate change, such as the concept of risk connected to extreme events and the need to make decisions about adaptation and mitigation measures.

At this point of the lesson, the two visitors led an activity connected to risk management in case of extreme events. In particular, the activity, named "explosive uncertainty", was meant for students to simulate the process of deciding when it is necessary to evacuate the population following specific warnings such as seismic tremors or symptoms of future volcanic eruptions.
To do so, the two researchers created a fake "volcano" using tear-away streamers connected to a hook and bucket into which weights, specifically bolts, were inserted (Figure 5.8).

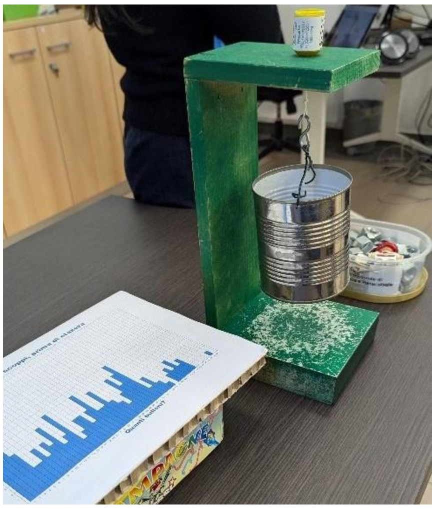


Figure 5.8 Apparatus created by researchers Micol Todesco and Barbara Lolli to simulate the behaviour of a volcano. In the picture are represented the structure (green), the basket (grey) hanging from the streamer (yellow), and a graph showing the historical series of the number of bolts needed to burst the streamer, gathered in previous implementations of the activity.

Due to the internal variability of tear-away strength, each streamer has a different weight at which it explodes, making it very difficult to know exactly when this will happen. Students were first asked to construct a statistic on the number of bolts needed to make the streamers explode and then decide how many bolts were needed to evacuate the population, represented by a researcher on top of the "volcano." This activity aimed to introduce the need to consider the inner uncertainty of specific phenomena to make decisions, specifically when the consequences can be dangerous for the population.

In the last part of the lesson, I focused explicitly on the consensus-building process of climate change knowledge and the need to share it with policymakers to implement the needed changes to deal with the issue. To do so, I presented the case of the IPCC in detail, as the leading exponent in the field of climate change studies. In this hour, I took up what had already been announced in Lecture 1 by Prof. Ruggieri and described the history of the institution, the internal division into working groups, the process followed to arrive at the summary for policymakers (SPM) (Figure 5.9).

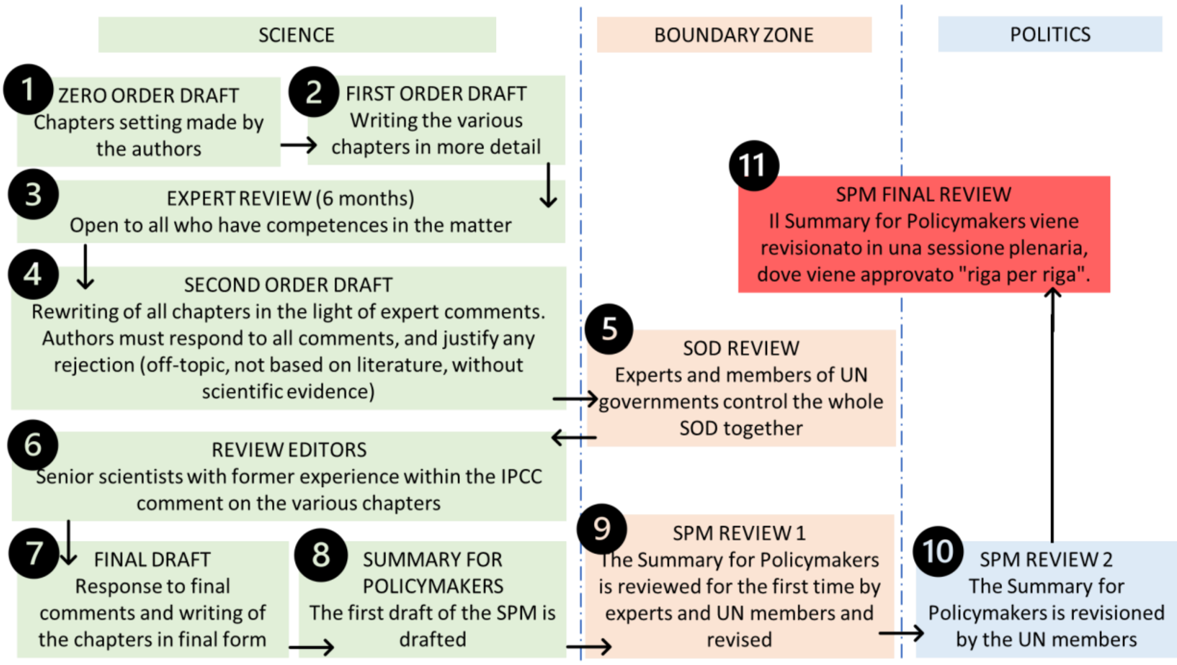


Figure 5.9 Structure of the SPM creation, following the description made in De Pryck & Hulme (2023).

In the last part of the lesson, we introduced the guidelines used by the IPCC to treat uncertainties (Mastrandrea et al., 2010), to present how scientists and policymakers can follow the decision-making process when dealing with climate change knowledge, i.e. a science in the making. Specifically, we presented some details on the differences between agreement, evidence and confidence.

5.4.4 Lesson 4: Futures studies and climate scenarios: RCPs and SSPs

Lesson 4 focused on the field of futures studies, their origin, methods and aims.
To introduce these discussions, I started by describing different ways in which the future has been addressed in general literature, referencing the concepts of utopia, dystopia and uchronia to show how we have always tried to think about possible and different futures.
This introduction helped present the field of futures studies as a way to systematise and credit the different approaches to exploring and studying the future.
In this part, the connection between science and policy has been stressed to show the differences between the epistemologies and their impact, using a quote from Wendell Bell, one of the main figures of the field (Bell, 1996):

> "Finally, there is a possible source of conflict in orientation between policy scientists and futurists on one crucial point. Futurists aim to open up the future; i.e. to make a virtue out of uncertainty in order to empower people to achieve a future that is better than the past and present. Futurists aim to teach people that the future is an open horizon that can be creatively explored. This means that for an active person, the future is actually another dimension of freedom. In contrast, policy scientists often aim to de-futurize! the future by increasing security. Policy scientists hope to secure the future through technology, law, policy and insurance, thus annulling our feelings of uncertainty. This may partially explain why the policy sciences have prospered more than the futures field. Security is comforting. Change, even desirable change, has its costs because it often causes both uncertainty and stress." (p.11)

After this introduction to the field, we asked students to respond to some questions by giving them a questionnaire that aimed at collecting their ideas regarding the future. As said before, the discussion around the questionnaires is part of Chapter 6.

After the questionnaire, we moved on to discuss the educational consequences of approaching the concept of future as an open concept in science education, by showing the ideas behind the future-oriented science education approach and the different categories of future using the futures cone (Voros, 2003).
Starting from these descriptions, we presented the ways in which the IPCC decided over the years to discuss its data regarding future projections by introducing the RCPs, the SSPs, and the idea behind what can be considered a sustainable future.

After this description we asked students to participate in a second activity, in which we asked the following questions:

1. Starting from your image of an ideal future as described above, what are the main values you put at the centre of your story?
2. Try asking Chat GPT to construct future scenarios revolving around those same values, and copy the generated text onto a word document, inserting comments if you deem it necessary.
3. Compare, in groups, the generated future scenarios, and choose one to represent using Bing's AI generator (powered by DALL-E 3). Then, try to retrace the choices that led to that given future scenario.

This activity has not been used to collect data for research but has been prepared as an exercise to imagine and explore possible ideas of future.

In the last part of the lesson, I presented a focus on the example of Solarpunk, an artistic movement formed in the last 20 years with the aim of changing the narrative with respect to the future. Following the different punk- movements (like the cyber-punk or steam-punk narratives), the Solarpunk movement is characterised by the creation of speculative worlds in which social ecology, democratic technology and solar, wind and tidal energy are crucial elements for collective well-being. The aim is to overcome what can be called the 'capitalocene' and its roots in social inequality and the extraction and burning of fossil fuels (Reina Rozo, 2021).
The narrative of Solarpunk can be defined as an uprising of hope against the daily despair of our times, as it is stressed in the manifesto of the movement, of which I report here only some extracts (Reina-Rozo, 2021, pp. 54-56):

1. We are solarpunks because optimism has been taken away from us and we are trying to take it back.
3. At its core, Solarpunk is a vision of a future that embodies the best of what humanity can achieve: a post-scarcity, post-hierarchy, post-capitalistic world where humanity sees itself as part of nature and clean energy replaces fossil fuels.
4. The “punk” in Solarpunk is about rebellion, counterculture, post-capitalism, decolonialism and enthusiasm. It is about going in a different direction than the mainstream, which is increasingly going in a scary direction.
7. Solarpunk provides a valuable new perspective, a paradigm and a vocabulary through which to describe one possible future. Instead of embracing retrofuturism, solarpunk looks completely to the future. Not an alternative future, but a possible future.

21. In Solarpunk we've pulled back just in time to stop the slow destruction of our planet. We've learned to use science wisely, for the betterment of our life conditions as part of our planet. We're no longer overlords. We're caretakers. We're gardeners.

5.4.5 Lesson 5: Scenario's representations and decision-making

In Lesson 5, we focused mainly on the concept of scenario and on the description of the five narratives produced by the IPCC to describe the Shared Socio-Economic Pathways (O'Neill et al., 2017).
In this lesson, we described each scenario individually, focusing specifically on the implications of the several aspects involved in the narratives and the different possible representations used by the IPCC and other scholars to describe the idea of an open future (Figures 5.10 and 5.11).

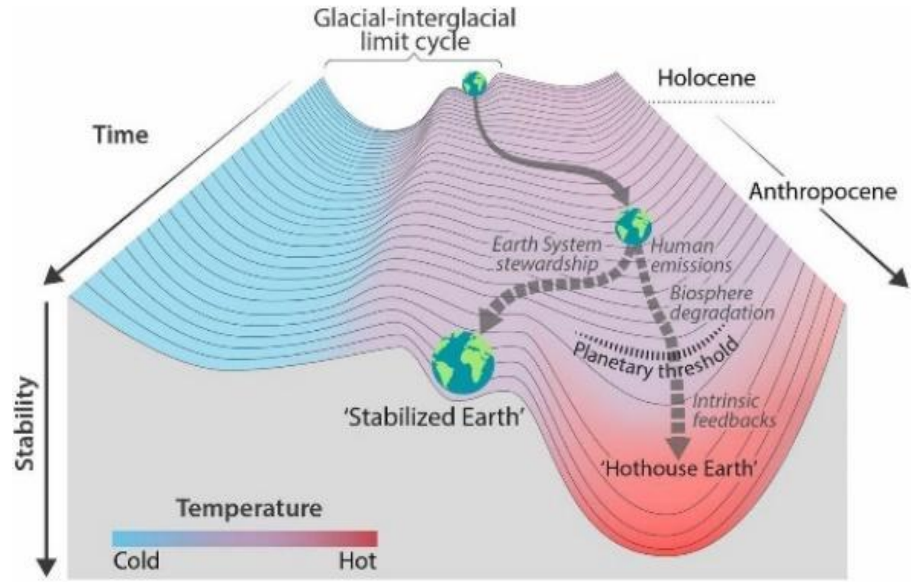


Figure 5.10 Representation of the stability of our planet in terms of temperature through the time. From Steffen and colleagues (2018).

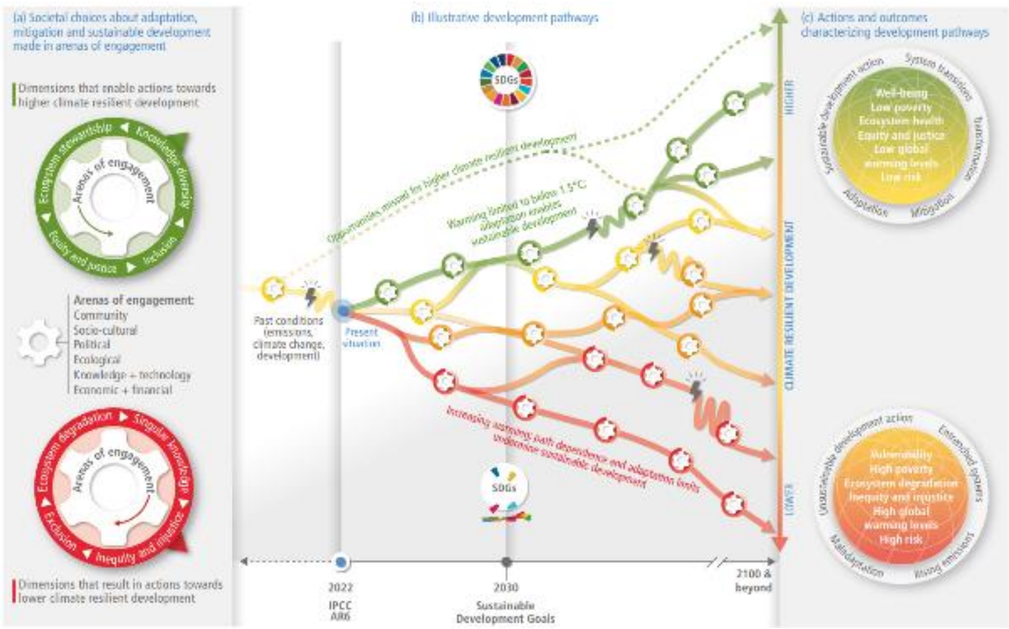


Figure 5.11 Representation of the different possible future climatic paths. From IPCC, Summary for Policymakers (2023).

The SSPs and the Summary for Policymakers produced by the IPCC (2023) provide an interesting example of how scientific data can be shared using different methods, from graphs to infographics and narratives.
The second part of the lesson focused on the difficulties of creating representations of dynamic systems by addressing the following questions:

- How to represent a space that changes over time?
- How to represent a space that is not empty?
- How to represent a space that keeps track of the actions of its agents?
- How to represent a space that is not immutable but changes quickly?
- How can we orient ourselves in such a space?

The discussion on this concept has been led by Francesco, following the work "Terra Forma: A Book of Speculative Maps" by Frédérique Aït-Touati, Alexandra Arènes and Axelle Grégoire (2022). In the book, the authors present different ways in which cartography can map reality, not as a dead, empty space to be conquered or colonized. The maps discussed in the book are speculative maps, i.e. maps in which the aim is to map what happens underside and not on the surface, like conventional cartography.

In the last part of the lesson, we laid the basis for an activity carried out in Lesson 6: the board game F*you*TURES, which was created appropriately for and during the course with Francesco.
In Lesson 6, I will describe the structure of the board game in detail, while here I present the two preparatory moments we shared with the students.

The first one is the presentation of En-ROADS (Energy-Rapid Overview and Decision Support) (Chikofksy et al., 2024), a global climate simulator developed by Climate Interactive in collaboration with MIT Sloan Sustainability Initiative and Ventana Systems. The simulator allows users to explore how various policies, such as electrification of transport, carbon pricing, or improved agricultural practices, can influence other factors like energy prices, global temperatures, air quality, or sea level rise. The simulator is based on a set of differential equations in time, representing physical processes and human decisions on climate, environment, economy, and energy systems both at the global level of aggregation and at the system-wide level of analysis (Chikofksy et al., 2024).
The simulator represents a good example of the complexity of climate change, as it uses different equations to represent the climate-energy system as a "high-dimensional dynamic system characterized by long time delays, multiple feedback loops, and nonlinearities" (Figure 5.12) (Kapmeier et al., 2021, p. 334).

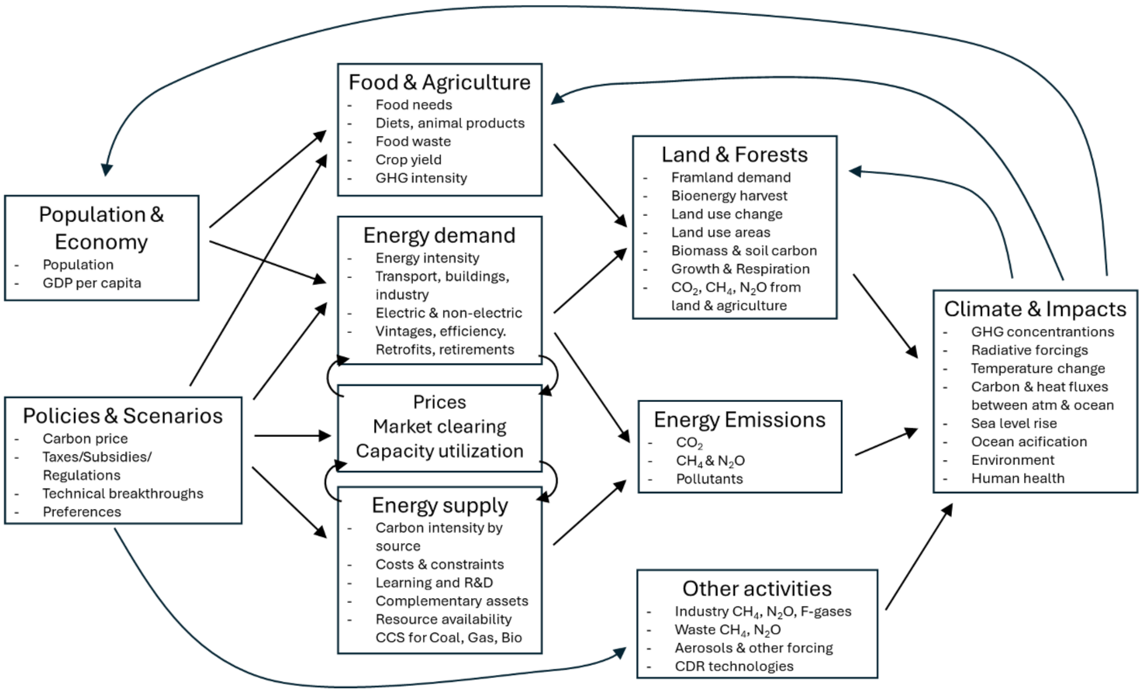


Figure 5.12 The En-ROADS model structure (from Chikofksy et al., 2024)

It is built on exogenous variables chosen by the user, like technology breakthroughs, base GDP growth or policy choices, and endogenous variables set by the developers, like energy specifics, climate impacts and other technical info. These values are determined by integrating external datasets for initial conditions and parameters and comparing them with historical and projected data from other climate models (Chikofksy et al., 2024). This system dynamics model is designed to provide real-time feedback to users through an intuitive web interface available in multiple languages (Figures 5.13 and 5.14).

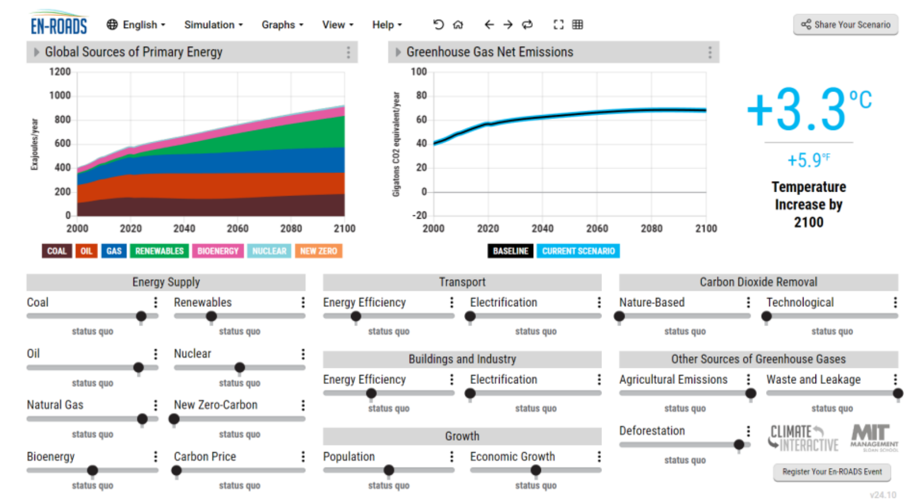


Figure 5.13 Interface of the En-ROADS simulator

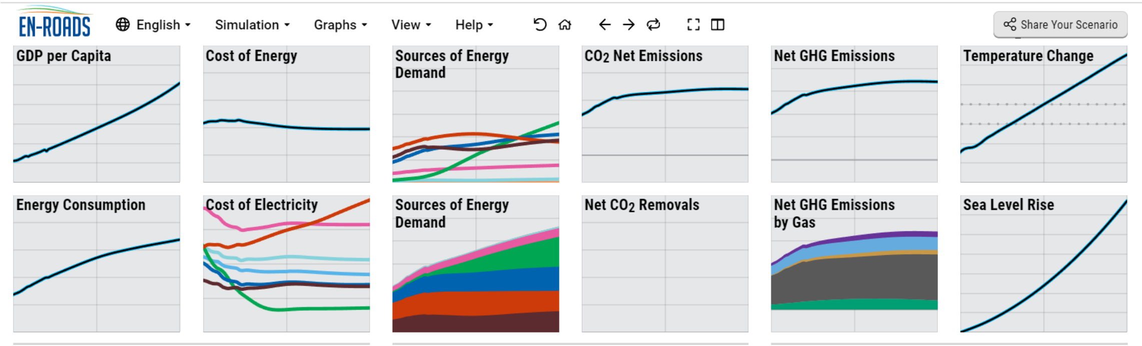


Figure 5.14 Detail of the interface of the En-ROADS simulator

En-ROADS helps users visualise the long-term outcomes of their proposed climate policies, allowing them to take the role of policymakers and social leaders to identify impactful and equitable solutions to global climate challenges. The simulator is grounded in extensive scientific research and calibrated against numerous climate and energy models (Kapmeier et al., 2021; Rooney-Varga et al., 2021; for technical info see Chikofksy et al., 2024). Furthermore, it is continuously updated and refined.
The simulator has been used on many occasions and is part of different types of events, like the Climate Action Simulation, a role-play activity in which "participants learn about the dynamics of the climate-energy system by simulating the climate and energy outcomes of their own decisions with the interactive computer model En-ROADS" (Rooney-Varga et al., 2021, p. 116).

