# Like a stone in a pond: palm oil as a trigger point for ever-expanding concentric circles of knowledge towards global citizenship and sustainability education

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The principal function of science education is to introduce students to core scientific concepts and practices; nevertheless, it is now impossible, in such a complex world, to neglect the ethical issues involved. Placing school science in a broader context motivates students and equips them with valuable critical skills. A meaningful example has been drawn from the production of palm oil and its pervasive use worldwide: plantations result in major deforestation in species-rich tropical regions, making the palm oil issue global in scope and highly critical for several aspects related to sustainability. This paper reports a sequence of didactic activities starting from palm oil chemistry, gradually extended initially with a multidisciplinary approach, then by interdisciplinary-systemic maps and, ultimately, through a holistic vision - involving anthropological and cultural considerations about the indigenous peoples of deforested territories. This progressive broadening corresponds to an ever-greater penetration into the personal sphere, a condition that could pave the way for a real ethical consciousness. The increased students' awareness was tested by qualitative – not quantitative – considerations; unlike other disciplinary contents, the emergence of moral feelings cannot be measured but only perceived. Chemistry provides key concepts essential for the development of global competence in order to deal with sustainability issues with an increased ethical awareness.

**Keywords:** palm oil, chemical education, ethics and science, Systems Thinking, Education for Sustainable Development.



## 1. INTRODUCTION

In the early 1990s, many science education research studies [1] described a clear situation of crisis concerning science teaching. Science education researchers explained what underpinned this circumstance: teaching methods based on simple contents transmission [2]; the lack of connections with daily life and the resulting difficulty for students in transferring scientific knowledge from the school context to new situations [3]. Concerning the last point, Howard E. Gardner (1943-) stated that "the capacity to take knowledge learned in one setting and apply it appropriately in a different setting is the most basic definition of understanding" [4]. Obviously, this capacity requires an interdisciplinary vision of the topics covered; this explains why studies on the importance of interdisciplinarity have increased over the years.

Currently, scholars agree that the use of interdisciplinarity is a fruitful strategy. The interdisciplinary approach does not require a science syllabus organized by individual contents, but specifies some general topics across the disciplines. In this way, detailed syllabuses are replaced with output-oriented standards focused on problem-solving, analysis and communication skills. There are many definitions of the interdisciplinary character, for example, "the capacity to integrate knowledge and modes of thinking drawn from two or more disciplines in

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order to answer a question, solve a problem or address a topic that is too complex to be dealt with adequately by a single discipline" [5]. The idea of combining disciplines appeared for the first time in curricular contexts in the 1920s; in 1958 Benjamin S. Bloom (1913-1999) advocated for an inquiry-oriented integrated curriculum. Some curricular integrations were fully realised, like combined courses in natural and social sciences [6].

Integrated curricula implementation tried to deal with several issues: the criticism of isolated disciplines, perceived as too removed from everyday life; the inclusion of personal points of view or experiences as relevant to the learning development; the importance of inquiry skills; the view that forming connections between different fields of knowledge is an essential educational requirement for success in the 21st century [7]. Edgar Morin (1921-) insisted on the last point in the framework of his theories on complexity being applied to education. According to Morin, "the education of the future is faced with this universal problem because our compartmentalised, piecemeal, disjointed learning is deeply and drastically inadequate to grasp realities and problems which are ever more global, transnational, multidimensional, transversal, poly-disciplinary and planetary". Therefore, information and data must be placed in their context to have meaning. Consequently, education must encourage "general intelligence" able to deal with the complex, the context, in a multidimensional way, within a global conception [8].

The establishment of Bachelor's and Master's courses, such as those offered by the London Interdisciplinary School, is a sign of considerable progress. At the secondary school level, the application of the interdisciplinary approach is complicated by the necessity of reconciling it with core concepts of learning. Chemistry provides a meaningful example: it requires an interdisciplinary approach to be more attractive and to make clear its essential role in implementing sustainable practices; nevertheless, in order to avoid falling short of chemistry learning outcomes, context-based chemical education requires special precautions. Outcomes of context-based approaches can be positive from an affective development perspective, but they are somewhat disappointing from a cognitive development point of view [9]. Therefore, criteria for selecting adequate contexts are needed: they should be well-known to and relevant for students; they should not distract students' attention from related chemistry concepts; they should not be too complicated for students or confuse them [9].

It is also necessary to overcome the "myths" of interdisciplinarity: among these is the belief that an interdisciplinary approach applied to environmental issues