In the last part of Lesson 5, we introduced the basics of the game. For the game, as I will show in the next section, we created a series of wildcards, i.e. cards representing specific events with a specific relation to the game. Each wildcard represents a different type of uncertainty that might be related to climate change:

- Epistemic wildcards: events connected to our capability of understanding the world and creating knowledge capable of addressing the problem (i.e. technological development or new research results);
- Aleatoric wildcards: events connected to the inner variability of nature, like for example a flood or a new pandemic;
- Reflexive wildcards: events connected to the future behaviour of society, like the birth of a no-coal movement, new policies for immigration or dastardly decisions by billionaires.

To make students active with respect to the game, we gathered them into 5 groups and asked each to produce a set of cards, with the rule of producing at least one for each type of uncertainty. We gave them some examples to start, and at the end of the lesson, we collectively shared the cards they created.

Between Lessons 5 and 6, Francesco and I refined these wildcards and made them fit the rules of the game. In the first implementation, we played with a set of 16 cards, while in the second implementation, we reached a total of 18 cards. I report some examples in Table 5.1.

IT'S WAR	FLOOD	EUREKA!
Extreme political event: a war breaks out with a neighbouring country. Energy costs increase significantly, capital is strongly redirected towards the military industry and armaments in general. No technological development actions can be taken for a round, you are forced to reduce taxes on fossil fuels because gas pipelines are cut, and power plants bombed. You must spend 4 coins to reduce 4 notches in total on conventional energies.	Extreme weather event: a sharp increase in rains causes numerous rivers in the surrounding areas to overflow, leading to extensive damage to structures and a consequent expenditure of funds for repairs. You have 4 fewer coins to spend on the next turn because you will have fewer funds available.	Cold fusion is finally achieved: energy costs drop significantly and technological development accelerates. Thus, from now on in the game energy efficiency actions can be done at half the cost (2 notches cost only 1 coin).

GO VEGAN	YOU? AGAIN?	I-HELP
Awareness of the need for a different diet increases extensively: there are fewer livestock farms and more crops, and the net balance results in a reduction of methane gas produced. Thus, 2 notches can be scaled down without spending coins on the methane slider, corresponding to a decrease in methane emissions from livestock farming. 1 notch corresponds to -20%.	A pandemic breaks out. People, unable to leave their homes, cause damage to the economy, generating a crisis. Reduce economic growth by 4 notches. Modify the sub-variables (opening the dropdown menu) of consumption by 10% in oil, coal, and natural gas use. A side effect of the pandemic increases ecosystem well-being: the "Afforestation and Reforestation" sector is increased by 1 notch for free.	Artificial intelligence escapes human control and takes over the codes of nuclear warheads, deactivating them forever. Wars decrease, trade increases and the prices of many goods decrease. You have 5 more coins to spend in your budget.

Table 5.1 A selection of two wildcards for each uncertainty embedded in the climate change discourse: aleatoric uncertainty (red), reflexive uncertainty (blue), and epistemic uncertainty (green).

The full list of cards and game rules are available at https://zenodo.org/records/13820082.

5.4.6 Lesson 6: FyouTURES: how to build sustainable futures

In Lesson 6, the students played the board game F*you*TURES.
I now briefly present its structure and design.

F*you*TURES is a game that Francesco and I created during the course to respond to the need to create an activity that could give students the opportunity to reason on all the concepts discussed during the course.
The main idea was to create an activity that would focus on different areas:

- Navigating uncertainty and complexity in decision-making;
- Creating sustainable future scenarios;
- Using real data and projections to make informed decisions;
- Imagining new ways to represent and visualize possibilities.

To reach this goal, we merged different ideas and insights from different worlds.

The basis for the scientific data comes from the simulator En-ROADS due to its capability of representing live projections of possible future worlds through an intuitive, accessible and easy-to-read webpage (https://en-roads.climateinteractive.org/scenario.html?v=24.11.0, last updated version 13 November 2024).
The first idea was to create an activity that could give the possibility of imagining possible futures. To address this aspect, we thought about shaping the activity in three rounds, moving from today to 2100, using 2030 and 2050 as target years to determine the end of each round.

The inspiration behind the game board comes from the book "Terra Forma: A Book of Speculative Maps" by Frédérique Aït-Touati, Alexandra Arènes, and Axelle Grégoire (2022), already described in the previous section. We focused here on the need to represent an object that could change in time and could include the possibility of representing different scenarios.
To do so, we started developing the game's mechanics using the structure of the En-ROADS simulator. The simulator is divided into five macro-categories: energy supply, transport, buildings and industry, growth, carbon dioxide removal, and other sources of greenhouse gases.
As visible in Figure 5.15, each category has different dimensions on which it is possible to work.
Each dimension represents a different element, like, for example, coal and oil in the energy supply one, electrification in the transport macro-category, and deforestation in other sources of greenhouse gases.
Starting from these dimensions and categories, we created our own sectors by grouping these elements by theme. By doing so, we created six main areas:

- Conventional sources of energy (coal, oil, natural gas, bioenergy);

- Emission control (carbon price, agricultural emissions, technological CO2 removal, waste and leakage);
- Green areas (nature-based, deforestation);
- Energy efficiency (transports, building and industries);
- Electrification (transports, building and industries);
- Green energies (renewables, nuclear).

We therefore thought of organising groups of six students, so to create a sort of ministry with the goal of creating sustainable futures.

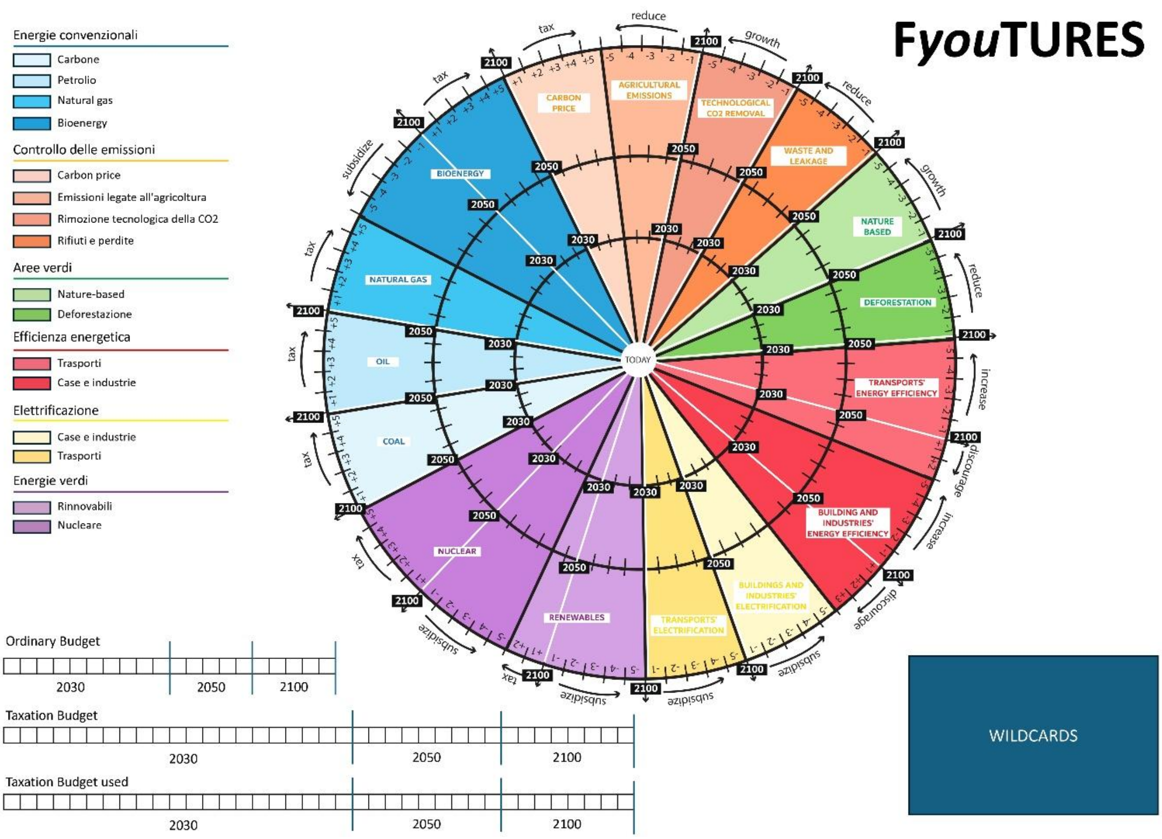


Figure 5.15 Board of the game F*you*TURES

At this point, we thought about creating a mechanic that would allow the students to build their scenarios with a sense of reality to represent the complexity of making decisions on issues like climate change.

To do so, we introduced two mechanics: the budget and the wildcards.

The need for a budget derives from the necessity of considering possible solutions to today's problems with a clear idea of what can actually be done in terms of resources.
We divided the budget into two parts: the ordinary and the taxation budgets. I report some details of the functioning here:
- The ordinary budget is given at the start of each of the game's three rounds, while the taxation budget can be obtained through the choices made in the game.
- To earn the taxation budget, students should increase the taxes in the simulator.
- Both budgets could be spent by increasing the incentives on specific sectors, representing the idea that sustainable choices have an inner cost, where the word cost is not only tied to the economic aspect.

- The budget was made of non-better-specified coins. Each coin corresponds to moving the sliders of one unit, where the units were calculated by dividing the maximum range of each slider by 5 or more, depending on its dimensions.
- The range of possible moves increases throughout the game.

All the rules can be found on the official rulebook published in Zenodo, accessible at the link: https://zenodo.org/records/13820082.

The need for wildcards derives from the fact that the simulator creates unique scenarios for each choice made, creating a sort of deterministic development for each action. In this way, the inner complexity and uncertainty rooted in scenario-making would collapse into a specific pathway.
To avoid that, we introduced the wildcards created in Lesson 5 to the students. At the start of each round, students were asked to draw three wildcards out of the 16 cards set and then act accordingly in the game. Each wildcard is connected to a different type of uncertainty and describes a specific event that influences the students in their decisions. The wildcards are also useful for creating the scenario from a narrative perspective.

Also, answering to a requests of the students to avoid a fixed scenario of economic development, we gave them the possibility to play in two different ways: economic growth or economic de-growth. At the start of the game, students decided which version they would play. The two versions differ in two aspects:

- in the growth version, students were forced to invest a specific amount of the budget in the slider "economic growth";
- in the degrowth version, students didn't have to increase the voice growth, but started with a reduced budget.

At the end of each round, students were asked to consider the type of world they were creating and reason about the specific characteristics of their scenarios.

5.4.7 Lesson 7: restitution

In the last lesson, we asked the students to present the scenarios they had created while playing.
Each group presented their work using the screens of the simulator through the rounds and described the type of world they ended up building.
We asked each group some questions about their play, the group dynamics, their main strategies, and their thoughts on the final scenarios.

At the end of the lesson, we asked them to fill in the same questionnaire administered in the first lesson to compare the process during the course.

5.5 Overall picture of the course

As just described, the course has been designed and implemented to unpack and describe how and why uncertainty must be considered when dealing with climate change education.
Specifically, we shifted the focus in the course according to the four-level scheme described in section 5.2.2.
In the first part of the course, the concept of uncertainty has been addressed from a disciplinary and practical perspective, showing how physics and climate sciences treat and work with it.
Along the course, we then moved through the different layers of the scheme to provide examples and insights on how to use uncertainty thinking to understand how science works and to make decisions to inhabit and act in risk society.

As can be seen in Figure 5.16, the second layer was present in almost every lesson. We consider this aspect very relevant. By understanding how uncertainty enters the scientific process and, most importantly, why science must deal with uncertainty and not only aim to solve it, we can have a clearer, genuine, and honest perception of scientists' work.

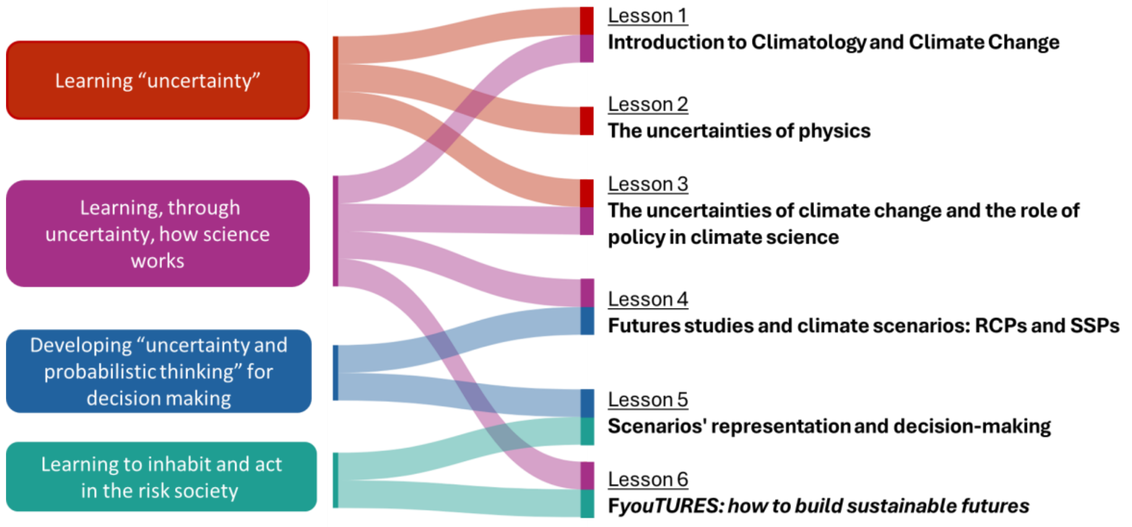


Figure 5.16 Description of how the four levels of the role that uncertainty can have in science education have been distributed along the course.

In this way, when the phenomena itself is still under study, like climate change or COVID-19, it is possible to have informed responses on scientists' take and positionings, knowing that there is an underlying uncertainty that cannot be avoided. To resume this positioning, the idea is to dismantle the image of scientists as messiahs and consider their results as the truth, but to present them as experts working to produce knowledge with the lowest level of uncertainty.

Chapter 6. Analysing the impact of the course

After presenting the approach and the design of the course in Chapter 5, I now present the research conducted during my third and last year of PhD using the data and the experience collected during the course.
The course was implemented between October and November 2023, so I spent a good portion of the last year of my PhD working on those data together with Francesco.
This chapter is divided into three main parts. In the first part, I present the type of data collected during the course and the approach used to analyse them. Here, I also explain why we decided to proceed with a certain type of data collection and analysis, an aspect connected to the very nature of the course and central to the considerations I will make later.
During the analysis phase, we realised that many different aspects emerged connected to the approach and the game. Sections 6.3 and 6.4 discuss the emerging results related to what images of science emerge from the course, how sustainability entered the discussion, the connection between science and policy, and aspects connected to decision-making, awareness, and agency.
Another emerging aspect, less expected than the others, is related to the study of extreme events and their impact on the personal perception of agency. Although the data used for the analysis are the same, I dedicate a different chapter to this analysis due to a specific need to reposition the study with respect to the approach. This analysis is discussed in Chapter 7.

6.1 Data collection

The data collected during the course are diverse, both in aim and in nature.
Some aspects to explore were already clear before starting the course, while others emerged during the implementation.
During the course, we collected data through two types of questionnaires (sustainability competences, first and last lesson; futures perception, during the fourth lesson) and by recording all the lessons and the group activities.
At the end of the course, we asked students if they wanted to participate in a final data collection moment, i.e. semi-structured individual interviews. 9 students agreed to take part.
Francesco and I have conducted each interview, and on some occasions, Prof. Levrini has also participated.
I present now the structure and the specifics of the different data-collection moments.

6.1.1 Sustainability competences questionnaires

The sustainability competences questionnaire is composed of two different parts.
The first main set of open questions asked students to write a small story about an event connected to climate change tied to their personal experience and describe it.
A second set of questions was shaped around the twelve GreenComp competences. Each question aimed to gather information on how each student perceived a specific aspect of GreenComp related to the event described. Students were asked to answer by inserting a number from 0 to 10, moving between two extremes. The number 10 represents the level of perception that the problem mentioned in the story is deeply related to the described competence, while the number 0 represents the opposite. I report a couple of examples for clarity in Tables 6.1 and 6.2

Competence	Systems thinking
Competence definition	To approach a sustainability problem from all sides; to consider time, space and context in order to understand how elements interact within and between systems.
Question	Regarding your story, how do you perceive your ability to consider the variables of the problem?
Option = 0	I cannot get an overview of the problem
Option = 10	I feel capable of understanding the interaction between the various elements of the problem

Table 6.1 Description of the question regarding the competence “systems thinking”.

Competence	Individual initiative
Competence definition	To identify own potential for sustainability and to actively contribute to improving prospects for the community and the planet.
Question	To address the problem described in your story, how much do you think your individual actions can contribute?
Option = 0	Not at all
Option = 10	Very much

Table 6.2 Description of the question regarding the competence “individual initiative”.

The aim of the questionnaire was to collect personal stories on the climate change perception of students in their daily lives and their personal perception of the sustainability competences needed to deal with that issue.
This questionnaire was administered in the first and last lessons to see if students changed the description of the story and the sustainability competences personal perception.
The data collected with this questionnaire have been used to organise specific interview questions.
32 students participated in the first administration, while 23 participated in the last.
This “drop” is due to the fact that attending the last lesson, the restitution one, was not mandatory. Therefore, some students decided not to participate as they already achieved their required credits.

6.1.2 Futures questionnaire

The second questionnaire was administered in lesson 4 before introducing the concepts connected to the field of future studies.
The questionnaire includes three main open questions:

- What is your image of a future 25 years from today?
- What is your image of an ideal future 25 years from today?
- What decisions, choices and actions should be made to reach your ideal future?

This brief questionnaire aimed to collect information on the differences between the students’ visions of the future, distinguishing between “business-as-usual” and “ideal.”
We wanted to collect this data at this point in the course to see if and how the discussion of futures studies’ methods and ideas influenced students' perceptions of the future.
The data collected with this questionnaire, as for the first one, have been used in the interviews. 26 students participated in this data collection.

6.1.3 Recordings

After asking the students for permission, we decided to record the audio of each lesson to keep track of students' interventions throughout the course and some specific activities.
After a confrontation with Francesco, we decided to record the audio of the following moments:

- wildcard creation in lesson 5;
- gameplay in lesson 6;
- restitution in lesson 7.

Starting from the first of these three moments, we asked students to form five groups of six students each, as the number of students for each lesson was stable at around 30.
Each of these three recorded activities was carried out in the same groups. Therefore, for the following analysis, I will refer to them as G1, G2, G3, G4, and G5.
Due to a technical malfunction, the recording of the gameplay of G4 has been lost.
Also, G5 decided not to participate in lesson 7, so we do not have the oral presentation of their gameplay.
The wildcard creation activity lasted around one hour for each group, while the gameplay lasted three hours. Each restitution was around 15 minutes, plus a final open discussion. Among the interventions made during the lessons, we identified around three to four hours of interesting conversations.
The quality of the audio recorded during the lessons was low due to the closeness of the groups and the distance with respect to the microphone. Nonetheless, we managed to transcribe the passages we considered interesting for designing the interviews.
Overall, we gathered almost 22 hours of recordings from the course, most of which have been used to shape the interviews.

6.1.4 Gameplay Report

At the end of each gameplay, we asked students to collect information from their "simulation" in a short report.
In the report, students were asked to keep track of the evolution of their scenarios for each round by including a screen of the En-ROADS situation in 2030, 2050, and 2100. We also asked them to discuss the type of worlds they were building during gameplay and to include a description of the influence of each wildcard.
All the groups produced this report and discussed it in lesson 7, except G5, of which we only have the written report and the gameplay recordings.

6.1.5 Interviews

As said above, at the end of the course, we asked students if they wanted to participate in a dedicated moment of sharing and analysis of the course experience. In a first moment, 14 students expressed their interest in participating in this final moment of data collection.
When we invited these students to participate in the interviews, five said they were unfortunately too busy with school exams. Therefore, we were able to interview nine students. These students represented the groups G1, G2, G3 and G4, while we have not been able to interview students from G5.
The interviewing phase lasted from the middle of December until the first weeks of January. We conducted nine interviews, each lasting between 80 and 120 minutes, for a total of 900 minutes.
The interviews were structured into 6 sections:

- Introduction
- Sustainability competences' questionnaire
- Futures questionnaire
- Uncertainty

- Gameplay description
- Identity

The goal of the interviews was to explore the effects that the course had on the student's perspective regarding:

- Their idea of climate change before and after the course;
- Their idea of physics and science before and after the course;
- Their sense of agency and hope towards the future;
- Their level of understanding of uncertainties in science and the effects of this discussion on their positioning towards science.

Each interview has been personalised according to the answers to the questionnaires, the gameplay recordings, the reports, and the eventual interventions made during the lessons.
The final structure of the interviews comprised 26 questions.
The idea behind the structure of the interviews was to allow both Francesco and me to gather relevant data for our theses due to shared interests and purposes.
For this reason, the last section of the interview appears far from my research foci. Instead, it matches the goals of Francesco's thesis, which focuses on how physics can activate students on an identity level (De Zuani, 2025).

6.2 Methods of data analysis

We started analysing the written data (questionnaires and game reports) during the course to get an idea of how students reacted to the content shared and their perceptions. To do this, we mainly used Google Sheets and Microsoft Excel to put all the data in one place and confront them.
It is important to stress that no data reported personal or sensible information and that we only kept track of the names to have the possibility to confront the answers and to prepare the personalised interviews.
I refer to them in the following chapters using the code S followed by a number. Numbers 1 to 9 are assigned to the students who participated in the interviews, while other students from the course are eventually numbered with 10, 11, etc.
We used the software NVivo to analyse the recorded data from the group activities and the interviews. We used the software to transcribe the recordings and then code them.
We used a qualitative approach to analyse the data, due to the nature of the data collected and the aim of our research. Specifically, we opted for a reflective bottom-up thematic analysis (Braun & Clarke, 2006, 2012).
First, we identified general themes from conversations with students during the course and the main emerging themes from the questionnaires. This helped us disclose some clues about the learning dynamics that occurred over the course. The themes were then refined and defined through researchers' triangulation and transformed into operational codes to be used in NVivo.

These themes were then used to code the nine interviews, with sentences as basic elements of analysis. The first phase of coding was conducted independently by Francesco and me in a double-blind process. After this phase, we discussed our coding (Morrissey et al., 1974) until we reached a final agreement. Although the coding was aligned in many cases, a relevant part of the analysis needed a confrontation. In those cases, when coded sentences were assigned with different themes or just coded by one of us, they have either been confirmed in one of the original assignments or recoded to a new theme. At the end of this two-round process, we reached a full agreement on codification.

The whole analysis was realised together with Francesco; therefore, I mostly use the pronoun "we." This analysis has been used to write two different articles that are currently under review.

In the following, I present the two studies that I led as part of my PhD thesis, being framed with the research theme of climate change education. On the same corpus of data Francesco carried out other analyses, focused on students' epistemic emotions and identity, reported in his PhD thesis (De Zuani, 2025).
The two studies related to my thesis are focused on analysing students' processes of scenario building enacted during the game and on students' reactions to the whole course.
In the following report of the first study (§6.3), I first provide a picture of how groups G1, G2, G3, and G4 approached the game. The picture has been built by analysing the data collected through the recordings, the restitution, and the interviews. In the picture, I also illustrate how students reacted to their scenarios by recalling transcripts from the final lecture and the interviews. Then, I present the strategies' analysis by characterising them in terms of types, values and other factors at stake during the gameplay and how they informed the scenario-making.
As for the second study (§6.4), I focus on the main themes that emerged from the interviews and that have been coded as previously described.

6.3 Findings: Students' game strategies in scenarios building

6.3.1 Picture of students' strategies in scenario building

Each of the four groups came up with their own unique strategies to tackle the assigned goals and navigate the various challenges presented by wildcards.
Two groups embraced the degrowth economic model because it negatively impacted global warming and sea level rise in the En-ROADS simulator. A third group chose degrowth based on their core values, while the fourth opted for economic growth to focus on advancing technological development.
Students mainly concentrated on taxing coal and oil as energy sources, focusing less on natural gas. However, some groups had to revise these taxes due to the economic impacts of the wildcards. Wars and financial crises pushed certain groups to reduce their energy conversion initiatives, leading to a decline in conventional energy taxes. They allocated nearly equal investments in renewable energy and nuclear power, yet their spending on transportation energy efficiency was minimal. Furthermore, students prioritised investments in building efficiency over electrification. Regarding green initiatives, they focused largely on reforestation while neglecting actions in the deforestation sector.
The carbon price was certainly the most adopted solution to mitigate global warming and sea level rise, and it can be used as a key to gaining insights into the rationale behind groups' game choices. Two groups, in particular, decided to push the carbon price over the rounds to the highest value, as they realised it was the most efficient slider in reducing global warming and sea level rise. In the last round, one group saw a significant carbon price but began considering the potential social inequalities arising from such stringent measures. Consequently, they chose to alleviate the impact by making substantial investments in technology and the renewable energy sector, aiming to promote widespread and affordable access to renewables. Another group instead was well aware of both the efficacy of carbon price for environmental parameters and the risk of social counter-effects, so they decided to initially set a medium-high carbon price level to reach a better environmental situation and then reduce it to decrease the inequalities related to this scenario. Ultimately, all groups noted moderate rises in global temperature and sea levels, achieving different success levels in capping global warming between 1.6°C and 2.0°C by 2100, with sea levels increasing from 0.5m to 0.55m.

Throughout the game, students were free to choose their own strategies to meet the specified goal without external influence or judgment. As facilitators, Francesco and I supported them when the rules were unclear.

By the end of the third round, as groups were finalising their reports, we inquired about the types of scenarios they were working to shape. Students engaged in discussions, sharing ongoing reflections within their teams regarding the repercussions of their choices. They particularly debated how their actions influenced factors not directly represented in the simulator, including economic stability, social welfare, and political dynamics security.
Throughout this phase, especially during the restitution phase, we observed that a secure classroom environment emerged as students engaged in a collective discussion about their perspectives on their own and others' situations.

For instance, some students stated that their constructed scenario was unbalanced, focusing solely on environmental aspects and neglecting social and economic considerations.

> “It is an unequal world... because we have chosen to prioritise the planet over humanity”. (S#5)

Consequently, this reflection was integrated into the scenario reports and the final collective lecture presentation. The conversation shifted the focus from the climate parameters achieved to the possible inequalities and instabilities of their scenarios.

> “What I think about the world we built was that it was a somewhat unfair world. [...] as I said before, [...] the problem of pollution was practically solved but at the expense of values… at the expense of certain human rights” (S#2)

The general feeling perceived in students’ interviews regarding their future scenarios was that they created an ideal world for what concerned the environment, but they did not take into account other aspects of their scenarios. In this case, for example, a student refers to their scenario by saying they created a dystopian world, but at the same time all the environmental aspects were under control:

> “It's a dystopian world, it would be utopian if everyone could live in this world. But it's very nice, emissions are low, electrification everywhere, lots of reforestation…” (S#5)

Many of the students reported that they did not want to live in their future scenarios.
Students noted that certain actions taken during the game, particularly those deemed most effective, had a significant impact on variables like the ‘cost of electricity.’ As a result, the world they created would have only been suitable for a small portion of the population, especially the wealthiest and most advanced in terms of industry, infrastructure, and technology.

> “Yes there was the carbon price, which screwed everything up, I mean that obviously increasing the price of the carbon price, mh, increased the social gap between the rich population and the poor population. And so this generated a lot of inequality”. (S#6)
>
> “In the end, all of our worlds came from countries where like the carbon price was very high everywhere and so they were basically pseudo-dictatorships, where the democratic aspect was not considered very much”. (S#2)

To this extent, it is interesting to notice how all the groups and almost all the students were surprised by the misalignment between the values behind their strategies and the scenarios created.

We borrowed the term 'reality shock' (Dean & Wanous, 1983) to describe the discrepancy between students' expectations of being able to address climate issues and the feeling of grasping the inner complexity of socioeconomic challenges related to climate change and decision-making. The term has been firstly used to describe the reaction that newly graduated nurses had once entered the hospital.

This feeling happened at different times. For some groups, it happened spontaneously during the game,

> "But in the first round, when we did the graphs on En-ROADS, we saw that there had been a spike in the price of conventional energies, which was actually a problem that we had to solve, so let's say that in some way they had seen that there was an element that was influencing society a lot, but we didn't immediately link it to an actual social problem. It was only when you asked us to think about it that we really defined it as it actually was and not just as an economic problem". (S#9)

whereas for other groups it was triggered by our questions and the final discussion:

> "It is a world with a lot of economic disparity, with a lot of differences. We didn't even think about this side of the game initially, we were asked the question at the end [of the gameplay] and we realised". (S#8)

We also asked them if they would have changed their game strategy after the "reality shock". Even in this case, all the students mentioned that they would have changed their game strategies, saying that in a possible following iteration they would have invested in other solutions rather than, for example, increasing carbon price to that level.

> "Yes, I would definitely do it differently. I would do it with more, precisely, awareness [...] I would certainly be more careful also of all the parameters that would create social inequalities, mh, and I certainly don't know if I would achieve [...] the goal because actually, without taking into account the increase of the carbon tax, I don't know if it would have been so easy [...] But I would definitely do it differently. Because in the end what we had created was not our ideal world". (S#8)

In the analysis of groups' scenario-making we also considered how single individuals may have affected the gameplay by orienting the group choices. We noticed indeed that in two groups in particular there were some participants more active than others. Nonetheless, when analysing the recordings, we found out that the choices made at the end were more influenced by the participants' opinions than by intra-group dynamics. This can be seen by looking at how the strategies suggested by the most active figures in the two groups mentioned were nonetheless always evaluated by the whole group, and sometimes even rejected.

6.3.2 Scenario-building analysis

6.3.2.1 Making decisions without a systemic view

From the qualitative analysis of the groups' gameplay recordings, the scenario reports, the collective discussion and the individual interviews, it was possible to identify some trends in the ways of making decisions and developing scenarios.

Three groups showed similar characteristics in the way they played. All these groups chose to play with the mode of economic degrowth, as for them it was more compatible with an idea of respect for the environment. For all these groups, the reasoning strategy used in the game focused on the impacts of possible choices with respect to temperature and sea level values, bypassing discussions on possible consequences in terms of social impacts, equity or equality.

The first one shifted strategy once they became aware of the possible social inequalities derived from their choices. Thus, they decided to push for measures aimed at achieving economic and social equity by investing in renewable energy.

> "Since we have been clipping the wings of these countries by taxing the most affordable energy, we finally thought (with an eye on society) to invest in renewables, so that developing countries could also develop". (S#1)

The second group adopted a utilitarian perspective, focusing their investments on sectors with the greatest influence on temperature. Despite having leftover funds at the end of the round, they opted not to invest in additional sectors. They finished the three rounds ahead of the others, so they had more time to work on the final report. During this period, they engaged in discussions about the ramifications of their decisions, recognising the signs of social and economic crises.

> "So yes, the thinking, in the end, was that the scenario was sustainable on a natural level, so on the level of temperature and sea level, but not sustainable on a social level because there would be just too much inequality and in the end it would not be an ideal world, [it would not be] a future that even we would ideally like." (S#6)

Another group mainly focused on the mitigation of climate change causes, such as pollution from non-renewable energy sources and deforestation. What emerges from the analysis is that this group aimed at reaching the goal without considering the social impacts of the actions taken. For example, in the following excerpt, it is possible to see how students first identified which slider was the most effective for global warming reduction and then decided to invest heavily in this one, without weighing the consequences of this action.

> S#2: 'What does it affect a lot?
> S#10: Oil and coal, they affect a lot...
> S#11: So let's put two… Put 2 on coal
> S#12: Maybe if we have more left over, let's invest 3 or 4 [coins]
> S#4: I'll put 2 on oil and 3 on methane
> S#11: I'd make it 3 on methane

This group did not consider dimensions other than environmental ones until the final discussion of the reports. Here, together with the other students, they proceeded to evaluate their scenario according also to other aspects, such as the ethical ones.

At the end of the game and during the last lesson, when the students presented the reports produced in front of their classmates, a debate emerged between students regarding the groups' scenarios and the choices made. The students asked each other questions, referring to the similarities and differences between their ideal futures, the scenarios created and the SSPs. In this sense, the peer discussion helped in disclosing specific reflections on a general level, and this led other groups to discuss issues that had not been treated before (as for the last group).

To conclude, these three groups demonstrated similar aspects during the game phase:

- efficacy-based criterion: evaluation of the sliders mainly for their efficacy with respect to global temperature reduction;
- cause-oriented approach to sustainability: predominance of mitigation actions focused on the environment, without the consideration of impacts on the society or economy;
- "late" reality shock: the acknowledgement of the misalignment between initial values and created scenarios once the game ended.

6.3.2.2 Making decisions with a systemic view

The fourth group applied different reasoning strategies compared to the groups described above.
This group is the only one to have chosen an economic growth model (instead of degrowth). They motivated this decision by saying that they wanted to invest heavily and immediately in technological research to achieve technological breakthroughs as soon as possible.

Through the analysis of the gameplay recording and through the interviews of students from this group, we noticed that, in this case, students actually pondered the collateral consequences of each action throughout the whole play. For example, students described how the scenarios related to 2030 and 2050 were characterised by an economic crisis lasting more than 30 years, leading to social inequalities. and other consequences.

> "As can be seen, for 2030 the price of energy has risen dramatically even if the climate targets are met, but for 2100 and actually after 2030 the kilowatt/dollar energy price has fallen dramatically. By 2050 it is back to the normal level of 2023. [...] There has been a period of great suffering for the people but the end has been more than good. Everyone is well, it is almost a paradise on earth, the climate problem solved". (S#3)

When asked about this choice, the students defended their positions by pointing out that at the end of the game, the initial tax increase had positive effects, as the price of energy had dropped dramatically by 2100.

> "The future world of 2100 suffered severe economic environmental and social crises. There was an in-between period that was characterised by severe economic and social crises [...] However, the extreme consequences led to the achievement of the goals". (S#3)

From a social point of view, the group was aware that certain actions had a very harsh effect on the population; therefore, they agreed already not to increase the carbon price after the second round to avoid further crises. Hence, they decided to prioritise the environmental aspects but were aware of other dimensions and tried to make up for them as much as possible.
Thus, even though the scenario created has similar results to the ones obtained by the other groups, there is a noticeable difference in awareness of the choices made and considerations of the issues at stake.
This group showed that it used systemic and critical thinking as strategies to approach the game. They systematically considered the multiple dimensions of the issues and their mutual relationships, questioning a basis of linear cause-effect dynamics. They carefully analysed the implications of the choices and made decisions by comparing and balancing conflicting values.

6.3.3 Discussion of the results

The comparison of the main strategies used by the groups to reach the goal of the game shows two main aspects.

The first one is a general tendency to embrace a reductionist and “solutionist” approach. Students’ effort was mainly devoted to optimising the strategy in search of a quick solution to the task. This optimization often involved isolating the different dimensions of the problem, disregarding the choices’ effects, and favouring cause-oriented strategies that prioritized problems’ mitigation while undermining socio-economic implications.
Many students ultimately created dystopian scenarios where temperature goals were quickly met at the expense of severe socio-economic inequalities. This outcome highlighted the risks of focusing solely on macro variables, such as temperature and sea level rise, and reducing sustainability to an environmental issue.
The course and, specifically, the game experience encouraged students to confront the limitations of classical views on problem-solving, illustrating how complex issues like climate change demand more than simplistic or monodimensional approaches.

The second aspect is the game's potential to unveil the complexity and multidimensionality of the issues at stake. They emerge either as “reality shock” after the scenarios are built when the students follow a reductionist approach or as part of the game when the students use systemic and critical thinking as game strategies.
The course and the game provided participants with an opportunity to explore the complexity and intricacy of sustainability and climate change decision-making, highlighting the interconnectedness of social, political, ethical, economic, natural, and technological factors.

What emerges from the interviews is that students appreciated the scenario-building exercise of the game, as it has been perceived as an opportunity to explore, even if through a simulation, “how the world works." They also recognised the intricacy of the climate issue, which encompasses social, political, ethical, economic, natural, and technological factors. These results align with our aims, in that we intentionally created the game to incorporate all these dimensions, highlighting the depth of "sustainability."

As discussed in a paper written together with Olivia and Francesco (Miani et al., under review) for a special issue on the role of new technologies and artificial intelligence in education, the En-ROADS simulator's role in the game must be specifically mentioned.

During gameplay, students initially approached the simulator as a straightforward tool, focusing primarily on reaching environmental goals without integrating social or economic factors. This approach reflected a persistent classical mindset: the tendency to see problems as technical or quantitative challenges rather than complex socio-environmental issues intertwined with ethical implications. Their inclination to view the simulator as a neutral instrument highlighted a common detachment between facts and values, whose connection is instead emphasised by post-normal science (Funtowicz & Ravetz, 1993) as necessary to address complex, value-laden problems.

At the same time, as observed during the implementation of the game, we noticed that the game’s inherent complexity was sufficient to accommodate reasoning patterns essential for addressing multifaceted challenges, and the structure of the game enabled students to think together and engage with climate change as a complex phenomenon. The final outcome of their scenarios showed how the construction of a desirable scenario was not a matter of reductionism but required grappling with interrelated values and issues, reflecting the non-separability of the three sustainability pillars (Purvis et al., 2019).

Our interventions aimed to reposition students to engage more critically with the tool, not merely seeking solutions but reasoning with and through the simulator to frame the problems and unfold them. This collaborative peer positioning is crucial, as it can promote open-ended ways of questioning and reasoning, allowing students to question the attitude to deal with wicked problems as they were complicated but solvable problems. By placing the simulator in a peer-like collaborative dynamic, the experience underscored the value of grappling with complexity, as opposed to eluding it.

This critical stance requires students to consider the tool as part of the problem, avoiding an ethically neutral approach and recognising that addressing sustainability issues involves engaging with conflicting values rather than delegating solutions solely to quantitative outcomes. This process encouraged students to understand that a systemic, ethically aware perspective is necessary for meaningful engagement with climate change.

In conclusion, the game experience provided an example of how a reflective, systemic approach to sustainability can be fostered through futures-oriented science education. This type of educational approach has potential beyond the classroom, contributing to developing a mindset suited for addressing complex, value-laden challenges in society, thereby fostering a mature understanding of sustainability through uncertainties and complexity.

I also recognise that the game has several limitations, which we are currently working on. First of all, the simulator is based on a specific economic model - the one currently in force - in which it is difficult to enact radical changes to achieve alternative futures. The “de-growth” option introduced by us is also not properly responding to the definition of economic degrowth due to the fact that, even when reducing the rate in the simulator, the variables are still connected to economic growth in time, even if at a slower rate.
Another aspect worth to take into account is that in the simulator there are only a few options for modelling human behaviour. We are now in the process of refining some aspects of the game, such as enhancing the narrative dimension to work more on the social pillar of sustainability.

6.4 Findings: Students’ reactions to the whole course

To point out the main reactions to the whole course, we articulated the analysis in two phases. We first carried out a bottom-up thematic analysis on the interviews to address this research question: How did the course impact students' views of climate change and of decision-making processes related to the issue?
The data analysis led us to point out four general themes that emerged as main areas of impact. The results of this phase are reported in section 6.4.1.
Then, we searched for a way to visualise how and to what extent the students talked of the themes throughout the interviews (section 6.4.2). This process of visualization allowed us to point out sub-themes that unveiled patterns of evolution in students’ thinking throughout the course (section 6.4.3).

6.4.1 General themes emerging from the interviews

6.4.1.1 Awareness of the complexity of science and climate change

A first theme that emerges from a bottom-up analysis of the data is a change in the way students perceive science, and the scientific process. I report here two cases in which students reflected on the change in their conception of what science is.

To be neutral in the description of the excerpts, I use the pronouns they/them to talk about students' perspectives and reasonings.

In S#4, the student acknowledged that prior to the course, they considered climate change a serious issue they were part of, yet felt it wouldn't impact them personally. When asked what shifted their perspective, they mentioned that the first lesson featured a map illustrating how Italy would face significant consequences from rising temperatures, emphasizing the necessity for preparation against future disasters events.

This realisation forced them to enlarge their vision towards climate change, opening to a multi-dimensional way of thinking.

> "Let's say that I, thinking just in the abstract about the climate phenomenon, was thinking more about the mitigation aspect and less about the adaptation aspect. Now more 50 - 50 [...] because I saw it more as a quote-unquote dimension, as a provincial [one], in the sense that it can have an effect perhaps on me in my small way but I didn't see it as something that, then, I couldn't really imagine it as something extended globally as to say. And instead, this one here gave me the idea that it can be obviously also in certain measures globally. I really conceived of it differently, I had never imagined it." (S#4)

For S#1, thanks to the course they changed their perspective on science. In detail, it is possible to underline how they realised that different topics in science require different approaches, in particular in terms of uncertainty in this case:

> "[...] if one deals with phenomena like climate [...] one must consider certain types of uncertainty rather than those considered when talking about quantum physics, which is not the same as using a certain instrument to measure something. There are different ways to approach different [...] aspects of science that I tended to see mostly in one way before and now I can see in slightly different aspects." (S#1)

The student noted that after completing the course, their understanding of science transformed from a singular perspective to a more diverse one. This newfound view of science, referred to as "new paths," could assist in scenarios where the constraints of standardized scientific thinking hinder our understanding.

> "However, you reach a point where even to know more you can no longer do it in the same way as before, but you have to go through this other way as well, because it's still something that always concerns our...areas of our universe, of the reality in which we live. So we can't ignore it, because otherwise we couldn't go on anyway. There would be many mysteries that would remain unsolved, but perhaps many things remain that are not known but could not be investigated without these, that is, without these new paths." (S#1)

As for this first theme, students' interviews led us to conjecture that the shift in their view of science may stem from discussions on uncertainties in science, climate change, and complex systems. Many students acknowledged that they were only familiar with one type of uncertainty—the epistemic kind recognised during the course—while their school experiences rarely addressed complexity.