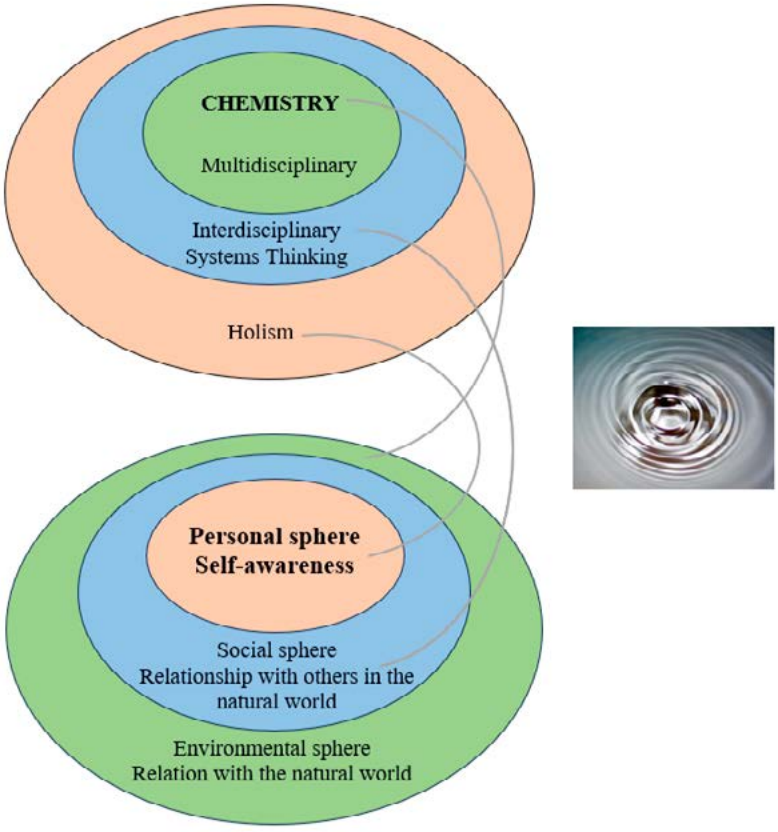


**Figure 1 -** The issues highlighted in the concentric circles originate from the chemical contents, which act like the stone thrown into the pond metaphor: they trigger an expansion of knowledge starting from disciplinary foundations. The picture of the water is an image courtesy of Roger McLassus /Wikimedia Commons (2006).

can be obtained mainly from problem-solving, underestimating the hermeneutic methods of the humanities [10]. Besides, the interdisciplinary approach requires either strong disciplinarian knowledge or some knowledge of other domains, with a clear perception of one's limits: even when a project is developed as a team, each member must not limit him or herself or their field and delegate some aspects to the other members in their entirety; it is important that the individual (for example, a teacher) has extensive cultural appreciation and an open mind [10]. For example, chemistry must be reformulated so as to embrace the different dimensions of sustainability; there is a need for teachers' training to take account of a broad social-political framework [11].

Implementing context-oriented chemistry teaching requires particular attention because of the nature of chemistry knowledge, characterised by continuous links between macroscopic and microscopic levels. Focusing on students' everyday experiences, there is the risk that neglecting to pay due attention to the microscopic level, as well as non-scientific fields, can potentially create difficulties in gaining disciplinary content knowledge.

Based on these considerations, this work describes a sequence aimed at the gradual implementation of some activities revolving around a current problem of global scope that involves the multiple dimensions of sustainability: the production and use of palm oil.

The sequence is divided into three main parts, starting from chemistry concepts and gradually broadening (Figure 1): in the first part, a multidisciplinary approach is adopted, starting from chemical knowledge; in the second part, students deal with the issues involved from an interdisciplinary-systemic point of view, the bridge that connects disciplinary and holistic knowledge [12]; in the last part, the holistic dimension is addressed. The phases listed correspond to a progressive penetration of knowledge into the personal sphere so that it can be internalised without remaining at an epidermal level [13], as shown in Figure 1. This is possible thanks to the emphasis placed on ethical issues, which play a key role in any discussion on sustainability [14].

## 2. PALM OIL: A SHORT OVERVIEW

Palm oil is a vegetable oil derived from the mesocarp of the fruits of oil palms. This oil is highly saturated and semi-solid at room temperature; like all other oils and fats, palm oil is composed of fatty acids esterified with glycerol, and a high concentration (44% by weight) of palmitic acid, a 16-carbon saturated fatty acid. There are various types of palm oil depending on the parts of the plant processed, the extraction process, the degree of refining and other factors.

From December 2014, in the European Union, the use of the generic term "vegetable oil/fat" was prohibited because palm oil must be clearly indicated in the ingredients list on food packaging [15]. Palm oil's low price and its chemical and physical properties make it particularly suitable for the confectionery industry (where it substitutes for animal butter); about 50% of common consumer products contain palm oil, such as biscuits, chocolate and various snacks. Moreover, approximately 70% of personal care products and household detergents contain products derived from palm oil.

Based on the data for the years 2024/2025, the top producing countries are Indonesia and Malaysia, with 46.5 and 19.2 million metric tons respectively (58% and 24% of global production); total production amounts to 79.53 million metric tons, with a constantly increasing average growth [16]. In the US, the palm oil market size was estimated at USD 2.02 billion in 2024 and is projected to grow at a Compound Annual Growth Rate of 8.4% from 2025 to 2030 [17]. Exponentially rising demand from the food, beverage, biofuel, energy, personal care, and cosmetics sectors is the primary driver of this market. The market itself is highly competitive and complex, with numerous players of all sizes employing advanced production, effective distribution, quality products, and diverse strategies to gain an advantage [18]. As for the end-use, the food and beverage sector held the largest market share at 68.9% in 2024, and it is predicted to maintain dominance. This is driven by increasing product application in the industry, expanding portfolios of products requiring palm oil, and global population growth fuelling international demand [18]. While palm oil as biofuel is a growing market with strong future prospects due to dwindling non-renewable resources, its demand in animal feed is currently also increasing because it's a cost-effective, readily available energy source that enhances feed efficiency and weight gain in livestock, offering formulation flexibility [18].

Several studies linked palm oil to cardiovascular diseases [19], although other oils have a higher saturated fats percentage than palm oil: coconut oil, much used in the food industry, is 86% saturated, whereas in palm oil, the saturated fats percentage is about 49% by weight; in animal butter, the percentage is around 51%, in cocoa butter approximately 60% [20]. Therefore, other oils and fats are more saturated than palm oil. In the didactic sequence presented, students are invited to reflect upon that, but the main issue presented is related to another risk lately considered to be linked to palm oil: the onset of cancer.

In March 2016, the European Food Safety Authority (EFSA) published a study carried out by the EFSA Panel on Contaminants in the Food Chain [21]; the study concerned the risk to human health related to the presence of some chemicals, including 3- and

2-monochloropropanediol (MCPD). These chemicals are formed during the food processing of vegetable oils and fats at temperatures up to 200 °C (higher than usual temperatures in the confectionery industry). According to EFSA data, oil “palm oil/fat” contained a percentage of between 2- and 3- MCPD higher than the respective percentages of other vegetable oils and fats [21]. These chemicals can cause cancer in vitro at very high concentrations, displaying evidence of genotoxic potential (in the same way as caffeine or alcohol). Concentrations involved in genotoxic effects evaluation are not usual in normal nutrition, since “with a normal diet it is very difficult to reach the quantities that would really measurably increase the individual’s risk of developing cancer” [20]. In any event, in the opinion of toxicologists, the daily dose of 3-MCPD would have to be below 0.8 µg/kg body weight [21]; toxicological information is too limited to establish a safe level for 2-MCPD [21]. In 2018, EFSA experts updated the 2016 opinion by setting new limits for the Tolerable Daily Intake (TDI) of 3-MCPD in µg/kg body weight, raising the level of security, including taking account of potential risks to the kidneys and male fertility [22]. They found that the established TDI of 2 µg/kg body weight per day was not surpassed in the average and high-consuming adult population [22]. However, a slight surplus of TDI was observed among high consumers in younger age groups, particularly in scenarios where infants were exclusively formula-fed: exposure levels of 2.4 and 3.2 µg 3-MCPD/kg body weight per day were estimated in specific scenarios for infants receiving formula only [22].

In the broader picture, the real risk is linked to the frequency and amount of consumption of food containing palm oil; this applies to all types of potentially carcinogenic food, not only palm oil [20]. Moreover, cancer is not the only disease involved: as specified above, cardiovascular diseases can also be caused by a poorly balanced diet, even if palm oil is replaced with other oils/fats.

In order to produce all the oil palm needed by the food industry, many countries gave up other crops, sometimes causing deforestation. It constitutes a serious problem in Southeast Asia, the geographical area exposed to the risk of drastically reducing biodiversity [23]. Furthermore, the poorest farmers convert their crops to oil palms, profitable but not sufficient to adequately feed local populations. In 2004 the Roundtable on Sustainable Palm Oil (RSPO) established international standards for sustainable palm oil production, but some aspects of RSPO certification were rejected [24]. It should be specified that the production of coconut oil and cocoa butter presents similar problems in producing countries because of the environmental and economic issues involved. In conclusion, the oil palm case study shows the very complex issues involved in evaluating food when considering all the factors in play.

It should be noted that many companies have pledged to eliminate forest loss from their supply chains by purchasing only certified “sustainable” products. Using statistical analysis on satellite estimates of tree cover loss to infer the impact of the certification system on deforestation in Indonesian oil palm plantations, a 2018 study found that certification reduced deforestation by 33% (although certification was mainly adopted in older plantations with little remaining forest). This suggested that broader adoption of certified practices by oil palm growers can have a significant impact on reducing deforestation [25]. Consequently, following the annual Roundtable Conference on Sustainable Palm Oil, RSPO members approved the 2024 RSPO improved principles and criteria. The adoption of these is set to advance the global partnership's goal of sustainable palm oil. The 2024 Standards not only retain the strengths of the 2018 version but also offer enhanced clarity, auditability, and ease of use for members. Furthermore, the integration with the RSPO's new digital system for data and supply chain tracking will provide valuable tools for members to strengthen their risk assessment and comply with emerging regulations [26].

## 3. MATERIALS AND METHODS

This didactic sequence has been implemented with 4th and 5th year Italian secondary school students over the course of about two months; it was repeated three times, in 2021, 2022, 2023, making some improvements from year to year. Italian secondary school lasts for five years, so it is attended by students from 14 to 19 years old; therefore, 4th-5th year Italian secondary school students are aged 18-19, whereas corresponding students within K-12 system attending the final two years of secondary level (eleventh-twelfth grade of K-12 system) are 17-18 years old.

The teaching sequence starts with students being asked three questions:

1) Why do the labels of various brands of biscuits leave out palm oil content on the packaging?
2) Can palm oil cause cancer?
3) Does palm oil use damage biodiversity?

The didactic sequence is structured in three sections (Sections 1–4), each corresponding to one of the questions above; each section is organised into three phases, according to a work scheme already tested with two other case studies [27,28]. Contents involved, phases and activities are specified in Tables 1 and 2 and described in detail in the file attached (the link to download it is provided at the end of this paper); this file contains all the students’ worksheets needed, in reference to the different sections and phases. The Sections relating to the three questions reported are described in the following paragraphs.