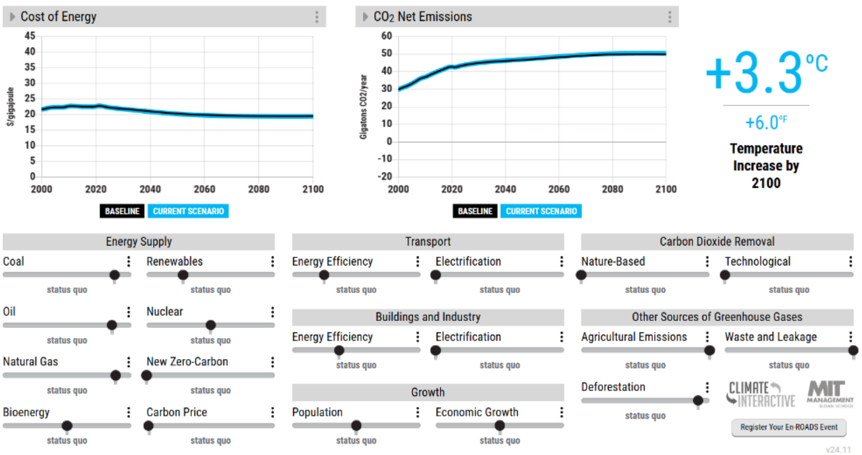
6.4.1.2 Balance between sustainability's dimensions

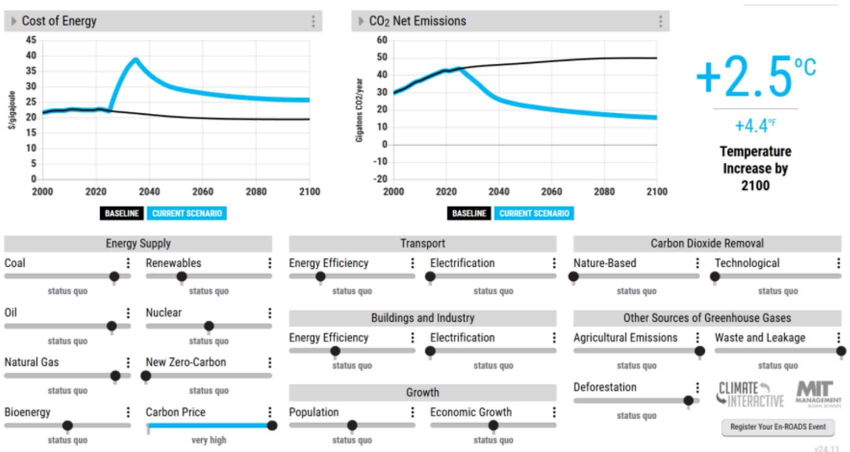
An interesting outcome from the game is that students recognized sustainability is more complex than they previously believed, and that linking its various elements is quite challenging. This difficulty emerged during the last phase of the game, when students were asked to critically discuss the type of scenario they created with their choices. Here are two examples where this issue emerges clearly.

Student S#8 describes how, as a group, they realised the consequences of their actions during the game.

> “We chose economic degrowth and after that we [...] applied all the choices but in a way to achieve the goal. We as a group didn't give much thought to how sustainable it was, especially on a global level in the sense of society, to what we were creating because we saw, for example, that the carbon tax was decreasing the temperature very significantly.” (S#8)

The behaviour mentioned in this excerpt is frequently observed among various groups that participated in the game, including in other versions. The "carbon tax" slider, due to its significant ability to affect fossil fuel energy production, has the most substantial impact on the anticipated temperature rise by 2100. Additionally, the slider’s maximum setting of \$250 per ton of CO2, compared to the current rate of \$4 per ton, can lead to considerable economic instability, as illustrated by the graphs titled "cost of energy” (Figures 6.1 and 6.2).





Figures 6.1 and 6.2 Detail of a simulation in which the only slider moved is the “carbon price” one. In the graph “cost of energy” it is possible to see a spike in the first 15 years, followed by a slow decrease. At the same time, the CO2 Net Emission graph shows a deep decrease, followed by a clear reduction of the projected increase in temperature (-0.8 °C).

Students observed that this could result in a world where only a portion of the population can carry on with their lives, leaving the remainder to face a significant crisis. Once the students grasped the impact of the slider, they changed their perspective on it and discussed on the ramifications of this high taxation.

> “We had achieved something that seemed sustainable but in reality was not so easy, so we thought it would be easy using these techniques, maybe even in reality, to achieve what we had said, so to achieve the goal and the temperatures would not rise more than a certain level, the sea [level] wouldn't rise more than a certain level. Then we actually went and looked at what we had actually created and asked ourselves the question for a moment. Then maybe it wasn't so easy, as it happened that is how we did it, to create an ideal world by also looking at this aspect that we hadn't paid attention to.” (S#8)

This moment of insight led the students to analyse the concept of sustainability differently. When we asked if they would change their decisions in a future iteration of the game, every student indicated that they would strive to consider all levels simultaneously.

> “Yes, I would definitely do it differently. I would do it with more, precisely, awareness, of the mistake I had made, so I would certainly be more careful also of all the parameters that would precisely create social inequalities, um, and I certainly don't know if I would achieve, I would be so good as to achieve the goal because actually, without taking into account the increase of the carbon tax, I don't know if it would have been so easy, you know, to achieve the goal in the end. But I would definitely do it differently. Because in the end what we had created was not our ideal world.” (S#8)

Interestingly, even though this group aimed to incorporate their values into their scenario through their chosen *economic de-growth* approach (which they proposed), they ended up creating a situation in which values like social and economic equity were undermined by a disproportionately high increase in carbon price taxation.

In another group of students, represented by S#7, we can see how the game made this difficulty in balancing the different dimensions of sustainability emerge.

> “During this course, where I became more aware of the problem and so, always regarding the game, I understood that some things need to be done in a certain way and that it's not easy to do them by only looking at the ethical side of the situation. [...] That is the protection of the environment. So stopping from one day to the next using fossil fuels, or shutting down every intensive training and stopping using planes because they pollute, those things.” (S#7)

This type of reasoning highlights an acknowledgement of the impossibility of proceeding solely with what can be seen as a simplistic solution, in this case taking into account only the ethical side, and a subsequent realisation of the difficulty of pursuing a plural discourse containing all the pillars of sustainability.

> “It is a bit more complex to do than I thought before, because we saw that there would be many economic crises.” (S#7)

Additionally, the student shared that while they had previously read numerous books on the topic, the course fostered a deeper comprehension and awareness of the issue.

> “No, because before I looked at them only from an ethical point of view rather than a social point of view, and what could have happened if these actions had been implemented. So no, I never had [thought about it before].” (S#7)

6.4.1.3 Awareness of the complexity of the decision-making process

Along with understanding the complexities of the scientific process and the challenges associated with long-term sustainability, many students emphasised that the course helped them reevaluate their perspectives on the figure of decision-makers and the inherent challenges involved in the decision-making process.

This outcome can be linked to the specific design of the game, where students took the role of policymakers and utilised the data provided by the simulator. By assigning each student a particular area of expertise, they were responsible for making decisions that would affect both the group's outcome and the final scenario.

S#4 admitted that before the course and the game, they thought politicians were corrupt and only considered their interests. After the game, however, this vision changed.

> "[...] in other ways a bit changed, mainly from the perspective of those who have to make decisions. Maybe trying to put myself in their shoes a bit, to understand why they made certain decisions instead of others that perhaps from the point of view of climate change would have had more effect." (S#4)

As the interviews were realised during the 28th United Nations Climate Change Conference, or Conference of the Parties (COP28), we inquired whether their perspectives on the themes shifted based on what they had learned during the course.

> "[...] I didn't follow it, I heard before that they were talking but I didn't follow much of what they were saying, so I don't know. But I know that the Arab countries have already given the okay to reduce the use of coal and so this is a good thing, but at the same time, maybe if they had said no, I would have tried to understand a little more the reasons why they said what they said." (S#4)

S#1 responded differently to the same question, voicing their fatigue regarding the numerous news reports about unsustainable choices

> "I know that in the end there was... that on some things it was a failure because they actually ended up making agreements on oil, and when I heard this, I felt like saying 'No, enough, I don't want to hear anything anymore,' it didn't make me want to know more but to say 'Let's just leave it' and so on." (S#1)

The student noted that while they found the agreements at COP28 engaging and understood the efforts involved, they perceived the experience as largely chaotic or merely informational. They acknowledged that even though decision-making tools exist, their effective usage is inconsistent. To emphasize this, the student shared how their viewpoint shifted dramatically, coming to understand the deep interconnection between science and politics, far beyond their initial impressions thought.

> "It completely changed my perspective, it helped me understand that in the end, these two areas are much more connected than I thought, and there are different ways in which science can communicate with the field of politics, but this doesn't always have great consequences." (S#1)

6.4.1.4 Agency and reality shock

Overall, from the study of these three themes emerges a shared sentiment among most students. The growing awareness of the scientific complexity of climate change, along with the difficulty of making sustainable choices that are advantageous not just environmentally but also socially and economically, has resulted in what we called *reality shock* (Dean & Wanous, 1983). This insight has prompted different responses from students regarding their sense of agency.

At the beginning of the course and during the first part of the game, students made decisions based primarily on their existing knowledge and personal values. However, while playing the game and participating in follow-up interviews, some students reevaluated their understanding of science and their views on sustainability dimensions, leading them to reconsider the values relevant to climate issues. This growth in a forward-thinking environment encouraged students to shift from a straightforward and simplistic perspective to a more complex and multifaceted approach.

As students reflected on the course and the game's impact, they noted that the enhanced complexity of all elements related to climate change shaped their sense of agency.

> "The spectrum of futures, the cone of light that goes to illuminate possible futures with all the possible, probable drawbacks. That [was] very interesting and also has, has also pushed me to think about my future in general, not just the future of the planet, but my own personal future." (S#2)

By applying the distinctions outlined in GreenComp (Bianchi et al., 2022) regarding individual, collective, and political levels of agency, we can identify the key actors associated with each level. This includes recognising the impact of individual daily choices, the necessity for collectives to progress to the political level, and the critical need for dialogue between scientists and policymakers to ensure informed decision-making (e.g., IPCC, volcanologists, EN-ROADS) simulator).

The increased awareness had different effects on students, leading them to take action or creating a sense of powerlessness. Some students reported that, upon experiencing this "reality shock," they felt an increased sense of helplessness, due to the increased perception of the seriousness of the situation. At the same time, in response to this initial reaction, they engaged with the issue more deeply and thoughtfully.

> "[...] there is powerlessness I think, all living beings feel towards something bigger than themselves. It's not necessarily something you have to fear, I mean you have to be aware that you can't change everything. That you are, however... that is, that your own actions, although they may have some value, cannot influence all of humanity or the whole universe. So, yes, one does feel quite powerless, but I think with respect to everything, not only with respect to climate change, and so feeling powerless is fine, but it shouldn't stop you from doing things, from trying to do things that might influence just one person." (S#2)

Many students felt that their ability to make a difference seemed limited, especially when it came to discussing the power of individual actions. However, as noted by S #3, we also observed a growing desire for change through teamwork and a positive view of what we can achieve together.

> "Now I have the conception that people, for example, if they have a general uneasiness and they report it, they show it through a rebellion, a protest for example. [...] For me, if we collaborate, the more people are on the same fact on the same concept, the more this concept is felt. For example, if there are only 10,000 of us saying yes to this, 10,000

already is not a substantial number, but 10,000 compared to 100,000 or even 1,000,000... quite another thing." (S#3)

6.4.2 Thematic coding visualisation

We decided to use a "spectral representation" for each interview to represent the coding (Figure 6.3). The process needed to create these representations has been the following.
We first created the transcript on Microsoft Excel, using a standardised width for the column related to the text. Each interview entry was placed into one cell.
An entry corresponds to a segment of dialogue in which only one speaker speaks. Therefore, each entry corresponds to the basic element of analysis.
After this preparation, we selected a palette for each of the 4 themes that emerged during the coding phase, and we painted each entry with a specific colour depending on the prevalent theme emergent from that entry. The entries that have not been coded have been left white.

In this way, we obtained a series of coloured and white cells for each interview, which is the spectrum of the interview. This process produced diverse spectra of various lengths due to the different lengths of each interview. To make a comparison, we normalised them and put one close to another in a single picture (Figure 6.3). In this way, we aimed to provide a way to give back a sense of the themes' distribution within and across the interviews.

Some entries, vertical lines in the spectrum, have a larger width than others, depending on the length of the dialogue segment.

Figure 6.3 Spectra of the interviews, in which we highlighted with different colours the moments in which the students talked about one of the four themes.

The spectra displayed show that the themes are present in all the interviews, although their distribution is uneven.

There are some similarities in how the four main themes in the interviews have been covered and addressed by students in the interviews. In order to search for these patterns, a more fine-grained analysis has been carried out. The second-order analysis resulted in the finer categorisation reported in Table 6.3, where we specified a series of subthemes for each main theme, for a total of 10 subthemes.

Theme	Subtheme	Definition of the subtheme
Image of science and climate change	Naïve vision of science and climate change's inner complexities	Moments when students show or acknowledge their naïve view of science and climate change.
	Awareness of the complexity of science and climate change	Moments when students express how the course and the game helped them recognise the inherent complexity of climate change, highlighting a shift away from a simplistic and linear view
Sustainability dimensions	Naïve approach to sustainability	Moments when students show a simplistic and naïve view of the balance between sustainable values to achieve sustainable change
	Balance between sustainability's dimensions	Moments when students recognise that there is an inherent complexity in climate issues and the need to balance the different dimensions of sustainability (social, economic, environmental)
Decision-making and relation between science and policy	Naïveté about the science-politics link	Moments when students show a lack of trust in the political class, the motivations behind their choices and the values that guide them
	Awareness of the complexity of the decision-making process	Moments when students show awareness of the decision-making difficulty and acknowledge the need for collaboration and consideration of all the variables involved in making decisions
Agency and reality shock	Individual agency	Moments when students refer to their potentiality in the sustainability discourse and actively contribute to improving prospects for the community and the planet (Bianchi et al., 2022)
	Collective agency	Moments when students refer to the potentiality to act for change as a group (Bianchi et al., 2022)
	Political agency	Moments when students refer to their own potentiality to identify political responsibility and accountability for unsustainable behaviour, and demand effective policies for sustainability (Bianchi et al., 2022)
	Lack of agency	Moments when students refer to a sense of lack of agency in the decision-making process about sustainability

Table 6.3 Series of the themes identified from the codification, each with the corresponding dimensions and definitions.

6.4.3 The dynamic of students' reflection

The more fine-grained analysis shows some patterns in students' reflections triggered by the course. Overall, we noticed how students changed their perspective with respect to: i) climate change impacts and drivers, ii) the complexity of applying mitigation and adaptation measures and iii) the need for acting on many aspects of daily life. By saying this, and from the data collected, we are not claiming that all students improved their understanding of the issue or started to act in their daily lives, but we

can argue that most students became aware of their level of understanding and comprehension of the complexity of the issue.
This rise in awareness can be noticed in the interviews, which look more fine-grainedly at the spectra presented in Figure 6.3 according to the subthemes presented in Table 6.3. This finer analysis is presented in Figure 6.4.

When students spoke about their image of science and climate change, they reported to have shifted from a more naïve perspective to a more mature one. This dynamic, from naïveté to awareness, was also detected in relation to the sustainability dimensions and science-politics interaction. In the four pictures represented in Figure 6.4, lines with lighter and darker colours can be noticed, showing the moments in which students reflected on their awareness process.

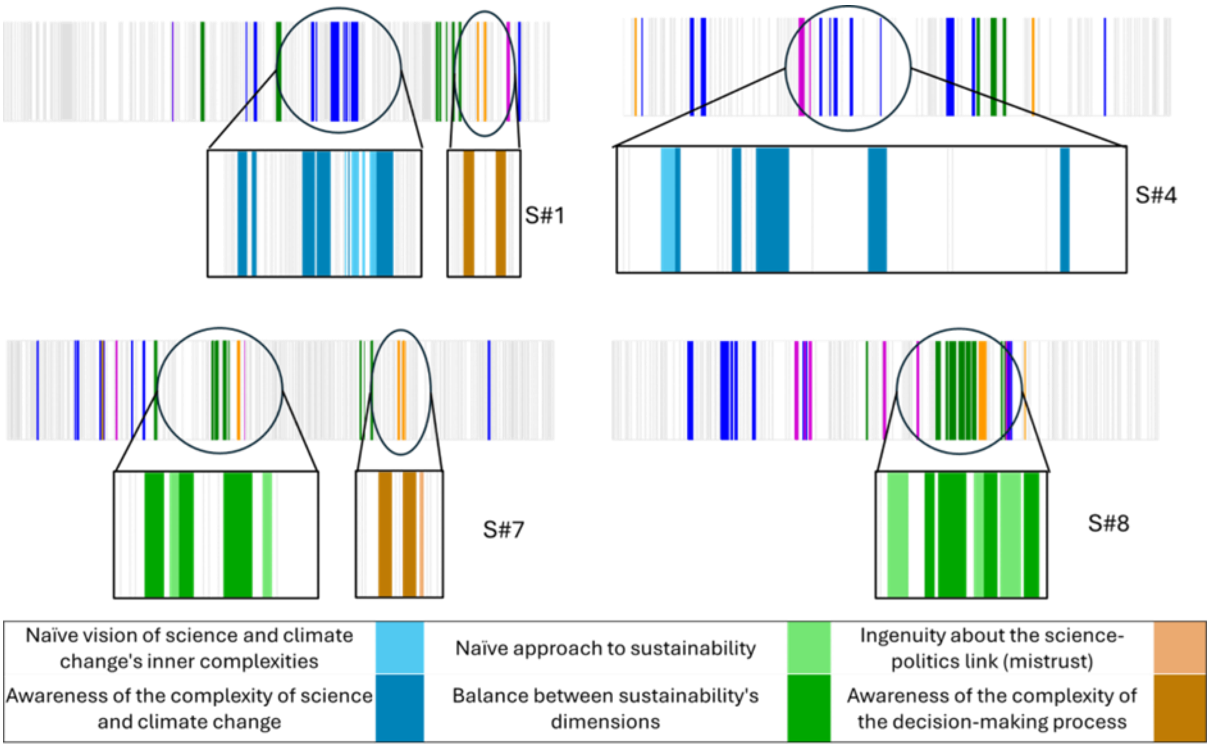


Figure 6.4 Detailed representation of the fine-grained analysis carried out on the interviews. In the circles, it is possible to see how, in each coded sequence, there is a dynamic between naive visions and awareness.

In Figure 6.4, it is possible to see in detail how students moved back and forth between naive visions and awareness regarding climate change complexity, sustainability, and the science-politics relationship. These lines are mainly connected to the moments in which students reflected on their previous understanding or positioning with respect to the course or the role of specific factors in making decisions, as experienced during the gameplay.
This increase in awareness has also been noticed in the fourth theme, connected to the agency. This theme was subdivided into four levels, whose difference was not directly linked to the level of awareness with respect to their role in the issue, but to the complexity of the sense of agency. At the same time, as has been shown in the previous sections, it emerged how the course activated students reasoning on the agency's complexity and their willingness to become more active.

6.5 Discussion of the findings

The empirical studies provide evidence-based contribution to two research themes that are nowadays very timing but so wide that sometimes there is a risk of being too vague to produce relevant reflections. The two themes revolve around the challenges of educating towards sustainability and the possible ways of using science education to promote an informed active hope to serve as a gateway for agency by avoiding harmful simplifications.
I now comment on how the findings emerging from the data analysis can provide new insights into the discussions around these two research themes.

6.5.1 Education for Sustainability

To explore this theme, it is useful to discuss the three-pillar description of sustainability (Purvis et al., 2019). Although, as the authors say, the concept of the three pillars does not have a clear origin and it's deeply tied to the concept of sustainable development, it can be used to discuss the reasonings that students put in place during the gameplay.

The three-pillar model emphasises the need for simultaneous sustainable actions across environmental, economic, and social dimensions. Together with Francesco, we considered representing this description in a graphical way, as shown in Figure 6.5.
In the image, each vertex represents a pillar (green for the environmental, blue for the social, and orange for the economic), and the trapezoids on the border represent a mix of two of the three pillars (light blue for the socio-environmental, yellow for the economic-environmental, and pink for the socio-economic). We named the centre of the main triangle "systemic sustainability," intending to underlie the necessity for systemic thinking to properly think, act, and behave in a sustainable way at all levels.

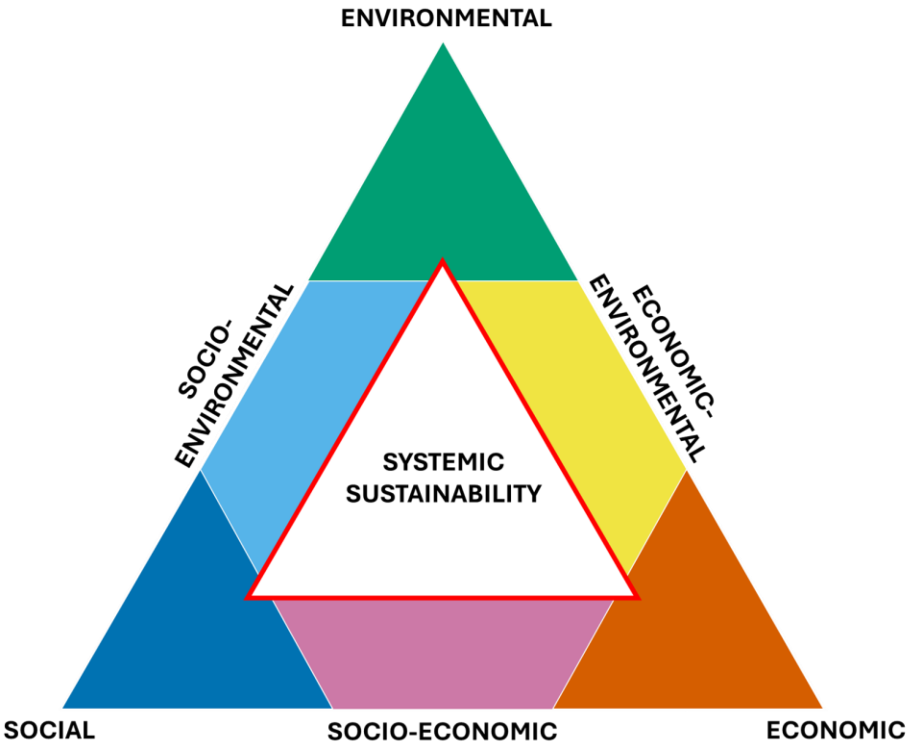


Figure 6.5 A visual representation of the three sustainability pillars.