**Table I -** Chemistry content involved in sections 1–3. The syllabus contents list takes into account that some topics are part of cross-cutting subjects for all the secondary school years.

| Students Activities | 4th - 5th Year High School Chemistry Syllabus Contents |
|---|---|
| **Section 1** | |
| Analysis of labels and claims of commercial products. | Percentage concentrations. CLP regulations. |
| Extraction and characterisation of palm oil. | Separation techniques of organic compounds. |
| Understanding of the relationship between the chemical structure of fatty acids and their physical properties. | Physical and chemical properties of oils and fats and their characterisation (carbon chain length, intermolecular interactions, polarity, melting points, etc.). |
| **Section 2** | |
| Evaluation of toxicity of different oils/fats. | Exposure assessment, effect assessment and risk characterisation of chemicals. Metabolism of lipids. |
| Evaluation of toxicity of palm oil. | Exposure assessment, effect assessment and risk characterisation of chemicals. Metabolism of lipids. |
| **Section 3** | |
| Research about palm oil's effects on biodiversity. | Industrial oil extraction process and yield of extraction. Environmental impact assessment. |
| Analysis of sustainable criteria concerning palm oil production | Chemical aspects of sustainability (reducing pollution and emissions, pesticides' use, minimising greenhouse gas emissions, etc.). |

**Table II -** Phases and activities involved in each section of the teaching sequence. The estimate of hours required includes individual study.

| Activities | | | | |
|---|---|---|---|---|
| **Question** | **Phase I** | **Phase II** | **Phase III** | **Hours** |
| 1 | Sample observation and analysis of tags' claims. Research about oils and fats used in the food industry. | Laboratory experience: oil extraction and characterisation. Analysis of the relationship of chemical structures and physical properties. Research about the health effects of oils and fats. | Overall considerations in the light of previous activities. | 6 |
| 2 | Web research about specific aspects. Critical discussion and individual contribution. | Stoichiometric exercise. | List of recommendations to consumers based on the acquired knowledge. | 4 |
| 3 | Collective discussion about effects on biodiversity. Diagram interpretation. | Brainstorming in order to conceive possible solutions. | Overall look at sustainable certification criteria (in the form of exercise). | 3 |

## 4. SECTION 1 - QUESTION 1: PALM OIL CONTENT IN FOOD

For this section, 6 h of class time and individual study are required. The students' worksheets 1–6 in S1 describe in detail the activities carried out. They are aimed at developing students' skills in relating ingredients and claims of different brands of cookies and understanding the choices underlying advertising messages that involve oil content.

### 4.1. PHASE I

The teacher leads students in analysing four different brands of biscuits showing different lists of ingredients and various claims related to oils/fats content (worksheet 1). Then, students carry out research about the very large use of palm oil in food and the reasons for that (worksheet 2). It is noted that palm oil content is always left out in the lists of ingredients, whereas the presence and the percentage values of other oils (sunflower oil, olive oil) are highlighted.

4.2. PHASE II

Palm oil was extracted using the Soxhlet extractor (worksheet 3 of S1) of Figure 2 (which also depicts the ground biscuit sample and the extracted oil) from the biscuits sample (list of ingredients no. 1, worksheet 1 of S1) [29] containing only this type of oil. The oil extracted can be characterised at least by appearance, density and smoke point to evaluate its degree of chemical purity. The length of the fatty acid carbon chains and the number of their double bonds affect the lipids' melting point; students have to explain changes in the melting points in terms of intermolecular interactions (worksheet 4).

If extraction is not possible, the average percentage value of palm oil resulting from the scientific literature can be considered in subsequent activities; according to the data collected, the weight percentage of palm oil can reach 2% or more [30]. Extraction of oil from biscuits (as well as seeds, stones and fruits) can also be achieved by sonication [30], a technique that provides students with a useful example of the application of the principles of green chemistry [31].

The quantities of oil isolated ranged from 1.5 to 2.8 g for the same type of biscuits. Smoke point and density measurements were also not uniform, presumably due to impurities. It should be noted that there are various types of palm oil depending on geographical origin, processing, etc.; a comparison with the data present in scientific literature is, therefore, difficult, as food packaging generally does not indicate the type of palm oil used. Indeed, at an industrial level, it is very common to use mixtures of different oils, even though they can be classified generically as "palm oil". In any case, the weights obtained are suitable for the subsequent activity on toxic substances in palm oil.

Because saturated fats in food are related to cardiovascular diseases, students are asked to compare saturation degrees of palm oil, animal butter and vegetable butter (cocoa butter), three common ingredients of many foods. In particular, frequent palm oil use in the food industry has been a source of concern in recent years because of well-known reasons brought to students' attention (worksheet 5).

4.3. PHASE III

The students read other time ingredients and claims reported in worksheet 1 and express their considerations in the light of the previous activities (worksheet 6); in this way, they focus on some advertising strategies not well understood at first glance.

## 5. SECTION 2 - QUESTION 2: CORRELATION WITH CANCER ONSET

This section requires 4 h of class time and individual study. The students' worksheets 7–9 in S2 describe in detail the activities carried out. This section deals with the quantitative evaluation concerning the correlation between food containing palm oil and its potential genotoxic effects.