Most of the scenarios produced by the students in the game can be positioned either in the green area or the yellow one of Figure 6.5 due to their unbalanced approach to the environmental aspects of climate change.

However, the insights gained from the reports' creation—both in discussions and interviews—helped cultivate an understanding of the factors that might result in unsustainable situations. Additionally, it emphasised the necessity of embracing a systemic approach and prompted students to consider the complexity of the term "sustainability," raising questions like "Sustainable for whom?" and "What type of sustainability?", instead of focusing on futures that perpetuate existing inequalities and disparities (Osberg et al., 2010; Barrineau et al., 2022).

In the following, I report how a student was commenting about what they defined as a "higher degree of awareness of the problems at stake" and on the influence that the course had regarding this aspect.

> "Like it happened for me during this course that I just became more aware of the problem and then also just about the game, I realised that there are certain things that have to be done in a way and that it's not easy to do by looking only at the ethical side of the situation. [...] So to stop using fossil fuels overnight, or to stop all intensive training and stop using planes because they pollute, these things here. [...] it's a little bit more complex to do that than what I thought before". (S#7)

Embracing complexity in building future scenarios impacted also the development of awareness in the other two areas of the GreenComp (embodying sustainability values and promoting actions): i) it helped participants appreciate the complexity of policy negotiation due to the many non-conciliable values presented by various stakeholders; ii) it underscored the necessity of considering both social and environmental justice (Mohai et al., 2009) values in our individual, collective, and political actions; iii) it engaged the students to explore the impacts of climate policies and understand the importance of weaving social and environmental justice into our decision-making (Rasa & Laherto, 2022); iv) it opened doors for personal growth, allowing students to shift from a simplistic and extreme idealist perspective to a more nuanced and multi-dimensional understanding of socio-ecological issues, using uncertainties to navigate different levels of agency (O'Brien & Sygna, 2013).

6.5.2 Informed Active Hope vs. Harmful Hope

Based on the results presented above, we considered framing the analysis using the concept of hope. Hope is typically considered a fundamental driver of actions (REF), but it can be also the gateway for blindness. For example, Ojala (2012) states that the concept of hope, particularly concerning a perceived better future, possesses positive attributes, like its capacity to motivate action and research toward potential solutions. However, it also poses risks of being harmful, particularly when associated with wishful thinking, denial, or a lack of essential information required to comprehend the issues' magnitude.

The concept of harmful hope does not belong to a specific field but moves between psychology, education, futures studies, and many others. Maria Ojala's works (2012, 2015, 2017) define the concept of harmful hope and describe the many possible outcomes that hope can have when educating about sustainability and climate change.

Our results show that the students' initial lack of systemic sustainable thinking in the decision-making process led them to produce future scenarios marked by social inequalities and economic disparities. The scenarios created ended up being sustainable only from an environmental point of view but harmful in many different aspects due to the possible consequences of huge tax increases.

Hence, these results lead us to argue that harmful hope can emerge as the idea that sustainability can be achieved only through environmentally oriented efforts.

This approach does not preclude achieving the game's explicit objectives, namely staying below the threshold values expressed in the Paris Agreement. In fact, all groups managed to achieve this goal.

However, the aspect that makes the game an epistemologically thick tool is its ability to trigger reasoning that questions the very foundations of our society and exposes the flaws of solution-oriented approaches that lack systemic vision.
This phenomenon has also been common on other occasions when students, teachers, or friends played the game.

In this way, the game demonstrated that even with good intentions and common values, focusing on attitudes and aspirations that overlook the intricate aspects of complex issues like climate change, rather than embracing a systemic viewpoint, can be harmful.

To avoid this, it is essential to focus on fostering *informed* active hope, i.e. navigating the uncertainties associated with complex problems to make decisions and take actions aligned with the objective of achieving a desirable future.
The awareness gained through the game can develop reflections on sustainability that can be used as tools to anticipate and question possible new forms of harmful hope regarding sustainability.

Chapter 7. Analysing extreme weather and climatic events through the lens of Disaster Education

The third analysis of the data collected during the course focuses on extreme events' role in promoting action and developing sustainable competences for climate change education. This aspect emerged from the questionnaires and the answers that students gave during the course and the interviews; therefore, I decided to focus on it with the help of Prof. Wonyong Park, Associate Professor of Science Education at the Southampton Education School, University of Southampton.

In recent years, Wonyong oriented his research towards disaster studies and disaster education. The decision to work with an expert in disaster education to deal with climate change education is motivated by the idea that climate change resembles the definition of disasters, as shown in the first section of this chapter, with extreme events as the most evident and urgent sign.

I officially spent three months visiting the Faculty of Education at the University of Southampton from the end of January 2024 until the first half of April 2024, for a total time of 12 weeks, to work with Wonyong on the data collected and on the approach that I was developing throughout my PhD.
In the first two meetings with Wonyong, I presented to him the work conducted up to that point in my PhD, and we discussed the details of the course and the data collection.

The discussion revolved around:

- Students' personal experiences with extreme events;
- Their perception of what climate change is and of the complexity behind policymakers' decision-making process.

This operation led to the suggestion from Wonyong to explore and study two possible constructs that could have helped in understanding what happened during the course: the psychological distance one (McDonald et al., 2015) and the Socio-Scientific Perspective Taking (SSPT) (Newton & Zeidler, 2020).

After studying and reading the literature, I started to look again at the data to verify the possibility of applying the constructs. These constructs share some commonalities and can help in focusing on different aspects of the emerging results. In particular, the psychological distance construct can help in understanding the reaction that students felt towards climate change, while the SSPT can be useful in describing the process that led students to impersonate themselves with the policymakers through the game.

While going through the data I noticed how many students shared personal experiences of the flood that happened in Emilia Romagna in May 2023.
This emerging trend gave us an empirical basis for analysing the role that extreme events can have in reducing the psychological distance towards climate change and, therefore, promoting agency.
The description of the personal experiences made by the students also gave us the opportunity to explore the similarities between these results (i.e. the course) and a different project in which Prof. Park is involved, that is a study of the 2022 Buffalo Blizzard in terms of disaster education connected to climate change. This confrontation has been used to write a piece for the UNDRR's blog, titled "How to talk about climate disasters in the classroom", written by Wonyong, Olivia and me (https://iddrr.undrr.org/drr-community-voices/disasters-classroom-lessons-talking-students-about-extreme-climate-events).

In this Chapter, I briefly describe the disaster education field and these two constructs, the analysis of the data collected during the course and the possible influences of the results for the general approach.

7.1 Disaster studies and disaster education

Several frameworks have been produced in the last years to emphasise the role of education and preparation in DRR. In the Hyogo Framework for Action (HFA), adopted at the 2005 World Conference on Disaster Reduction and in effect from 2005 to 2015, education is viewed as a means to support the gathering, organising, and sharing of essential knowledge and information about hazards, vulnerabilities, and capacities (Park, 2020; United Nations International Strategy for Disaster Reduction, 2007). Since 2015, a revision of the HFA led to the construction of the Sendai Framework for DRR 2015-2030, in which understanding disaster risk, reinforcing disaster risk governance to address disaster risks effectively, allocating resources to disaster reduction to build resilience, and enhancing disaster preparedness for effective response are considered as priorities to prevent and reduce disaster risk (Kitagawa, 2021). The Sendai Framework is a fairly high-profile agreement, signed and adopted by 187 UN member countries.
According to Shaw, Shiwaku, and Takeuchi (2011), Disaster Risk Reduction should lead to understanding the possible causes and consequences of disasters on an environmental and human level while advocating for possible and needed changes on a policy level.

In the Sendai Framework, a disaster is defined as:

> "A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts." (https://www.undrr.org/terminology/disaster).

Other important terms taken from the Sendai Framework are disaster damage, disaster impact, slow-onset and sudden-onset disasters.

- Disaster damage occurs during and immediately after the disaster. This is usually measured in physical units and describes the total or partial destruction of physical assets, the disruption of basic services and damages to sources of livelihood in the affected area.
- Disaster impact is the total effect, including negative effects (e.g., economic losses) and positive effects (e.g., economic gains), of a hazardous event or a disaster. The term includes economic, human and environmental impacts, and may include death, injuries, disease and other negative effects on human physical, mental and social well-being.
- A slow-onset disaster is defined as one that emerges gradually over time. Slow-onset disasters could be associated with, e.g., drought, desertification, sea-level rise, and epidemic disease.
- A sudden-onset disaster is one triggered by a hazardous event that emerges quickly or unexpectedly. Sudden-onset disasters could be associated with, e.g., earthquakes, volcanic eruptions, flash floods, chemical explosions, critical infrastructure failures, and transport accidents.

This terminology is useful for framing and distinguishing between causes, consequences, and timescales. Several programs and actions focused on educating people about DRR through formal, non-formal and informal education (Shaw et al., 2011).

It is also relevant for distinguishing between the education of and for disasters, which can and should happen before disasters, and education in disasters, which is instead focused on adapting and re-establishing educational settings during emergencies (Kitagawa, 2021).

Although the role of education in Disaster Risk Reduction (DRR) has been widely recognised, the concept of disaster education as an identifiable field of research is quite recent.
Nonetheless, due to the external conditions of our time, risk comes not only from natural hazards like earthquakes, tsunamis, or volcano eruptions, but is manufactured and connected to the ever-increasing role that human technologies play in our societies, thanks to scientific innovations. Therefore, there is a need to teach about disasters from an interdisciplinary perspective.

As discussed by Park (2020), there is a clash between the nature of disasters, profoundly interdisciplinary, and the mono-perspective of disaster education programmes, mainly focusing on social and human aspects. This separation between scientific and humanistic aspects of disasters follows the "two cultures" separation (Snow, 1959), a characteristic of Western societies that might lead to a rise in scepticism towards science and scientists, or a de-humanization of social aspects if treated only from a science-centric point of view.
By looking at them as failures in socio-technical systems, "disasters can be critical events that unveil the hidden actors and networks that comprise the socio-technical systems" (Park, 2020, p. 5). Therefore, their role in education is instrumental to preparing future citizens.

In his work, Park claims that a multi-inter-transdisciplinary approach should be adopted to integrate science curricula and disaster education. This approach would integrate different perspectives and epistemologies to foster a deeper understanding of the dynamics and interrelationships between different actors (Park, 2020).

The study of disasters can be relevant to "admit the limits of science and teach about them", while "appreciating and underscoring its accomplishments" (Park, 2020, p. 8).
In this regard, and given the reasoning developed in this work, the study of disasters can be seen as a natural space to explore the concept of uncertainties. To study, prevent, and adapt to disasters, it is necessary to deal with the different typologies and sources of uncertainties tied to the phenomena.

7.2 Reflections on the relation between extreme events and disasters

As shown in Chapter 2, the starting point of my PhD has been the study and confrontation of the approaches used in climatology to attribute extreme events to climate change. The study of extreme events is very interesting for many reasons, being events that highly affect societies at many levels. For the IPCC, "it is an established fact that human-induced greenhouse gas emissions have led to an increased frequency and/or intensity of some weather and climate extremes since pre-industrial time, in particular for temperature extremes" (Seneviratne et al., 2021, p. 1517).

Although there are many difficulties in the field of Detection and Attribution of Extreme Events to Climate Change, due to the inner variability of climate being a complex system and the high levels of uncertainty that are present in the whole process, extreme events can be considered and used from an educational point of view to address climate change education.
Using a metaphor, they can be considered the "tip of the iceberg" for climate change, as it is one of the most evident consequences of the changes that our society is causing to climate, due to their impact and short time scale. Therefore, is also one of the aspects of climate change that can resonate more with our communities, hence it's worthwhile understanding how to talk about it from an educational perspective and not only in terms of technological solutions.

Before going through the data, it is important to focus on the definition(s) of extreme events. The IPCC WGI gave three definitions in the Sixth Assessment Report (AR6) for "extreme weather event", "extreme/heavy precipitation event", and "climate extreme or extreme climate event".

Definition of Climate Extreme or Extreme Climate Event (IPCC, AR6, Annex VII, p. 2222)

> The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classified as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., high temperature, drought, or heavy rainfall over a season). For simplicity, both extreme weather events and extreme climate events are referred to collectively as climate extremes.

Definition of Extreme Weather Event (IPCC, AR6, Annex VII, p. 2229)

> An event that is rare at a particular place and time of year. Definitions of 'rare' vary, but an extreme weather event would normally be as rare as, or rarer than, the 10th or 90th percentile of a probability density function estimated from observations. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense.

Definition of Extreme/Heavy precipitation event (IPCC, AR6, Annex VII, p. 2229)

> An extreme/heavy precipitation event is an event that is of very high magnitude with a very rare occurrence at a particular place. Types of extreme precipitation may vary depending on its duration, hourly, daily or multi-days (e.g., 5 days), though all of them qualitatively represent high magnitude. The intensity of such events may be defined with a block maxima approach such as annual maxima or with peaks over threshold approach, such as rainfall above the 95th or 99th percentile at a particular place.

All these definitions focus on some characteristics of the event, like the magnitude, the perseverance, the length, and the rarity, and none of the definitions focus on the impact of the event. This distinction is non-trivial, as very often extreme events are directly tied to their impacts. McPhillips and colleagues (2018) explained how defining extreme events without focusing on their impacts is necessary for attesting the resilience of SETSs (social-ecological-technical systems). The authors raise a critical question about evaluating the resilience of SETSs in the context of extreme events, challenging the notion of defining such events solely based on their impacts, suggesting that this approach complicates the assessment of a system's ability to adapt, recover, and transform in response to these disruptions. Therefore, by focusing on the impacts, there is a risk of overlooking the complex interplay of social, ecological, and technical dimensions that contribute to the system's resilience, thereby limiting our understanding of how to enhance its capacity to withstand future challenges (McPhillips et al., 2018).

Taking from the description of disasters and disaster education in the previous section, we can see that some manifestations of Climate Change, like global warming or coastal flooding, can be seen as slow-onset disasters (i.e. one that emerges gradually over time), while other manifestations, such as extreme climatic events, can be seen as sudden-onset disasters (i.e. one triggered by a hazardous event that emerges quickly or unexpectedly).

In this sense, studying extreme events in Climate Change Education might help realise the severity of climate change, its development and its possible and future impacts, mainly because younger students often struggle to perceive and understand slow, gradual changes. Focusing on extreme events can be seen as a chance to tackle the distance that students usually perceive with respect to climate change and, therefore, to promote agency. Feeling climate change as something too big for us or too far away can prevent us from realising the need to act as soon as possible at all levels (Etkin & Ho, 2007). The agency can be hindered in this way.

An example of this can be seen in the series of wildfires that devastated the area of Los Angeles, USA (January 2025), or in the consequences of the passage of Hurricane Helene in the southeastern region of the USA (September 2024) (https://www.cleanenergy.org/blog/from-abstract-to-reality-when-your-hometown-becomes-a-climate-casualty/). During and after these disasters, many people on social media described the correlation between what they were seeing and climate change using a specific quote, whose author is unknown:

> "Climate change will manifest as a series of disasters viewed through phones with footage that gets closer and closer to where you live until you are the one filming it."

It is interesting to present also a categorisation made by Floridi in 2023 in an editor letter to the journal Philosophy & Technology (Floridi, 2023). In this brief piece, named "Climate Change and the Terrible Hope", Luciano Floridi introduces the concept of "terrible hope", a paradoxical yet compelling idea that a relatively small but impactful catastrophe might be the only force capable of breaking humanity's social akrasia, i.e. our collective tendency to act against better judgment despite knowing the consequences. This "terrible hope" arises from the frustration that, although the dangers of climate change are well understood, meaningful action remains elusive. Floridi suggests that the very nature of climate change, its gradual and prolonged development, renders it more akin to a tragedy than a sudden crisis, and thus more likely to be ignored or deferred, even as its impacts escalate.

Floridi draws a critical distinction between tragedies and catastrophes. Tragedies are slow-burning processes that give people time to become aware, but also to procrastinate and normalise the worsening conditions. Climate change, in his view, exemplifies such a tragedy: a crisis unfolding in real time but met with inadequate urgency. On the other hand, catastrophes are immediate, shocking events—like pandemics or natural disasters—that can provoke swift and decisive reactions. Floridi argues that sometimes it is precisely a minor catastrophe—one not devastating enough to cause irreparable damage but significant enough to disrupt the status quo—that may act as the trigger for behavioural and political change. The paper further explores the psychological and behavioural dimensions of change. Floridi compares society's response to climate change with a smoker who only decides to quit after suffering a non-fatal heart attack. The knowledge of harm isn't enough; it often takes a jarring experience to push individuals or societies toward transformation. If the climate crisis continues to unfold without major shocks, Floridi warns of a "slippery slope" effect, in which humanity becomes gradually desensitised to environmental degradation, reinforcing consumerist habits and delaying necessary reforms.

From a philosophical perspective, Floridi invokes Socratic ethics, which suggest that knowledge and self-awareness should lead to virtuous action. Yet he also acknowledges the limitations of rational understanding: many people continue to engage in destructive behaviours despite knowing the risks involved. This insight underlines a core tension in climate ethics: knowing is not the same as doing, especially when individual actions are embedded within larger systems of convenience, denial, and economic interest.

In conclusion, Floridi warns that placing hope in catastrophe is a dangerous gamble, even if it may seem like the only remaining catalyst for change. He advocates instead for a more mature, moral, and intelligent approach—one that moves beyond consumerism and actively embraces responsibility for planetary stewardship. Rather than waiting for disaster to force transformation, humanity must cultivate the ethical clarity and political will to act preemptively, turning philosophical understanding into real-world sustainability.

As it is visible, the discussion on extreme events is therefore tied with several concepts central in the science and physics class, such as complexity (how can we recognise the processes that led to the extreme event), uncertainty (at what level can we attribute a certain event to climate change), probability (in what way can we discuss on the rarity of the event), and predictability (what this extreme event tells us about possible future events). All these aspects are fundamental for discussing what science is and how the scientific process works.

As suggested by Wonyong during our collaboration in Southampton, it might be useful to use two constructs to discuss the connection between Disaster Education and Climate Change Education: psychological distance (McDonald et al., 2015) to describe how people usually feel with respect to climate change, and socio-scientific perspective taking (Newton & Zeidler, 2020) to elaborate on the process of decision-making and the perception of the role of policies and policymakers in extreme situations. I present here the psychological distance construct in detail. Due to time constraints, I did not explore the second construct so in detail to conduct a proper analysis, but I'm still in contact with Wonyong to continue the collaboration in the future.

7.3 Analysing the stories through the lens of psychological distance

7.3.1 Psychological distance

Psychological distance is described as a subjective experience of perceiving something close or far away, and can be seen as a construct that describes the difficulty in perceiving and acting towards an issue that is felt distant on mainly four different levels (Trope & Liberman, 2010):

- Hypothetical: questioning the existence of the issue;
- Spatial: treating the issue as something that exists but is far on a spatial level, for example on the other part of the world;
- Temporal: treating the issue as something that exists and can be close on a spatial level, but is far on a temporal level, for example, one hundred years from today;
- Social: treating the issue as something close both on a spatial and temporal level, but does not affect us specifically (e.g. other population groups).

This construct has been identified to frame the difficulty in keeping climate change as a relevant issue daily and acting on it (Büssing & Heuckmann, 2021; McDonald et al., 2015), due to a combination of these different levels. Specifically, literature shaped the four levels to resemble specific positionings on anthropogenic climate change:

- Hypothetical: I do not know if anthropogenic climate change exists or not;
- Spatial: I reckon climate change exists but does not happen close to me;
- Temporal: I reckon climate change exists and can happen close to me but only far in the future;
- Social: I reckon climate change exists and can happen close to me and now, but it does not affect me directly.

These levels are not independent from each other and can be modified to form other sub-levels.

As described by McDonald and colleagues (2015), evidence suggests that reducing the psychological distance towards climate change is necessary to promote action and change attitudes toward the issue. Usually, it has been seen that facing a problem firsthand can reduce all the levels of psychological distance. At the same time, experiencing directly the consequences of climate change cannot be seen as the only solution to reduce the psychological distance. The authors explicitly describe the uncertainty and the timescale of climate change as the main factors in making it difficult to reduce the psychological distance (McDonald et al., 2015).

7.3.2 Analysis

The data discussed and used for the analysis conducted at the University of Southampton with Wonyong were collected during the first implementation of the PLS course "Verso Nuovi Scenari Futuri", described in chapter 5.
These data comprehend:

- Pre/post questionnaires on climate change experience and sustainability competences;
- Middle course questionnaires on perceived futures;
- Recordings of the activities;
- Interviews.

Here, I focus on the pre/post questionnaires handled in lessons 1 and 7, which describe students' personal experiences connected to Climate Change.

The question asked was:

> "Think of an event concerning climate change. Share, through a story, your personal experience describing the impact of this event in your daily life. Your experience can be positive or negative, significant or not, routine or special."

The original italian version was:

> "Pensa a un evento che riguarda i cambiamenti climatici. Condividi, tramite una storia, una tua esperienza personale che descriva l'impatto di questo evento nella tua vita quotidiana. La tua esperienza può essere positiva o negativa, significativa o non, di routine o speciale."

As detailed in Chapters 5 and 6, a total of 33 students enrolled in the course. Of these, 32 attended the first lesson, where they shared short stories of personal experiences related to Climate Change. By the final lesson, 23 students participated, contributing to post-course short stories.
Consequently, 23 paired pre/post questionnaires are available to analyse how students' descriptions of the events evolved over the course. Additionally, out of the 23 students present in the final lesson, 9 consented to participate in interviews.
The stories described have an average length of 73 words, with a minimum of 11 and a maximum of 166.

Looking at the pre/post questionnaires, 3 main categories of events emerge:

- Extreme events (e.g. floods, wildfires, heatwaves);
- Changes in temperature, weather or seasonal patterns;
- Human aspects or activities (e.g. pollution, health, recycling).

Out of the 32 pre-course short stories, extreme events and weather/climate changes are described 15 times, while human aspects or activities are described 5 times each (Figure 7.1, left).
In the post-course short stories, extreme events have been described 15 times, weather/climate changes 6 times, and human aspects or activities 3 times (Figure 7.1, right)

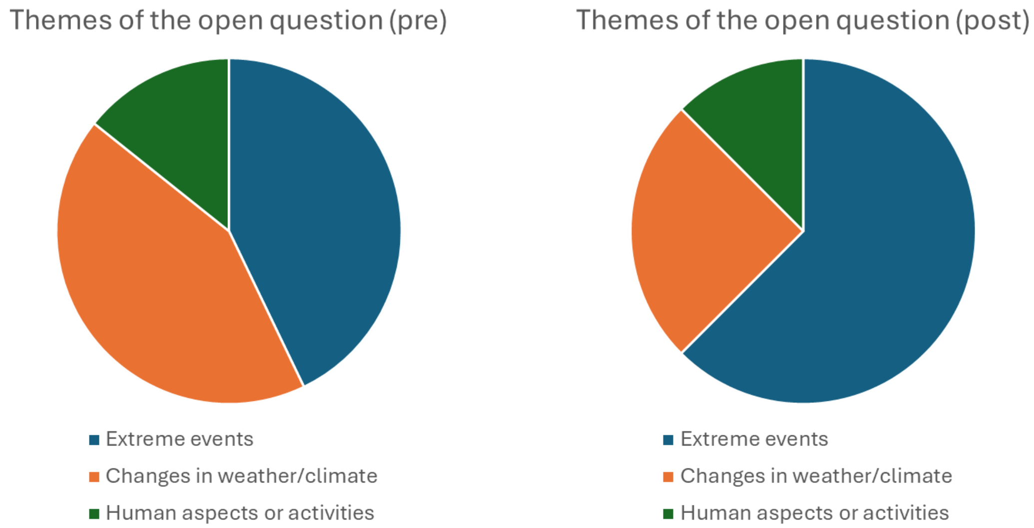


Figure 7.1 Distribution of the themes for the first question of the questionnaire, pre-course (left) and post-course (right).

Looking at the whole ensemble of stories, 30 times there has been a discussion regarding an extreme weather event, of which 21 discussed the flood that happened in Emilia Romagna in May 2023.

The region of Emilia Romagna suffered from two flooding events connected to weather extremes in a span of two weeks, the first between 1-4 May and the second between 16-18 May 2023. The second event has been the most severe of the two, also because it affected areas that suffered already from the first one. The dimensions of the floods were unexpected and unprecedented, as the amount of rain that fell in those days (around 400-450 millimetres total in the two events) had never been detected before. The floods resulted in more than 100 flooded municipalities, 23 rivers flooded, and more than 65,000 landslides, with at least 15 people killed, over 50,000 displaced and damage estimated at more than 10 billion euros (Figure 7.2) (Il Post, 2023; Regione Emilia Romagna, 2023; Wired, 2024; Il Sole 24 ore, 2024).

The meteorological reasons behind the flood have been explained by Arrighi and Domeneghetti (2024):

> "The second event, in particular, was due to a vast area of low atmospheric pressure affecting the entire central Mediterranean basin that channelled moisture-laden air masses from North African coasts toward the Italian peninsula. The cyclone circulation moved the air masses towards central Italy, where the combination with cold air coming from the north and the hills of the Apennines caused the persistence of heavy rainfall over eastern ER (Emilia Romagna) and Marche regions. Several gauging stations on hill basins recorded rainfall of more than 200 mm in 48 h (the highest value ever recorded in some cases since their installation)". (Arrighi & Domeneghetti, 2024, p. 674).

Figure 7.2 Emilia Romagna flood of May 2023. Antonio Masiello/Getty Images

The serious consequences of the event were due to a combination of extreme weather events, the land's inability to absorb the fallen water, and a lack of effective adaptation measures. In this case, as shown by different studies (see, for example, https://www.imperial.ac.uk/news/245215/italys-deadly-floods-cant-blamed-climate/), even if the event cannot be directly linked with climate change, it is evident that the frequency and severity of these extreme events have risen in recent years. At the same time, the long series of droughts and heavy rains left a deep mark on the land's capability to react to these extremes. Therefore, as suggested by Wonyong, this can be seen as a telling example of how climate change causes disasters not only by creating hazards but also by increasing vulnerability and exposure.

In October 2024, another event of similar dimensions occurred in the same region (350 mm in 48 hours), but luckily, it did not lead to the same consequences. Therefore, what was perceived as a "once-in-a-century" event repeated only after 16 months (Il Sole 24 ore, 2024).

The course was held in October 2023. Therefore, many students were recently directly affected by the flood, either personally or through friends and families.

It is interesting but not surprising that many students described extreme weather events that they linked to climate change, although the question did not explicitly ask about extreme events. Also, students did not only focus on the event but explained quite often how that extreme event and the impact that followed made them realise the severity of climate change, specifically for those who were directly involved or closely involved.
The terms used by the students show a process of realising the dimensions of a certain problem as a result of direct experience. This process took place at different levels and can be described using the "psychological distance" framework (McDonald et al., 2015; Trope & Liberman, 2010).

I present now some examples from the questionnaires, translated into English.

Students from the course did not put the existence of climate change into discussion, therefore there was no effect on the hypothetical level. Nonetheless, many of them shared how the direct experience of the flood made them realise the severity of the issue. The following quotes can serve as a monitor on what type of distances have been affected by the direct experience of the flood

> "It made me reflect on the fact that in the face of extreme events and the 'force of nature' we are small and I don't know if we are capable of intervening, except with enormous shared efforts." (S#2)

> "This extreme weather event caused a lot of damage to structures in the area, but also to the population in terms of human lives, it also made me realise how devastating these events are and how dramatically they are becoming more and more frequent." (S#13)

> "All the objects were completely covered with mud and piles of rubbish had been created that cluttered the streets. The impression I got from his account was one of despondency for all the people who had lost everything. It was a visible sign of climate change and the disasters it causes." (S#14)

> "It opened the eyes of many to the need to address the issue of climate change." (S#15)

In these excerpts, it is possible to detect how the dimension of the event led students to an increased perception of the scale of the problem, particularly on the impact on human lives. It is interesting to notice how for some students, for example S#2 in this case, the reaction to the disaster can be seen as a manifestation of what is referred to as "sublime" in the literature, i.e. the feeling of being in front of something too big to handle or even comprehend, while for the others the event was a direct call to action with respect to climate change.

On the spatial level, students shared their reactions to being directly exposed to the flood.

> "I don't think I ever took the issue of climate change seriously until I had a taste of its consequences." (S#16)

> "An event that made us even more aware of this reality was the flood… […] we are perhaps all too used to seeing these problems as something abstract and distant from us, when in fact we are all more affected than we might think." (S#1)

In this case, spatiality can be seen both in terms of geographical distance and social distance, undermining the false perception that privileged countries and areas are more likely to be spared by climate change.

The students' descriptions of the flood are very heartfelt and personal, and from the way it is described, it affects several levels of psychological distance. Many students describe the event as something that "opened their eyes" and made them more aware of our involvement in the possible consequences of climate change.

> "Although it did not cause any damage to me and my family, seeing acquaintances and friends with their cellars full of mud or even being taken away from their homes by helicopter made me think a lot about how, in the richest and safest parts of the world, people see climate change problems as distant, sure that they will never touch us, when in reality the planet makes no distinction and we are all in danger, them as much as us." (S#15)

Here we can see a reduction in the social level of psychological distance, due to the impact that the flood had on acquaintances and friends.
The shortening is also visible from another aspect described often, that is the collaboration of many to act after the disaster.

> "However, despite the fear, everyone immediately made themselves available to help clean up. This solidarity was particularly pronounced on the part of us young people. In those days, a wonderful organisation of volunteers was created, so that they knew the

> areas where there was need and often also found some snacks offered by others. Everyone therefore contributed as much as they could." (S#4)

The spirit of solidarity is very present in situations like this, as has been the case for several floods that happened in Europe in the last year (see the Valencia one in October 2024).

On a general note, there are some differences between the stories shared in the first lesson and the ones gathered in the last one. Students have shown a more grounded perception of what types of events might be associated with climate change and what are instead only due to weather changes. Here we can see how the course helped a student frame extreme events more clearly:

> "In the light of what we did in this course, I was able to better understand, above all, the fact that these extreme events, as unpredictable as they are, are bound to happen more and more often due to global warming. This is a subject that has unfortunately been talked about very little, as it has been said many times in broadcasts and radio that it is due to climate change, but rarely has the data been explored in depth or explained why." (S#5)

Also, it is possible to see how some students shared the same stories but in a more detailed way, by explaining why that particular event was connected to climate change.
In the first lesson, many students talked about changes in the weather on a daily basis (in the morning, it is cold, while in the afternoon, it is very warm) or from a seasonal or year-to-year perspective. After the course, no students shared changes that were actually associated with weather changes but focused on bigger timescales and aspects of climate change, like, for example, the increased warming in specific seasons.
Although a systematic analysis should be made of the specific pre- and post- differences in students' perceived distances' shifts, we can see, on a general level, how the course helped students in differentiating the connection to climate change of specific events by complexifying the relationship between weather events and climate processes.

7.4 Comments and next steps

What emerges from the short stories of the students attending the course is that experiencing first-hand the dimensions of an extreme weather event, such as the Emilia-Romagna flood of May 2023, led them to reduce the psychological distance toward the issue.

We can see a similarity with the reasoning behind the storyline approach to detect and attribute extreme weather or climate events to anthropogenic climate change. As shown in Chapter 2 and in Miani & Levrini (2024), an approach like the storyline one may lead more easily to acting towards climate change since the episodes described in the approach are real events that happened in a specific time and place, with specific consequences. Therefore, as Shepherd (2019) says, it is easier for people to act if they already experienced an extreme event, or a disaster, and if they know that that event may happen again with more intensity.

It is necessary to stress here that it is not easy to assess if an event is due to climate change, or if its severity has increased or not. As described in Chapter 2, understanding the difficulty of the detection and attribution process, and the uncertainties that are connected to the phenomena, can give a more realistic idea of the scientific process of building confidence and validated results in cases in which there is no grounded knowledge.

At the same time, as McDonald and colleagues (2015) show, direct experience alone cannot be seen as the only way to reduce the psychological distance due to the timescale, the risk, and the severity of the extremes.
Therefore, it becomes necessary to create situations in which the study of extreme events becomes powerful enough to obtain similar results without the need to experience the consequences of a disaster directly. The need to activate similar reasoning can be exploited in an educational setting, where learners can simulate situations in which the impact of a certain extreme event and its consequences are studied. To this extent, McDonald and colleagues (2015) share the need for people to go through a process of perspective-taking to reach this goal.

As suggested by Wonyong, the framework elaborated by Newton and Zeidler (2020) of Socio-Scientific Perspective Taking can help describe what type of process students should need to promote meaningful learning and agency.
Climate change can be framed as a Socio-Scientific Issue, as it involves scientific and social aspects that cannot be easily separated due to the complexity of the system and the different types of uncertainty present. Moreover, climate change can directly touch on personal aspects like difficulties in imagining personal positive futures and anxiety due to the instability that such an issue might cause to ecosystems and our society.

Despite the documented benefits of enhanced perspective-taking skills, there is limited knowledge on how to cultivate these abilities within science classroom settings. Furthermore, research highlights the challenges of fostering perspective-taking, as students often resist engaging with viewpoints that differ from their own (Sadler et al., 2007; Newton & Zeidler, 2020).
Establishing a Socio-Scientific Issue setting allows students to reflect on their own perspectives and ways of thinking, to make emerge possible biases and contrasts (Newton & Zeidler, 2020).

As described in previous chapters, the design of the course, and in particular of the game, made students think in ways that are not usually present in a scientific classroom, like, for example, dealing with the economic, political and social aspects of climate change. The process of perspective-taking is emphasised as a process in which the students develop a proper perspective on the issue due to their engagement and ability to "shift back and forth between an insiders' and outsiders' perspective about those issues and traverse the moral domain of those issues" (Newton & Zeidler, 2020, p. 6).

We can see how disaster education and Socio-Scientific Perspective Taking share some commonalities and can help in dealing with climate change.
The results of the analyses conducted in the previous chapters show how the course and the game succeeded to some extent in activating dimensions related to knowledge, perspective and values. These dimensions partly resemble the categories expressed by GreenComp, necessary to promote education for sustainability.

As a possible next step for future research, it might be interesting to explore how the game situation can be better framed by incorporating perspectives from disaster education and SSPT, fostering an effective learning process that drives the realisation of the need for agency.

Chapter 8. Conclusions

The main objective of my PhD was to develop an innovative approach to deal with Climate Change in a physics Education environment, rethinking traditional methods to adapt to an interdisciplinary, uncertain, and complex society.

The background of my research deeply influenced the orientation of my work. In fact, the work conducted together with the research group in several European projects (IDENTITIES, FEDORA, CLIMADEMY) led me to place my project in the framework of future-oriented science education due to its relevance and epistemological stance towards the nature of science in dealing with climate change. A very relevant reason for this choice is that, as shown in the chapter written together with Antti Laherto, Tapio Rasa, my supervisor Olivia Levrini and Sibel Erduran (Laherto et al., 2023), the future-oriented science education approach aligns with the aims and positioning of GreenComp, i.e. the main reference framework of the European Commission in terms of sustainability and sustainable education. The approach gave me the necessary tools to explore the field of futures studies, from an ontological, epistemological, axiological and methodological perspective, and has been presented at the EARLI Conference held in Thessaloniki, Greece, in August 2023.

The nature of the climate crisis requires an interdisciplinary perspective due to the multiple and multifaceted issues involved, which are necessary to deal with from an educational perspective.
To this extent, the work conducted in my master thesis and continued within the IDENTITIES project, as presented in Chapter 4, has provided a useful starting point on which to build the approach. In fact, the boundary framework (Akkerman & Bakker, 2011) laid the foundation for thinking about effective ways of moving across the boundaries of disciplines, both from a content and methodological point of view. The prototypical activity presented in the chapter, whose analysis is the focus of the paper written together with Olivia Levrini and colleagues from the University of Crete Chara Bitsaki, Giannis Metaxas and Prof. Dimitris Stavrou (Miani et al., major revisions), provided useful insights on how to deal with the interdisciplinary nature of climate change. Specifically, the possibility of working with pre-service teachers coming from different backgrounds and different countries highlighted the need to explore how the issue could and must be addressed from multiple perspectives at the same time.
I discussed this study as a poster in the 2023 ESERA Summer School, held in July in Neustadt an der Weinstrasse, Germany, approssimately at the half of my doctoral path.

Continuing on opening the perspective on the needs of climate change education, the research activity carried out within the Italian packaging recycling consortium CONAI (Consorzio Nazionale Imballaggi), presented in Chapter 3, offered a fruitful point of view on the possible ways of promoting sustainability competences to different targets and stakeholders. The analysis conducted with CONAI allowed me to explore how training activities on sustainability are led on different scales and dimensions, moving from formal, non-formal and informal education. Thanks to this activity I reached a higher awareness of the need to embrace sustainability at different levels in the education process without avoiding the discussions connected to real-life situations.

In addition, the study was very helpful in turning GreenComp into a qualitative assessment model for educational and formational activities. In the study, I reshaped the definitions of the twelve competences of the framework to create a set of guiding questions, with the aim of analysing the potential of specific activities to develop sustainability competences.
The assessment tool, named TASC (Tool for Assessing Sustainability Competences), proved to be useful for unpacking the structure of each activity and understanding its capability of promoting sustainable knowledge, skills, and attitudes.

The analysis has been presented to the CONAI executive and considered the basis for a research article I will work on after the PhD. The collaboration with CONAI proved to be very effective, leading to a systemisation of the formation activities promoted by the consortium.
I presented the study at the International Scientific Workshop on Challenges of Sustainable Education, which was held in Trento, Italy, in June 2024.

The TASC has been developed from the analysis of the approaches used in the detection and attribute field of extreme events from a perspective of education for sustainability and climate change education. The study, discussed in Chapter 2, has been presented at the 2022 GIREP conference as a poster. The paper that has been written starting from the presentation has been selected by the Editors and the GIREP Board for inclusion in the book of selected papers "Effective Learning in Physics: from Contemporary Physics to Remote Settings", published by Springer in the book series "Challenges in Physics Education" in late 2024, with the title "Analysing the Storyline Approach's Competence-Developing Potential for Climate Change in Science Education" (Miani & Levrini, 2024).
The study, and in particular, the application of the TASC following the four main competence areas, highlighted how the approaches used in the D&A field, i.e., the risk-based and the storyline approaches, have different epistemological positionings towards the embedded uncertainties of climate change and how these differences can lead to the possible development of sustainability competences if used in a future-oriented educational setting.
After the paper was published in December 2024, one of the lead authors and creators of the storyline approach, Prof. Ted Shepherd, University of Reading, reached out due to his interest in the analysis presented. The discussion has been brought forward and led to a series of three seminars held in March 2025 in the Department of Physics and Astronomy. In these seminars, co-organised together with the research group in Physics of the Atmosphere and Climate Physics of the University of Bologna, led by Prof. Di Sabatino, Shepherd explored the epistemological basis of physical climate storylines and their probabilistic logic. This collaboration has led our research group to deeper explore the differences between storylines and other approaches used in Climatology, and will be the basis for future collaborations and research.

Starting from these three case studies and the work carried out in the research group, I developed an approach that would focus on the need to deal with uncertainties in climate change education to promote agency and decision-making competences.
As presented in Chapter 5, the approach unites uncertainty, sustainability and futures studies, adopting an interdisciplinary and multi-layered perspective on the role that uncertainty can play in preparing students to the challenges of climate change.

The approach has been put in practice twice in a course for secondary students, and partially once in a summer school of the project CLIMADEMY.
From a practical point of view, the design of the first iteration of the course, its implementation, and the following data analysis have been the core of my PhD. In fact, the course can be considered a point of arrival for positioning with respect to the field of Climate Change Education after the three case studies and a starting point for exploring the effects of using uncertainty as a lens to promote decision-making, informed active hope, and meaningful learning.
Around 60 students participated in the two implementations of the course, which were composed of six lessons for a total of 20 hours.
I co-taught the course with my colleague Francesco De Zuani Cassina, and the data collected during the implementations (mostly qualitative through recordings, questionnaires, and interviews) has been used to conduct different analyses on our research themes.

The course revolves around the role of uncertainty in Climate Change, starting from its dimensions in physics and expanding towards the fields of climatology, futures studies, and education for

sustainability. As presented in the second part of Chapter 5, a set of different interdisciplinary topics has been treated and connected, with the aim of showing the need to overcome the inner boundaries of complex issues.
I presented the design process of the course at the JURE2023, the EARLI-related conference for early career researchers held in Thessaloniki in August 2023.

Also, in the course, we hosted two interventions from experts in the field of climate change and risk reduction: Prof. Paolo Ruggieri, a researcher in the field of climatology at the Department of Physics and Astronomy in Bologna; Micol Todesco, the director of the Bologna branch of the National Institute of Geophysics and Volcanology, and Barbara Lolli, a colleague researcher of Micol, also from INGV.

As part of the course, Francesco and I designed a special activity to let students create and explore possible future-informed scenarios. The activity, a board game called F*you*TURES (De Zuani et al., 2024), proved to be a very interesting experience for students to build a personal idea of the difficulty of decision-making in dealing with climate change and to train their capability of using systemic thinking when dealing with complex, uncertain issues. The game was presented at the Climademy Final Conference held in Finland in April 2025 and at the European Geoscience Union Assembly EGU25 in Wien in May 2025, receiving several positive comments and interest from many colleagues worldwide.

The empirical findings of the research contribute to two critical and contemporary themes: the challenges of educating for sustainability and the role of science education in fostering informed active hope. While broad in scope, these themes are anchored in the complex interplay between environmental, social, and economic dimensions. Through the data analysis, new insights emerged into how sustainability can be framed and taught, particularly by emphasising systemic thinking and avoiding oversimplifications that may hinder meaningful engagement with sustainability issues.

The exploration of sustainability education was guided by the three-pillar model (Purvis et al., 2019), which highlights the interdependence of environmental, social, and economic dimensions. This framework provided a lens to examine student-generated scenarios during gameplay, revealing a predominant focus on environmental concerns, often at the expense of social and economic justice. The reflective discussions and interviews underscored the importance of cultivating a systemic approach that embraces complexity and interrogates assumptions about "sustainability." Students were prompted to consider critical questions such as "Sustainable for whom?" and "What type of sustainability?". These reflections not only deepened their understanding of the topic but also revealed the tension between idealistic aspirations and the multifaceted realities of sustainable decision-making. Through this process, students developed a nuanced appreciation for socio-environmental justice and recognized the intricacies of negotiating diverse values and priorities.

Moreover, from the analysis, the concept of hope emerged as a central theme in framing these findings, particularly its dual role as a motivator for action and a potential risk factor when misinformed or overly idealistic. While hope is a powerful driver in addressing sustainability challenges (Ojala, 2012, 2017), it can also lead to harmful outcomes when associated with wishful thinking or simplistic solutions. The students' initial scenarios often reflected this type of "harmful hope," where environmental goals were achieved at the expense of social and economic equity, resulting in unsustainable outcomes marked by inequality and disparity. Despite this, the game's capacity to foster epistemological questioning and critical reasoning highlighted its value as a pedagogical tool. By engaging with the game's scenarios, students moved beyond solution-oriented approaches and began to navigate the uncertainties and complexities of systemic sustainability.