5.1. PHASE I

The highest occurrence values of the toxic compounds 2- and 3-MCPD were found in the food group 'Fats and oils', with 'Palm oil/fat' showing a mean middle bound (MB) level of 2,912 µg/kg for 3-MCPD (from esters), 1.565 µg/kg for 2-MCPD (from esters). The meaning of MB, LB, and UB has to be explained



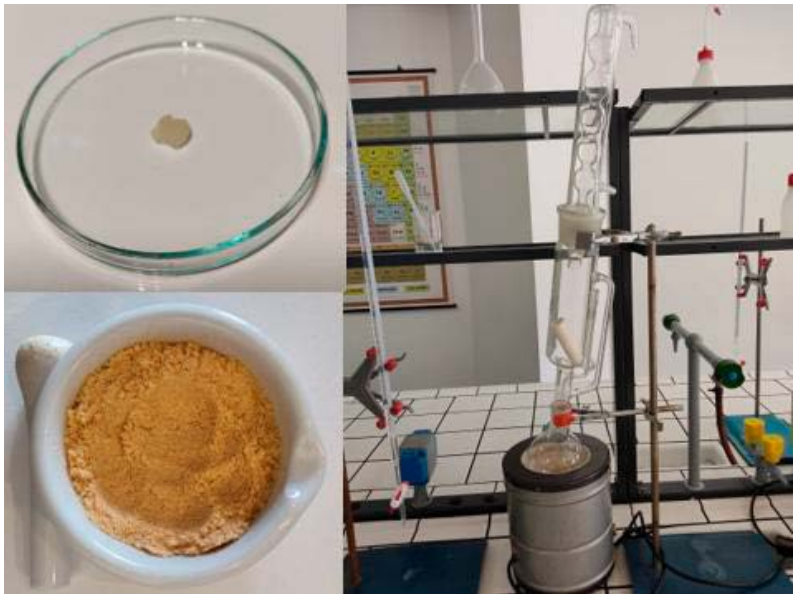

**Figure 2 -** Biscuit powder and oil extracted from some samples; Soxhlet apparatus

in advance during a mathematics class. Considering the values of 3-MCPD related to different oils and fats (including palm oil) and the TDI according to EFSA experts (2 µg/kg body weight) [22], each student can present his or her oral contribution during a collective discussion about one or more of the following issues (worksheet 7):

- The usual temperatures of food processing in the confectionery industry (where palm oil is largely used).
- All the oils/fats that can develop carcinogenic substances.
- The typical diseases caused by nutrition characterised by large amounts of oils and fats (is cancer the most probable disease?).
- The presence of palm oil among infant formula ingredients.
- The claim "palm oil free" used in advertisements.

5.2. PHASE II

Taking account of the amount of palm oil extracted in the laboratory and the body weight, the students calculate how many biscuits (sample no. 1, worksheet 1 of S1) must be eaten per day in order to ingest the maximum amount of 3-MCPD allowed in the opinion of toxicologists (worksheet 8). It is easy to confirm that the quantity of this toxic chemical necessary to trigger a possible malignant effect would require very high doses of food containing palm oil.

5.3. PHASE III

On the basis of the activities carried out, the students are guided in coming up with some concise recommendations to consumers on buying biscuits, including considerations about health effects and economic interests (worksheet 9).

## 6. SECTION 3 - QUESTION 3: CONCERNS ABOUT BIODIVERSITY

For this section, 3 h of class time and individual study are required. The students' worksheets 10–12 in S3 describe in detail the activities carried out. In this section, loss of biodiversity and the social impacts of palm oil production are presented. Oil palm cultivation causes deforestation in some geographical areas. Primary forests have been cleared and replaced by palm oil plantations. Many palm oil plantations have been developed without agreements with local communities and by displacing people from their land. Violations of workers' rights have also occurred. Other types of plantations allowing vegetable oil extraction generate similar problems, but oil palm is the most convenient oil because palm trees produce 4-10 times more oil than other crops per unit of cultivated land [32].

6.1. PHASE I

A collective discussion can take place in order to deal with the environmental and social impact of oil palm plantations (worksheet 10). Some hints could be:

- Do other types of plantations for vegetable oil industrial production raise similar problems?
- Many people residing in the exploited lands earn their living from the palm oil production industry.

During the following activity, students analyse and comment on a diagram extracted from an article [23] about palm tree plantations (worksheets 11); the diagram shows how plantation lands are situated mainly in Malaysia and Indonesia. This poses serious dangers for biodiversity and human rights in these geographical areas. This exercise stimulates the skills necessary to interpret visual representations as simple charts, gathering all the implications on the basis of the acquired knowledge.

6.2. PHASE II

A subsequent brainstorming session could be conducted in order to suggest measures aimed at minimising palm oil production's negative consequences (worksheet 12).

6.3. PHASE III

Sustainable palm oil production is a possible solution in order to contain the negative consequences of the palm oil business. Students analyse shortly all the different aspects involved in sustainable palm oil certification (worksheet 13).

## 7. CONSIDERATIONS ON MULTIDISCIPLINARY ACTIVITIES OUTCOMES

The didactic sequences described here involve several issues: oil chemistry, deforestation and biodiversity loss, conditions for agricultural production, health problems, human rights and the laws of the market. Teachers must be particularly proficient in focusing on chemistry content, avoiding dispersive activities. That requires not only ongoing further training centred on multidisciplinary methods, but also a strong preparation on disciplinary contents. This last point involves problematic issues in Italy, where most science teachers do not have the cultural background adequate in order to teach chemistry. In many Italian secondary schools, a single teacher - in general with poor academic preparation in chemistry - teaches earth sciences, life sciences and chemistry. Probably, the low interdisciplinary character of science education in Italy is connected to this prevailing academic profile. In fact, while it is true that some university qualifications (e.g. forestry, earth science, agronomy, food science, etc.) guarantee a particularly effective overall view of the natural world, chemistry is the "central science" [33] acting as the link with different fields because of its privileged position.

## 8. INTERDISCIPLINARY-SYSTEMIC APPROACH

Systems Thinking (ST) is crucial in order to develop sustainability competence [34] and, in general, an understanding of complex issues needed for reaching the goals of the UN 2030 Agenda conceived on a global scale [35]. An essential condition of authentic systemic thinking in understanding global dynamics is the acquisition of the concept of global citizenship. Global citizenship implies a concept of a multitude committed to developing the skills required in nurturing the sustainability of the physical, psychological and spiritual sides of planet Earth [36].
Western students should develop a clear perception of the weight of the factors in play: the European Union constitutes less than 6% of the world population, and the inhabitants of the entire West make up around 13%. Assuming our limited world view embraces the extended world is a typical mistake of Westerners, generating idealistic, self-centred considerations and, therefore, a distorted vision of reality [37].
Global Citizenship Education (GCE) refers to a complex system of relationships and actions [38,39]. The current distorted geopolitics of knowledge is causing ethical destabilisation of global school ecosystems [40,41]. ST is a useful tool to broaden horizons and begin to acquire a global mindset. After an introduction to the different ST graphical tools, simplified causal loop diagrams are used [42], adequately addressing the needs of students dealing with ST diagrams for the first time. Figures 3-6 show some diagrams made by the students' groups. The arrows indicate the direction of connections and the presence of feedback loops; the positive sign indicates a strengthening of the variable in the direction of the arrow, while the negative sign indicates a decrease.