The findings underscore the need to nurture informed active hope—a mindset that balances aspiration with critical awareness and systemic thinking. This approach empowers individuals to navigate uncertainties and make decisions that align with long-term sustainability goals. By cultivating informed active hope, students can develop the skills and perspectives needed to anticipate and address new forms of harmful hope in sustainability discourse. Ultimately, this research reaffirms the importance of education that embraces complexity, fosters critical reflection, and equips learners to engage thoughtfully and systemically with the pressing challenges of our time.

I presented these studies in several conferences, like the World Conference on Physics Education (WCPE) in Cracow, August 2024, and the Anticipation Conference in Lancaster, UK, in September 2024, always receiving positive feedbacks regarding the specificity of the approach and the innovative aspect of using uncertainty not only for problem solving but mostly to frame complex issues.

Also, together with Francesco and Olivia, we wrote three papers to present the analyses presented in Chapter 6: one focusing on the decision-making aspects of the course, one connected to the concept of harmful hope, and one exploring the specific role that the simulator En-ROADS had in the course. These papers have been submitted at the time of writing (December 2024) and are currently under review.

Finally, as discussed in Chapter 7, the course analyses revealed a third main aspect connected to the role of extreme events in climate change education.

The students' reflections reveal that firsthand experiences with extreme weather events, such as the Emilia-Romagna flood of May 2023, played a pivotal role in reducing their psychological distance from climate change. This aligns with the storyline approach, which ties specific events to anthropogenic climate change, making the issue more tangible and actionable. As discussed in Chapter 2 and by Shepherd (2019), individuals are more likely to act when they experience or foresee the recurrence of extreme events. However, attributing such events to climate change remains a scientifically complex process, emphasising the importance of understanding the uncertainties and iterative nature of detection and attribution.

While direct experience can significantly influence perceptions, it is not always feasible or sufficient. Educational approaches that simulate the study of extreme events can evoke similar cognitive and emotional responses. By engaging students in perspective-taking processes, such as those outlined in Newton and Zeidler's (2020) Socio-Scientific Perspective Taking framework, educators can foster meaningful learning. This enables students to grapple with the complexities of climate change, reflect on their biases, and develop a more nuanced and empathetic understanding of its impacts, ultimately enhancing their agency in addressing this global challenge.

The data analysis phase and the refining of the approach was carried out in the third year of my PhD, during which I conducted several research periods as a visiting PhD, two short ones and two longer ones.
I spent the short ones, of two weeks each, in two universities in the UK: the first in the Institute of Education at the University College London (UCL), under the supervision of Prof. Justin Dillon; the second one at the Faculty of Education of the University of Oxford, under the supervision of Professors Steve Puttick and Liam Guilfoyle. During these two short visits, I mostly focused on presenting my work and enlarging my network by meeting several researchers and professors working in the fields of science education, climate change education and sustainability education.
The longer visits have been spent in England and Finland.
In the first one, which lasted 12 weeks (January-April 2024), I worked under the supervision of Prof. Wonyong Park to explore the field of Disaster Education and to connect it with my research.

This collaboration led to the writing of a blog post on the United Nations Disaster Risk Reduction (UNDRR) website, in collaboration with Wonyong and Olivia (https://iddrr.undrr.org/drr-community-voices/disasters-classroom-lessons-talking-students-about-extreme-climate-events).

I conducted the second extended visiting period at the University of Helsinki, in the Department of Education (12 weeks, August-November 2024), under the supervision of Prof. Antti Laherto. During the visit, I explored the future-oriented science education framework developed through the years in more detail and connected with fellow researchers working on closely related topics.

Overall, the work conducted during these three years allowed me to deeply explore the field of Climate Change Education, both in terms of research and in terms of people.
The work conducted shaped me, as I shaped my work, leading to many changes in the way I deal with the world, mainly thanks to the amazing people I had the privilege of meeting and working with.
It is thanks to them that I continue to have hope towards the future, and for them that I will continue with my research, because a different future is going to be possible.

Chapter 9. Appendix

9.1.1 Schools and universities

9.1.1.1 Classroom recycling (primary school)

General description

The "Riciclo di Classe" educational project aims to educate primary school children in responsible and conscious behaviour regarding the separate collection and recycling of packaging materials. The project is developed in cooperation with Corriere della Sera. In the school year 2021/2022, it was developed in 2,400 schools nationwide for 3,000 classes in total. The 'Class Recycling' project was included in the 'School Regeneration Plan', promoted by the Ministry of Education, to support educational institutions towards achieving the goals of Agenda 2030 and the National Strategy for Sustainable Development. The environmental education project has visibility on the MIUR platform https://www.istruzione.it/ri-generazione-scuola/home.html , available to interested teachers.
The sustainable development education pathways are also included in the teaching of civic education, which became a real teaching subject with National Law 92 of August 2019, whose guidelines for the start of teaching in school institutions were defined with Ministerial Decree 35 of June 2020 and Provincial Resolution 1233 of August 2020. The project is now in its seventh edition, and follows two other projects implemented by CONAI in previous years called "Riciclando s'impara" and "Riciclo TVB".

Target

"Riciclando s'impara" and "Riciclo TVB" were targeted at secondary schools, while "Riciclo di classe" targeted primary schools.
The 'Riciclando si impara' project was patronaged by the Ministry of Education and the Ministry of the Environment. It was structured as field meetings for secondary school teachers, who received a certificate of participation. Therefore, the project was contextualised as a refresher programme.
'TVB Recycling' was the first project with an online development, with downloadable materials.

Main theme

"Recycling Class" started as an environmental citizenship education project.
In the first phase of the project, i.e. in the first three years, an illustrated story called 'Gita a Riciclonia' was constructed, where Recyclonia was a fantastic city where everything worked well, there was perfect waste separation, and for example citizens used steel scraps to build the city's railway tracks. This ideal world is turned upside down by the arrival of an extraterrestrial, who knows nothing about recycling and disrupts everything. The students intervene at this point thanks to the scientists of the recycling business foundation and manage to convert this little monster to their world view, making him a very good recycler.
They then moved on to another type of project, which was theatre, a powerful inclusive medium that can make many students work with very different activities. Thanks to the collaboration with a theatre company, the play 'It depends on us' was developed. After the pandemic, this show was first reformulated as an online show, and then as a travelling show to be taken to schools all over Italy. At the heart of the project is 'It depends on us', a play that tells the story of a family grappling with the problem of redeveloping an old country house. This house could be bought by two unscrupulous

entrepreneurs, but the protagonists together with the help of the students manage to drive them away. The central theme of the play is the presence of the souls of the seven packaging materials that inhabit it: Steel, Aluminium, Bioplastic, Paper, Wood, Plastic and Glass, the true protagonists of the staging.
The main message of the show focuses on the theme of personal commitment and the issue of environmental information about packaging materials. The didactic commitment alongside the playful-creative one, therefore, aims to provide information on recycling methods and rules according to the characteristics of each material. In addition, the results of the recycling processes are presented, showing what the recycled materials are transformed into and highlighting the theme of transformation, a very intriguing concept for children to understand from what comes and becomes what.

Materials

On the website www.riciclodiclasse.it it is possible to request educational materials: a guide for teachers on the subject of separate waste collection and packaging recycling, an operational guide on activities to be carried out at school and at home to participate in the educational competition Riciclo di Classe, a decalogue with the main rules of separate waste collection, the script of the play and its video to be watched all together, in class and at home, to meet new friends and with them implement virtuous behaviour, now indispensable for the protection of environmental sustainability.
All these projects were and are linked to a final educational competition to collect feedback from schools in the form of entries. These essays are awarded prizes to encourage children's and young people's concrete work on recycling and sustainability issues and thus their active participation. In recent years, an educational competition has also been initiated in which the classes can demonstrate their understanding of the value of separate waste collection and recycling by engaging in their own staging of the play 'It depends on us' (Watch the show https://eventi.corriere.it/speciali/evento/dipende-da-noi/).

Competences

Through playful and creative activities, children can understand the concept of the transformation of packaging into secondary raw materials for the manufacture of new products and the value of eco-sustainable behaviour, but above all they can try their hand at theatrical art and put on a show. This type of activity can help translate respect and care for the environment into concrete actions, showing what behaviour should be followed on an individual and collective level in order to carry out good waste separation, with a view to environmental citizenship. The activity allows students to reflect on the values of sustainability, from recycling to reuse and respect for the environment. The moments of confrontation in the show help in the attempt to convey a sense of respect for objects, also allowing them to develop different capacities to innovate as far as the reuse of raw materials is concerned. The activities are always conducted in groups, as are the moments of discussion and the subsequent preparation of the exhibits.

This type of activity mainly refers to the GreenComp (Bianchi et al., 2022) competence areas "Embodying sustainability values" (A1), "Envisioning sustainable futures" (A3) and "Acting for sustainability" (A4).
In particular, through this training activity it is possible to work on the development of competences such as "Valuing sustainability" (A1.1), "Promoting nature" (A1.3), "Exploratory thinking" (A3.3), "Collective action" (A4.3) and "Individual initiative" (A4.3).

ACTIVITY	**RECYCLING CLASS (RICICLO DI CLASSE)**
TARGET	Primary school students
TYPE OF ACTIVITY	Theatre performance Class lessons and group work

AIMS	1. Helping students to understand the concept of transforming packaging into secondary raw materials for the manufacture of new products and the value of eco-sustainable behaviour. 2. Getting students to engage in theatrical art to stage the performance. 3. Helping to translate respect and care for the environment into concrete actions, showing what behaviour should be followed on an individual and collective level in order to carry out good waste separation, with a view to environmental citizenship.
GREENCOMP COMPETENCES ACTIVATED	
COMPETENCES ACTIVATED	Valuing sustainability - Promoting nature - Exploratory thinking - Collective action - Individual initiative
STRENGTHS	The activity deals with the topic of waste collection through theatrical language, succeeding in entertaining the students and conveying the basic values needed to develop active citizenship skills and competences.
USEFUL LINKS	https://www.conai.org/comunicazione/scuola/ https://www.corriere.it/buone-notizie/riciclodiclasse/

9.1.1.2 Pathways for Transversal Competences and Orientation - PCTO (secondary school)

General description

The training project related to PCTOs (Percorsi per Competenze Trasversali e Orientamento - Pathways for Transversal Competences and Orientation) envisages the construction of online usable modules aimed at presenting the realities related to the circular economy, and in particular to the recycling of packaging waste carried out by CONAI, presenting what Conai is and what it represents in the process chain of sorting, collection and recycling. Information related to the topic of sustainability is provided and professions that could be affected by this topic are presented.
The PCTOs are compulsory for all students in the last three years of high school and are intended to help the student's orientation by providing an overview of the world of professions and helping them to identify their aptitudes. The project is currently in preparation, so it has not yet been implemented.
It will be conveyed through the Scuola.net online platform, through which students and teachers can register to check their actual participation and obtain the 40 compulsory hours.

Target

The course is designed for students in grades 11th to 13th .

Main theme

One module should be dedicated to green jobs, i.e. the world of professions related to the topic of sustainability and recycling. Another module should be dedicated to the communication projects carried out by Conai, such as the "Renaissance for the Environment" campaign or the "Recycling Class" project, to show how it is possible to develop green issues within very different working worlds.
The PCTO project should be developed in cooperation with the 7 packaging material recycling consortia. Each consortium should have a module dedicated to the individual material it deals with in

which the focus is put on special projects related to the activities they carry out in the field of communication and on the territory, in order to provide a 360° view of possible activities and job spin-offs.

Materials

The course consists of 40 hours via an e-learning platform. A certificate of participation is issued at the end of the activity. The PCTO project will also include another 40 hours of online activities managed between the school, the training provider and CONAI.

Competences

The PCTO course is designed to help students learn about sustainability, the circular economy and separate waste collection. Within the course the main values underlying the functioning of the consortium are promoted, together with the relationships and interconnections between the CONAI consortium, supply chain consortia, political, business and local stakeholders. Knowing how these stakeholders interact with each other can help in understanding the deep level of complexity behind sustainability issues, and provide the basis for developing critical comparisons that allow them to take ideas and conduct sustainable actions.

This type of activity refers to all four competence areas of GreenComp (Bianchi et al., 2022): "Embodying sustainability values (A1)", "Embracing complexity" (A2), "Envisioning sustainable futures" (A3) and "Acting for sustainability" (A4).
In particular, through this training activity it is possible to work on the development of competences such as "Supporting fairness" (A1.2), "Promoting nature" (A1.3), "Systems thinking" (A2.1), "Critical thinking" (A2.2), "Problem framing" (A2.3), "Adaptbility" (A3.2), "Exploratory thinking" (A3.3), "Political agency" (A4.1), "Collective action" (A4.3) and "Individual initiative" (A4.3).

ACTIVITY	**PCTO**
TARGET	10th to 12th grade
TYPE OF ACTIVITY	Online course
AIMS	1. To help students learn about sustainability, the circular economy and separate waste collection. 2. To promote the main values that underpin the functioning of the consortium, together with the relationships and interconnections between the CONAI consortium, supply chain consortia, political, business and territorial realities. 3. Raising awareness of how these stakeholders interact with each other to understand the deep level of complexity behind sustainability issues. 4. Giving the basis for developing critical comparisons that allow them to take ideas and conduct sustainable actions.
GREENCOMP COMPETENCES ACTIVATED	
COMPETENCES ACTIVATED	Supporting fairness - Promoting nature - Systems thinking - Critical thinking - Problem framing - Adaptability - Exploratory thinking - Political agency - Collective action - Individual initiative

STRENGTHS	The course seeks to exploit a regulatory duty to introduce topics and issues related to the world of separate collection and recycling, allowing a wide range of knowledge to be imparted on topics that are generally not discussed or presented in class.
USEFUL LINKS	https://www.conai.org/notizie/green-future-green-jobs-il-nuovo-progetto-conai-per-le-scuole-superiori/#:~:text=%C3%A8%20il%20PCTO%20che%20Conai,i%20trend%20dei%20prossimi%20anni

9.1.1.3 Academic Handbook “Economia circolare: la sfida del packaging” (university)

General description

The academic handbook (Acampora & Pratesi, 2023) is a project carried out by CONAI that aims to provide and build a basic knowledge base on the topic of the circular economy and packaging. The manual also aims to present the role played by the consortium and supply chain consortia within the packaging recycling processes. In particular, the manual is published on the 25-year anniversary of the consortium's formation and is a testimony to the consortium's constant efforts over the years. The objective of the handbook is to systematise all the knowledge accumulated in the management of packaging from a circular perspective, comparing the work of CONAI and the results found in the scientific literature. The handbook went through a peer review process after more than a year of collecting the material necessary for its construction. More than 30 professors from various Italian universities such as Politecnico di Milano, Università Bicocca, Sant'Anna di Pisa, the pool of AISME (Italian Association of Merchandise Science), Università della Tuscia, Università di Roma Tre, and Università della Basilicata contributed to the manual. The editors of the handbook are Professors Carlo Alberto Pratesi and Alessia Campora.
All this can become preparatory to acquiring a functional knowledge base for the world of work where transversal and interdisciplinary knowledge represents an added value in tackling a complex issue such as waste management.
The handbook fills a gap in teaching that addresses the complexity of packaging and its sustainable management within courses and teaching on the circular economy.

Target

The handbook is aimed at university students embarking on scientific-technological degree courses (engineering, science, architecture, etc.) and at those pursuing more humanistic subjects, such as economics, management, and law, aimed at sustainable development. It also lends itself to managers and environmental consultants interested in learning more about the circular economy.

Main theme

The manual is divided into two main parts. The first part, entitled 'Introduction to the Circular Economy: Principles, Policies and Tools' is divided into five units:

1. From waste to resources: the new paradigm of the circular economy
2. Waste and the circular economy: a regulatory framework
3. The role of consumers in the circular economy
4. 4. Sustainable and circular business models
5. Tools for the circular economy

The second part is entitled 'The Circular Economy and the Packaging Sector', and is also divided into five units:

6. The circular packaging
7. The governance and regulation of the packaging waste management cycle

8. The integrated packaging waste cycle
9. Ecodesign of packaging
10. The role of the public and private consumer in the development of a circular packaging system.

In the first part, the authors address the topic of circular economy in its broadest sense, taking an in-depth look at the context, schools of thought, tools, regulations and business models; in the second part, the topics are broken down into specific packaging areas. The handbook contains empirical research results aimed at investigating current and future trends in circular consumption, the related drivers and the role of communication in guiding consumer choices. The perspective adopted within the handbook is multidisciplinary (economic-management, legal, technical perspectives).

The academic handbook project was presented at various Italian universities such as the University of Tuscia, the University of Roma Tre, the University of Milan Bicocca and the Milan Polytechnic. In the coming months, presentations will also be made at the Iuav University of Venice, the Polidesign of Milan and the Sant'Anna Institute of Advanced Studies in Pisa. The presentation of the manual can be seen as an integral part of the project in that, in addition to the presentation of the manual by the authors and those who collaborated in the drafting of the manual, part of the event was reserved for the presentation of the so-called 'jobs of the future' by Randstad Research, whose representatives presented the study 'The 200 Professions of the Circular Economy' and provided an overview of the new jobs in the circular economy.
In particular, the objectives of the meetings were as follows:

- promote the knowledge and adoption of the handbook in the main lessons related to the area of Circular Economy and sustainability more generally;
- convey, also thanks to the contribution of the book's authors and experts, CONAI's commitment to sharing its know-how on circular economy;
- stimulate, among young students, interest in the topic of Green Jobs, proposing the prospects for development and employment in the circular economy sector.

Materials

The handbook consists of 23 chapters. Each chapter consists of a peer-reviewed scientific article written by experts from within the partner universities and the CONAI consortium.

Competences

The academic handbook focuses heavily on a systemic view of the issues related to the circular economy and packaging. The handbook provides an insight into the role played by different stakeholders within the recycling chain in the Italian landscape, together with the necessary information on regulations, standards and directives. The multi-disciplinary approach used in the manual to deal with these issues allows for the development of systemic and critical thinking skills, which are indispensable to be able to understand the dynamics of the problem, its most important aspects and their degree of interconnection and interdependence.

This type of activity refers to all four competence areas of GreenComp: "Embodying sustainability values (A1)", "Embracing complexity" (A2), "Envisioning sustainable futures" (A3) and "Acting for sustainability" (A4).
In particular, through this training activity it is possible to work on the development of competences such as "Supporting fairness" (A1.2), "Systems thinking" (A2.1), "Critical thinking" (A2.2), "Problem

framing" (A2.3), "Futures literacy" (A3.1), "Adaptability" (A3.2) "Exploratory thinking" (A3.3) and "Political agency" (A4.1).

ACTIVITY	**ACADEMIC HANDBOOK**
TARGET	University students in science, technology and the humanities (economics, law, jurisprudence)
TYPE OF ACTIVITY	Joint presentation and discussion Writing and editing of peer-reviewed chapters
AIMS	- To raise awareness of the role played by the different stakeholders within the recycling chain in the Italian landscape, together with the necessary information on regulations, standards and directives. - To develop systemic and critical thinking skills, indispensable to be able to understand the dynamics of the packaging and recycling problem, its most important aspects and their degree of interconnection and interdependence. - To encourage the knowledge and adoption of the manual in the main lessons that pertain to the area of Circular Economy and, more generally, of sustainability; - To make people perceive, thanks also to the contribution of the book's authors and experts in the sector, CONAI's commitment to sharing its know-how on the subject of circular economy; - To stimulate, among young students, interest in the subject of Green Jobs, proposing the prospects for development and employment in the circular economy sector.
GREENCOMP COMPETENCES ACTIVATED	
COMPETENCES ACTIVATED	Supporting fairness - Systems thinking - Critical thinking - Problem framing - Futures literacy – Adaptability - Exploratory thinking - Political agency
STRENGTHS	The handbook fills a gap in teaching that addresses the complexity of packaging and its sustainable management within courses and teaching on the circular economy.
USEFUL LINKS	https://www.conai.org/notizie/in-libreria-un-nuovo-viaggio-nella-sostenibilita/

9.1.1.4 GreenJobs – Waste management between law and technology (post-graduate)

General description

The 'Green Jobs' project concerns the post-graduate training of students living in or graduated from universities in central and southern Italy. The project was developed as an advanced training course for recent graduates and was first realised in conjunction with the events related to Matera 2019 - European Capital of Culture. The course aims to promote studies and professions related to the circular economy, and thus facilitate the development of so-called 'green jobs' by developing skills related to recycling and the circular economy. The focus on universities in southern Italy is because there is a difference in Italy in terms of infrastructure and separate collection and recycling percentages between north and south, and to bridge this gap it is increasingly urgent to invest in skills, starting with people and adequate training, to have trained and qualified personnel in the near future, especially for areas lagging behind. Achieving packaging waste recycling targets requires the cooperation of a civil society prepared to manage the life cycle of waste.
The course has also been offered in the north, on the occasion of 'Bergamo Brescia Italian Capital of Culture 2023'. The Green Jobs course is in its seventh edition and was previously implemented in Basilicata, Sicily, Calabria and Campania, training almost 500 new graduates in four years. During this

time, it received the patronage of MITE (Ministry for Ecological Transition), currently MASE (Ministry for the Environment and Energy Security).

Target

The course is primarily designed for recent graduates from universities in the south of Italy or who reside in the centre-south, but will also be taken to other regions in Italy. The course is organised by CONAI in cooperation with several universities and other institutional bodies and stakeholders. The course is free of charge for participants. The course is aimed at 80 participants per session, is repeated several times a year according to the different universities that request activation, and has so far trained around 500 people.