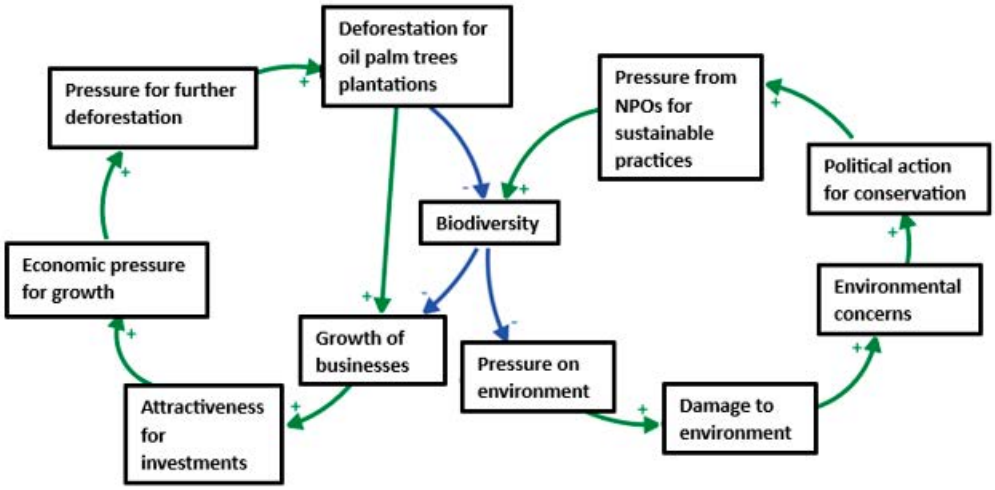


**Figure 3 -** Students' causal loop diagram revolving around biodiversity

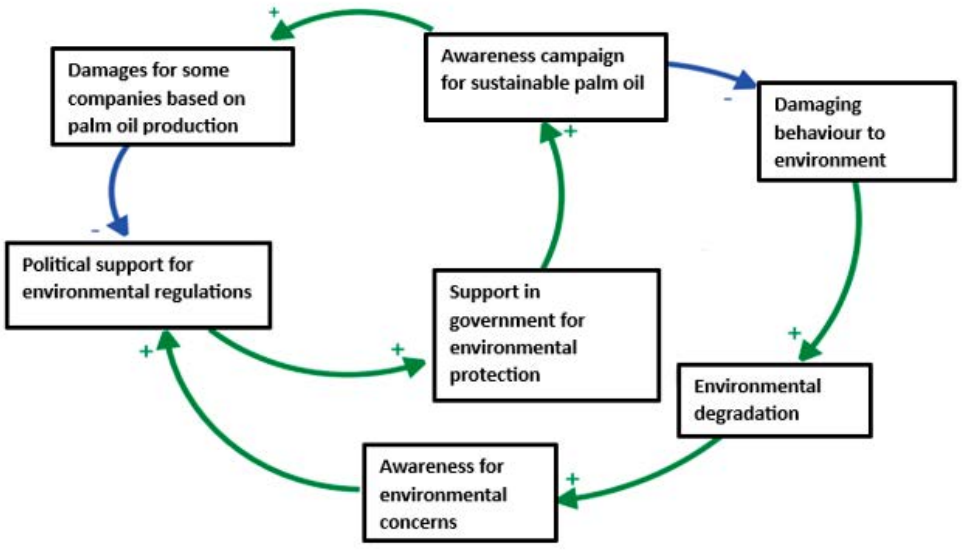


**Figure 4 -** Students' causal loop diagram revolving around environmental regulations

## 9. HOLISTIC APPROACH

Education for Sustainable Development (ESD) can benefit from Two-Eyed Seeing (TES), which combines a holistic and a scientific perspective [43]. TES was originally introduced to bring together the strengths of Indigenous and Western knowledge. The holistic aspect is important to give value to the psychological and spiritual dimensions of global citizenship [36], not considered in an exclusively scientific reference context. The analysis of some documents clearly explains the emotional value of palm oil, especially among African populations. The novels "Red Palm Oil Love" [44] and "The Palm Oil Stain" [45] refer to this oil in a symbolic way, associating it with romantic or nostalgic feelings. A Nigerian author writes [46]:

"As an undergraduate student in the U.S., I'd often come across many student demonstrations on campus calling for palm oil boycotts. I was confused at the time to learn that palm oil is a villain in the story of impending climate catastrophe […]. It's still odd to me to think of this gorgeous and delicious oil that stains most things it touches—many plastic containers have been permanently dyed reddish-orange from storing palm oil–heavy foods, many shirts have had to be bleached—as the same thing found in toothpaste, shampoo or even peanut butter. I'm still in love with palm oil, though. Not because I would like to ignore facts in order to enjoy my guilty pleasures in peace or because I don't care about orangutans and other endangered species. I truly do. I'm still in love with it because I understand that the problem isn't palm oil and its various potential uses. The massive scale on which it's harvested and refined and all the harrowing ways that the environment and workers are exploited in the process are more about the capitalist proliferation of everything and much less about palm oil itself."

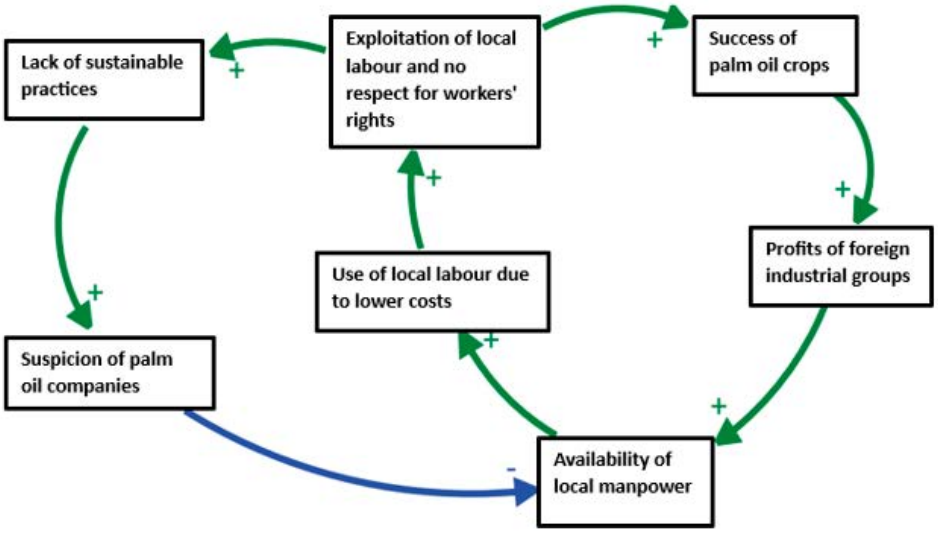


**Figure 5 -** Students' causal loop diagram revolving around local labour

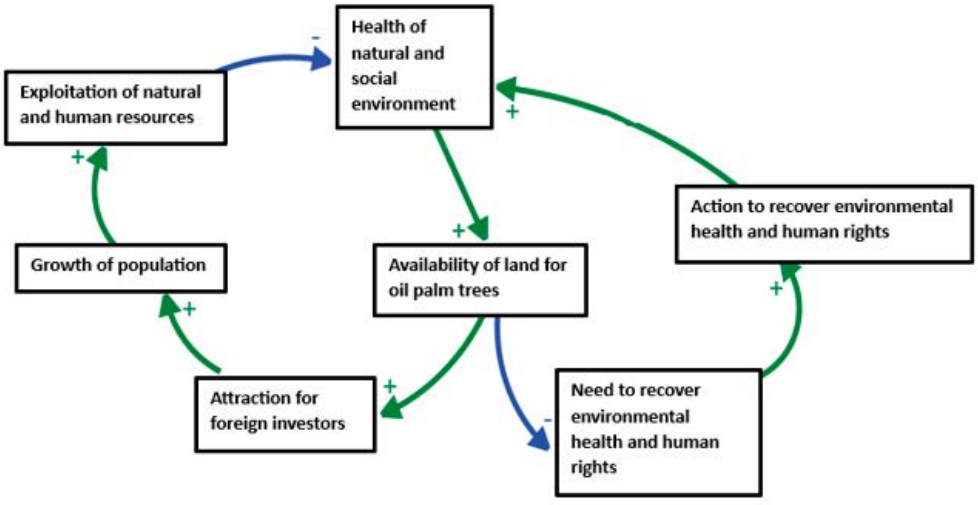


**Figure 6.** Students' causal loop diagram revolving around environmental damages.

These words highlight the conflict between two worlds, allowing us to take the point of view of a person who has lived in two very distant geographical areas. The entire article [46] synthetically and effectively calls into question the affective dimension, concern for the environment and economic interests at stake in a free-market system. Starting from these considerations, it is possible to more effectively interpret texts that also deal with the topic from an anthropological point of view [47]: for example, palm tree crops can be considered "racialised" since they might perpetuate some forms of slavery, even though slavery has been legally abolished.
Historical dynamics help to understand why current GCE is dominated by Western values and does not capture the values of other Western-dominated populations such as Africans. Within the context of Africa, the citizen concept is all-encompassing (it includes community, terrestrial and extra-terrestrial world) while, in ancient Greece, the citizen was conceived at first as belonging to the city-state, then extended to terrestrial and extra-terrestrial dimensions [48]. The system of capitalism previously confined to the West has now overrun the globe; so, typical Western GCE seems to equip learners in order to acquire the intellectual tools that would enable them to justify the status quo and understand any act that may have global repercussions [48]. While Western and modern GCE derived its origin and sustenance from the effects of the world built over past centuries, ancient African GCE is timeless, focused on the inner values belonging to the soul of humanity; this soul is the intrinsic source of a moral foundation which perceives humanity as a brotherhood [48]. Since Western civilization has provided an important and decisive contribution to scientific-technological progress, globally improving living conditions (albeit with large disparities), it is necessary to merge the scales of values for the benefit of the progress of all.
Other interesting considerations come from ethnographic research combined with the environmental history of western and central African countries: according to these studies, oil palms demonstrate the versatility and sustainability of local farming practices; in this area, forests have probably been advancing for the past 1,000 years, despite periods of drought, perhaps due to the "construction" of palm tree forests by local populations [49]. This is documented, for example, by the testimonies of colonial foresters: about a century ago, they spoke with the indigenous people, who recounted the habits of their ancestors [49]. Even today, in Southeast Asia, a Non-Governmental Organisation (NGO) is trying to strike agreements with palm oil growers to make this crop beneficial for nature [50]. In addition, it must be considered that alternative vegetable oil crops could be more environmentally harmful because of the lower yield from the same amount of land [32].
Oil palms have always been significant in material as well as culinary culture; they shape not only the environment but also history, nowadays through labour rights violations [51,52].
Palm tree plantations can therefore be sustainable only as long as all aspects of sustainability are considered [53]. That implies critical thinking skills in consumers, especially in Western countries [54], also in light of the fact that sustainable palm oil is still far from having a truly incisive impact [55].

## 10. CONCLUSIONS

The sequence described was qualitatively evaluated based on the students' considerations, their degree of participation and their attention to the proposed contents.
While carrying out activities obviously aimed at student learning, the teaching dimension was emphasised in the sense indicated by Gert Biesta [56]: the establishment of a dialogic and trusting relationship within the classes allowed for a relaxed and collaborative climate, where it was not important to demonstrate greater knowledge than classmates through verification tests. The teacher chose to aim at developing authentic interest, so as to solicit non-simplistic ethical considerations; in this way it is possible to attempt a GCE as a transition towards complexity, an unavoidable topic in teacher training today [57].
During the first part, characterised by experimental work, stoichiometric calculations and multidisciplinary connections closely connected to chemical and biochemical contents, the students deduced that the damage caused by palm tree plantations essentially concerns biodiversity and human rights; they also declared that they did not have sufficient elements to assume particular dangers to human health (health dangers appear comparable to those caused by animal-based butter). Usually, biscuit brands do not report considerations on the natural environment, instead highlighting the presence of oils considered healthier than palm oil: perhaps this can be explained with a commercial strategy. Since palm oil plantations have the highest yield in terms of oil produced per hectare, they represent the least-worst alternative compared to other types of crops [26]. So - the students said - perhaps highlighting the absence of palm oil responds to a boycott strategy of some food companies? In this way, everything could be traced back to a competition mechanism typical of capitalist logic.
In the second part, the ST diagrams allowed us to further broaden our view of different types of dynamics in play. The discussions in the working groups were lively, demonstrating the students' interest in this type of dynamic concept maps. Generating a ST diagram

helps to develop a global vision and better understand the underlying logic of the processes. GCE is based primarily on understanding interconnections, visible or hidden.
The third part produced increased students' awareness. Other documents were analysed, introducing new and more complex points of view with the important contribution of the humanities. At this stage, the moral sentiments likely to have emerged are based on a well-rounded vision of sustainability, not seen from an exclusively scientific perspective. In any case, the entire path described started from the examination of chemical contents and concepts of fundamental importance. ST diagrams have been a bridge between disciplinary contents and a holistic view of reality.

**Supplementary materials**
The supporting information (students' worksheets) can be downloaded at:
https://drive.google.com/drive/folders/1p3bD2WqiZ5YM4PrMEl-lChVY6r0-it0A

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