Main theme

The courses are divided into two main parts, a regulatory part and a technical part. In the first part, topics such as laws for the correct disposal of waste, management, sanctions, and liability are covered. The regulatory system is of central importance since to understand the realities of the circular economy, it is necessary to know what laws and regulations govern these processes. The technical part, on the other hand, focuses on waste treatment, the biological treatment of the organic fraction, the functioning of integrated waste management systems and processes, and product certifications (e.g. eco-labels). The technical part then focuses on the actual recycling processes, to show the reality of recycling in the area today. The technical part is developed together with supply chain consortia and companies operating in the recycling sector, which specify the differences in the recycling processes of different materials and related business opportunities.
The course approach is multidisciplinary. Several experts participate as lecturers in these courses, coming from research and business environments, but also from specialised supply chain consortia. The title of these courses is 'GreenJobs: waste management between law and technology'. It is held in 4 regions of South Italy, in collaboration with the University of Basilicata, Mediterranea University of Reggio Calabria, University of Palermo and the University of Campania.

Materials

The course is developed in 24 modules, run over 12 days (equivalent to a total of 72 hours of face-to-face teaching). The planned duration is therefore four weeks. The lectures are held in live webinar mode, with a final in-presence appointment for the delivery of the certificates. During the course, notions, examples of best practices, bibliographical references and useful slides are provided for studying the topics covered. It is envisaged that Reteambiente Formazione, a partner in the project, will provide participants with an online platform with study and in-depth study materials.

Competences

The GreenJobs training activity aims to develop in the participants the ability to understand the basic rules that describe the world of separate collection and recycling and therefore the consortium structure, through the presentation of the regulations that define what are the obligations, duties and rights of individuals concerning the systems in which they live. In addition, in the technical aspects of the course, the aim is to familiarise participants with the functioning of the consortium system, the role of the various stakeholders involved in the process and the procedures required to achieve higher levels of separate collection and recycling. The skills to be worked on are therefore related to aspects of knowledge, system vision and critical thinking, and the role of the legislative and therefore political world.

This type of activity refers to all four competence areas of GreenComp: "Embodying sustainability values" (A1), "Embracing complexity in sustainability" (A2), "Envisioning sustainable futures" (A3) and "Acting for sustainability" (A4).
In particular, through this training activity, it is possible to work on the development of skills such as "Suppporting fairness" (A1.2), "Systems thinking" (A2.1), "Critical thinking" (A2.2), "Problem framing" (A2.3), "Futures literacy" (A3.1), "Exploratory thinking" (A3.3) and "Political agency" (A4.1).

ACTIVITY	**GREEN JOBS**
TARGET	Graduated students (between 25 and 30 years)
TYPE OF ACTIVITY	Online courses with a final exam
AIMS	- To promote studies and professions related to the circular economy – - To develop the growth of skills related to recycling and the circular economy - To develop in participants the ability to understand the basic rules that describe the world of separate collection and recycling - To present the regulations that define what are the obligations, duties and rights of individuals with respect to the systems in which they live - Introduce them to the functioning of the consortium system, the role of the various stakeholders involved in the process and the procedures required to achieve higher levels of separate collection and recycling.
GREENCOMP COMPETENCES ACTIVATED	
COMPETENCES ACTIVATED	Supporting fairness - Systems thinking - Critical thinking - Problem framing - Futures literacy - Exploratory thinking - Political agency
STRENGTHS	The course manages to cover a wide range of topics, allowing you to develop skills in both regulatory and technical areas, which are essential to effectively enter the world of work and play important roles in the field of sustainability.
USEFUL LINKS	https://www.conai.org/notizie/corso-di-formazione-gestire-i-rifiuti-nelleconomia-circolare-aperte-le-candidature-per-bergamo-e-brescia/

9.1.2 Companies

9.1.2.1 Training for consortium members

General description

The National Packaging Consortium works directly with companies, businesses, and trade associations. This collaboration provides fulfilment and opportunities for consortium members. Among the fulfilments are the registration to the consortium, the application of the environmental contribution, the obligation of environmental labelling (in force as of 2023) and the request to comply with directives; as far as opportunities are concerned, consortium members can be exempt from the payment of the contribution in some particular cases, the possibility to receive personalised advice and the security of having support for everything concerning the production, sale, consumption and collection of packaging materials.
To make this cycle work, CONAI engages in several training activities dedicated to member companies and trade associations. Training events can be held either in person, as in the case of road shows, or as

webinars. Seminars generally last from one hour to three or four, depending on attendance and the importance of the topic. Seminars are generally held in face-to-face mode, with the opportunity for participants to speak and present specific cases.

Target

Training activities are mainly targeted at operational technicians from consortium member companies and trade associations at national and regional levels. As far as consortium members are concerned, we generally target administrative staff, the purchasing department, and in general those figures interested in technical aspects. If the subject of the training activity is particularly relevant, managing directors and reference figures of the associations may also attend these meetings.

Main theme

In the context of training activities for consortium members and associations, training activities are carried out regarding the application of the contribution or updates on directives and obligations, such as the environmental labelling obligation and updates on the SUP (Single Use Plastic) directive. The objective of these activities is to make people aware of the obligations and opportunities provided for in the agreements that CONAI undertakes with its consortium members.
As far as the environmental contribution is concerned, CONAI is committed to specific training on how to collect the contribution. CONAI's environmental contribution (CAC) is an economic contribution that producers (those who produce the packaging) add at the time of first transfer to users of this packaging. This contribution is then collected and transferred to CONAI, which in turn transfers it to the sector consortia that use it for their recycling processes. Furthermore, part of this contribution is given to the municipalities as provided for in the ANCI-CONAI agreement to support municipalities in the separate collection process. The guidelines on the operation of the application of the contribution change very often, which obliges the consortium to carry out training seminars and webinars where these changes are presented.
In the case of the directive on compulsory labelling, various measures were produced: webinars with association representatives to inform and train, and to address critical issues raised by stakeholders thanks to previously collected questions; sector webinars open to companies and promoted with the associations and focused on the presentation of contents and moments of exchange and comparison; production of FAQs on the site and guidelines for sectoral application; publication of results on the community; participation in events promoted by associations and confederations of industry as experts.
In the case of the UAS Directive on single-use plastics, guidelines were produced to facilitate the interpretation of the standard, providing multiple practical examples of the types of packaging involved, as well as a FAQ section structured through interaction and questions from companies and stakeholders. These guidelines were produced through the instrument of public consultation. The guidelines are divided into a presentation of the chronology, the regulatory aspects and subject measures of the directive, sanctions, and a description of the packaging articles covered.

Materials

During the seminars, slides are used to support the presentations made. In addition, specific guides are produced to present the details of the various fulfilments and opportunities, such as the 'Guide to Accession and Application of the Environmental Contribution'.

Competences

Training activities for consortium members (enterprises, companies, associations) aim to present the regulatory background behind the consortium management system and the correct way to adhere to legal requirements. In presenting and carrying out these activities, the regulatory aspects are supported by value aspects necessary to provide motivations and explanations as to why certain choices are made. In this way, the aim is to develop in those directly involved skills related to knowledge of the system, the ability to support the different stakeholders and the different links in the consortium chain.

This type of activity refers to the GreenComp competence areas "Embodying sustainability values (A1)", "Embracing complexity" (A2) and "Acting for sustainability" (A4).
In particular, this training activity allows one to develop competences such as "Valuing sustainability" (A1.1), "Supporting fairness" (A1.2), "Systems thinking" (A2.1), "Problem framing" (A2.3), "Political agency" (A4.1), and "Collective action" (A4.3).

ACTIVITY	**TRAINING FOR CONSORTIUM MEMBERS**
TARGET	Enterprises, companies, associations
TYPE OF ACTIVITY	Training seminars, Training webinars, Production of guidelines
AIMS	- make known the fulfilments and opportunities provided by the agreements that CONAI undertakes with its consortium members - present the regulatory background behind the consortium management system and the correct way to adhere to the fulfilments imposed by the laws - construct guidelines to present the chronology, regulatory aspects and the subject measures of the directive, sanctions, and a description of the packaging items that fall within the scope of application - help consortium members navigate the bureaucracy associated with the separate collection and recycling processes
GREENCOMP COMPETENCES ACTIVATED	
COMPETENCES ACTIVATED	Valuing sustainability - Supporting fairness - Systems thinking - Problem framing - Political agency - Individual initiative
STRENGTHS	Training activities for consortium members help to keep them up-to-date on the rights, duties and obligations of collection and recycling processes. The capillarity of the interventions, the diffusion throughout the territory and the dissemination of materials online allows for large catchment areas and therefore a very wide audience to create moments of sharing and exchange of ideas and good practices.
USEFUL LINKS	https://www.conai.org/notizie/le-novita-della-guida-al-contributo-ambientale-conai-il-23-febbraio-in-un-webinar/ https://www.conai.org/?dlm_download_category=guida-al-contributo https://www.conai.org/?dlm_download_category=prevenzione

9.1.2.2 CONAI Community

General description

The CONAI Community (https://www.conai.org/conai-academy-community/) is a digital platform that aims to provide support and guidance in activities related to packaging and the circular economy. The platform is aimed at companies, associations and all stakeholders of the packaging chain interested in these issues. The purpose of the Community is to provide a digital environment for networking, where members can share problems and solutions with other actors on the platform, and at the same time, keep up-to-date on the CONAI world, packaging and the circular economy. The community was developed

and tested in 2021 and launched in 2022. At the beginning of 2023, it exceeded 5,000 members. Companies, businesses and consultants have the possibility to structure their private profile and to publish or comment on posts, so as to create a dialogue and enable the building of a network of contacts. The platform's task is not to create an additional channel of communication but rather to build a place to find information and stay up-to-date on what is happening in the world related to the separate collection of packaging and the CONAI world. In this way, the aim is to build a community that is capable of self-managing, feeding and supporting each other.
The CONAI community is part of the CONAI Academy development project, i.e. an environment in which training is provided in different ways to touch different types of topics and audiences.

Target

The community refers mainly to companies, associations, supply chain stakeholders and consultants, but also private citizens and all actors who may be interested in these issues.

Main theme

The platform currently offers 12 different in-depth topics, with more than 370 posts published. The topics are environmental labelling of packaging, environmental contribution, regulatory news, packaging/non-packaging, projects and research for the circular economy, tools for eco-design, promotion of events and activities, facts from the world, the ANCI-CONAI agreement, green jobs, and experts in ecological transition. Furthermore, the platform is used to communicate CONAI world events such as webinars, presentation events, document launches, and sustainability reports.
For some documents in particular, such as the vademecum for the digital environmental labelling of packaging or the guidance on the UAS directive, public consultation of the document was used via the community. Users (companies, consultants, consortia and member companies) in this way can access the document, read it, comment on it and leave suggestions for changes or suggestions for doing so.
The topics to be posted on the community are decided through a PED (Digital Editorial Plan), in which the topics to be covered are entered bi-weekly. A graphics support company then handles the construction of the posts/videos to be uploaded to the platform.

Materials

The platform is structured as a social network. On it, links to events, pages, documents to be discussed in public reading, and informative videos by experts are shared.

Competences

The aim of the community is to link together consortium companies and businesses and, in general, people interested in the topics of packaging and separate waste collection in the context of an environment in which an attempt is being made to develop a circular economy model. The contents presented within the community aim to develop skills related to the system vision, the multidisciplinary approach and the role of individuals within a system such as the consortium. Peer interaction is supported, as is their active role in decision-making processes. This helps to develop skills related to collaboration and collective action.

This type of activity refers to the GreenComp competence areas "Embracing complexity" (A2), "Envisioning sustainable futures" (A3) and "Acting for sustainability" (A4).
In particular, through this training activity, it is possible to work on the development of competences such as "Systems thinking" (A2.1), "Problem framing" (A2.3), "Exploratory thinking" (A3.3), "Political agency" (A4.1), "Collective action" (A4.3 "Individual initiative" (A4.3).

ACTIVITY	**CONAI COMMUNITY**
TARGET	Companies, associations, stakeholders, consultants, citizens
TYPE OF ACTIVITY	Communication and sharing of content, activities, information materials
AIMS	- provide support and guidance in activities related to packaging and the circular economy; - provide a digital environment for networking, where members can share problems and solutions with other actors on the platform; - create a space to keep up-to-date on the CONAI world, packaging and the circular economy.
GREENCOMP COMPETENCES ACTIVATED	
COMPETENCES ACTIVATED	Systems thinking - Problem framing - Exploratory thinking - Political agency - Collective action - Individual initiative
STRENGTHS	The Community platform has the ability to bring together actors in the CONAI network, to share the knowledge built up over years of experience among members, and to present news in terms of innovations, changes in regulations and novelties in general, all in one place open to all stakeholders.
USEFUL LINKS	https://www.conai.org/conai-academy-community/ https://conaiacademy.tribe.so/

9.1.3 Municipal technicians

9.1.3.1 Training Seminars/Webinars

General description

CONAI is pursuing a four-year agreement with the National Association of Italian Municipalities (ANCI). The ANCI-CONAI Framework Agreement guarantees municipalities that collect steel, aluminium, paper, plastic, bioplastic and glass packaging waste in differentiated form the possibility of signing, either directly or through a third party delegated by them, the ANCI-CONAI conventions with the individual supply chain Consortia and conferring the collected packaging waste to them. The Consortia take it back and send it for recycling, recognising predefined fees to the municipalities for the higher charges incurred for separate collection. Various activities are planned within this agreement, including specific training seminars. In 2021, CONAI has developed a two-year training plan spread over five points:

1. Standard training seminars
   Approximately 20/25 seminars of 6 hours each are organised each year, one for each provincial capital of each region. These seminars are organised by the communication section of ANCI from a logistical point of view (e.g. contact with lecturers and experts), while CONAI supports the actions and defines the educational programme of the events. Each seminar is held both online and in person. The main topics of these seminars are the presentation and description of the ANCI-CONAI framework agreement, the description of the technical annexes, training on opportunities for municipalities such as conventions, how they work and how to manage material collection. Focuses on specific topics are then added each year, such as the regulatory framework, procurement management, the UAS directive.

2. <u>Annual event on circular economy</u>
   This event consists of organising a large event, to be followed both in person and remotely, on a different topic year by year that is closely linked to circular economy issues. For example, the 2022 event was focused on DRS (Deposit Return System, or security deposit), on the draft regulation under discussion at European level, and on the presentation of mayors of some particular realities where particularly effective management is present. The event lasted one day.
3. <u>Metarial-specific Webinars</u>
   This activity involves developing specific webinars on the individual packaging materials to be sorted and sent for recycling. These specific webinars are developed together with a communication and video production agency and involve the discussion of the technical annexes of the ANCI-CONAI framework agreement by the in-house technicians of CONAI and the various chain consortia. The webinars also included a part dedicated to answering questions previously asked by participants. Five such webinars were held in the 2021-2022 two-year plan.
4. <u>Specific seminars for high-risk territories</u>
   This measure envisaged the development of three special seminars to be held in specific locations in the South where there was a major lag in the development of an efficient and effective separate collection system.
5. <u>Support for local communities</u>
   This measure concerns support to be given to local realities in the South to help intercept PNRR (National Recovery and Resilience Plan) funds. It is a project between training and planning but is part of the two-year plan.

Target

These training activities are primarily targeted at municipal technicians, and in particular the waste collection service managers of each municipality and their staff. Classic seminars and annual events are also open to outsiders, e.g. also the managers of collection companies and citizens interested in these events.

Main theme

The main objective of the project is to inform and train stakeholders on the functioning of the framework agreement, its existence, and the benefits and consequences of its implementation. In addition, these activities aim to train on the subject of waste management, both from a regulatory and administrative point of view and from a technical point of view. For example, some of the topics covered are what is a home waste collection, what happens to the waste after it has been collected, how to make an assignment, how to entrust the service, how to deal with a tender, etc.

Materials

Each activity always consists of the use of specific slides prepared by the sector experts called upon to present. These slides are then provided and remain viewable on the https://anciconaiformazione.it website. In addition, webinar recordings and ad hoc videos prepared for the technical focuses are available.

Competences

Training activities for municipal technicians are designed to present the functioning of the consortium system with regard to separate collection and recycling processes and the regulations in place. These activities have a very strong training purpose, which aims to develop skills related to overview, framing of problems that cannot always be solved and the role played by all stakeholders and citizens in the collection process.

This type of activity relates to all four of GreenComp's competence areas "Embodying sustainability values (A1)", "Embracing complexity" (A2), "Envisioning sustainable futures" (A3) and "Acting for sustainability" (A4).
In particular, this training allows one to develop competences such as "Supporting fairness" (A1.2), "Promoting nature" (A1.3), "Systems thinking" (A2.1), "Problem framing" (A2.3), "Exploratory thinking" (A3.3), "Political agency" (A4.1), "Collective action" (A4.2), and "Individual initiative" (A4.3).

ACTIVITY	**TRAINING SEMINARS FOR MUNICIPALITY TECHNICIANS**
TARGET	Municipal technicians (in particular, waste collection service managers from each municipality and employees), collection company managers, citizens
TYPE OF ACTIVITY	Seminars, webinars, communication events
AIMS	- inform and train stakeholders on the functioning of the framework agreement, its existence, and the benefits and consequences linked to its implementation - train on the subject of waste management, both from a regulatory and administrative point of view as well as from a technical point of view - present the functioning of the consortium system with regard to separate collection and recycling processes - develop skills related to overview, framing of problems that cannot always be solved and the roles played by stakeholders and citizens in the collection process.
GREENCOMP COMPETENCE S ACTIVATED	
COMPETENCE S ACTIVATED	Supporting fairness - Promoting nature - Systems thinking - Problem framing - Exploratory thinking - Political agency - Collective action - Individual initiative
STRENGTHS	The activities are very helpful in keeping local responsible persons up-to-date with regard to their rights and obligations in the area of separate collection. This ensures a continuous and targeted update programme for those responsible who have to make decisions in the short and long term, which will have significant impacts on the lives of citizens, and on the outcome of the waste collection process.
USEFUL LINKS	https://www.conai.org/?dlm_download_category=accordo-anci-conai

9.1.4 Journalists

9.1.4.1 Training seminars

General description

CONAI has organised training activities reserved for members of the Journalists' Association in recent years. These activities are developed in the form of seminars, which are useful for obtaining credits for the continuous professional training of journalists (provided for by art. 3, paragraph 5, lett. B), of Decree Law no. 138 of 13 August 2011, converted with amendments by Law no. 148/2011). The format envisages a four-hour seminar in which various speakers from inside and outside CONAI take part, presenting how packaging and recycling waste is managed in Italy. The programme also includes personalities from the institutional and academic world.

The first two meetings were held in Palermo (May 2022) for members of the Order from Sicily, and in Milan (June 2022) for members of the Order from Lombardy. These events are organised in different regions from time to time to cover the entire national territory. The aim of the seminar is to provide basic information on the world of separate waste collection in Italy and on collection and recycling processes in order to help share these realities on the various communication platforms used.

Target

The activity is designed to train journalists registered with the various regional orders. The offer is part of the training obligation of journalists, who must collect 60 training credits every three years.

Main theme

At the training events, the figure of the National Packaging Consortium and the various supply chain consortia is presented, the role CONAI plays in the process of separate waste collection in Italy, its cooperation with businesses and companies, the agreement made with municipalities, but also the collection results at national level and the relationship with the demands coming from Europe.

Materials

In the edition dedicated to the Tuscany Region Order held on 14 April in Florence, the event was entitled "Recycling and Circular Economy. The Italy model that sets the standard in Europe: how it works and how it is communicated". During the four hours, various representatives of the consortium and also external experts spoke, presenting data and information on the CONAI model and the realities of the collection and recycling chain in Italy.

Competences

The main objective of the training activity for journalists is to train them in the functioning and structure of the consortium system for selective waste collection. On the one hand, this activity serves to provide information and disseminate knowledge about the CONAI system, while on the other hand it aims to enable journalists to communicate and disseminate information on the consortium system and its functioning. In this way, the service that is rendered to the public regarding waste collection processes has a lower potential to contain inaccuracies, and consequently allows for a greater dissemination of information regarding waste collection processes.

This type of activity refers to the GreenComp competence areas "Embodying sustainability values (A1)", "Embracing complexity" (A2) and "Acting for sustainability" (A4).
In particular, this training activity allows one to develop competences such as "Valuing sustainability" (A1.1), "Supporting fairness" (A1.2), "Systems thinking" (A2.1), "Problem framing" (A2.3), "Political agency" (A4.1), "Collective action" (A4.3), and "Individual initiative" (A4.3).

ACTIVITY	**TRAINING SEMINARS FOR JOURNALISTS**
TARGET	Target to whom the activity is directed (students, postgraduates, public administration, politicians, entrepreneurs, journalists, etc.)
TYPE OF ACTIVITY	Type of activity (seminars, online courses, publications, etc.)
AIMS	- provide basic information on the world of separate waste collection in Italy and on collection and recycling processes - help share the realities related to the world of separate waste collection on the various communication platforms used - allow an in-depth understanding of CONAI's achievements compared to other European realities and to European constraints

	- ensure direct contact between journalists and CONAI managers to allow effective and truthful information sharing
GREENCOMP COMPETENCES ACTIVATED	
COMPETENCES ACTIVATED	Valuing sustainability - Supporting fairness - Systems thinking - Critical thinking - Problem framing - Political agency - Collective action - Individual initiative
STRENGTHS	The training seminars succeed in the twofold objective of providing the necessary training for journalists and providing an overview of the activities and initiatives that CONAI conducts in the various fields.
USEFUL LINKS	https://www.conai.org/notizie/al-via-la-prima-edizione-della-fenice-conai-per-il-giornalismo-ambientale-giovane/

And we will never be alone again.

Instant Crush – Daft Punk ft. Julian Casablanca

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