IMPROVING TENTH GRADERS' UNDERSTANDING OF GLOBAL CARBON CYCLE: A SYSTEMS LEARNING APPROACH

by

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Dedicated to my lovely five-year-old son. We wrote this thesis together.

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ABSTRACT

IMPROVING 10th GRADERS' UNDERSTANDING OF GLOBAL CARBON CYCLE: A SYSTEM LEARNING APPROACH

This study investigated whether studying the global carbon cycle through a systems learning approach helps 10th-grade students better understand the atmospheric carbon reduction strategies. Global carbon circulation with the principles of stock-flow networks was developed and used in order to improve the learning of global carbon dynamics. The research was a case study that enabled to compare the performance of students on carbon reduction potentials of different forestation practices in the long term, with a specifically designed Coal Substitution Test. The sample of the study includes twenty-five 10th-grade students (16-17-year-old). The study was conducted in biology class at a high school. All twenty-five students firstly completed their biology courses about the carbon cycle with their teachers according to the 10^{th} grade biology curriculum approved given by the Ministry of Education. After completing their curriculum objectives, the students took Coal Substitution Test. Following this, they were given two hours system dynamics lesson about global carbon cycle. The following week they retook Coal Substitution Test. The responses to the tests before and after the intervention were statistically compared. It was found after the intervention, the group performed better according to t-test results and for each question at .002 and .001 significance levels. Cohen's d effect size was found to be "large". The results indicated students improved their understanding of particular aspects of the dynamics of the global carbon cycle.

ÖZET

SİSTEM ÖĞRENME YAKLAŞIMI İLE 10. SINIFLARIN KÜRESEL KARBON DÖNGÜSÜNÜ ANLAYIŞININ GELİŞTİRİLMESİ

Bu çalışmada, küresel karbon döngüsünü sistem öğrenme yaklaşımıyla öğretmenin 10. sınıf öğrencilerinin atmosferik karbon azaltma stratejisini daha iyi anlamalarına yardımcı olup olmadığı araştırıldı. Bu araştırmada, Küresel karbon dinamiklerinin öğrenimini arttırmak için stok akış ağlarının prensipleriyle sunulan küresel karbon döngüsü geliştirildi ve kullanıldı. Araştırma, öğrencilerin farklı ağaçlandırma uygulamalarının uzun vadede karbon azaltma potansiyeli üzerindeki performansını müdahele öncesi ve sonrası uygulanan özel olarak tasarlanmış Kömür İkame Testi ile karşılaştırmaya imkan veren bir vaka çalışmasıydı. Çalışmanın örneklemi, yirmi beş 10. sınıf öğrencisinden (16-17 yaş) oluşmaktadır. Araştırma, lisede bir biyoloji dersinde yürütülmüştür. Yirmi beş öğrencinin hepsi öncelikle, Milli Eğitim Bakanlığı tarafından verilen müfredata göre, karbon konusu ile ilgili biyoloji derslerini öğretmenleri ile birlikte tamamladı. Müfredat tamamladıktan sonra öğrenciler Kömür İkame Testi aldılar. Bunu takiben öğrenciler küresel karbon döngüsü ile ilgili iki sistem dinamiği dersi verildi ve öğrenciler ilk test tarihinden bir hafta sonra tekrar Kömür İkame Testini aldılar. Yapılan testlerde verilen cevaplar istatiksel olarak analiz edildi.İki system dinamiği dersinden sonra, grubun t-test sonuçlarına göre her soru için .002 ve .001 anlamlılık düzeylerinde daha iyi performans gösterdiği ve cohen d etki düzeyinin de "büyük" olduğu bulundu. Sonuçlar, öğrencilerin küresel karbon döngüsünün dinamiklerinin anlamasında gelişmeler olduğunu göstermektedir.

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LIST OF SYMBOLS/ABBREVIATIONS

Symbol	**Explanation**
CO_2	Carbon dioxide
GHGs	Greenhouse Gases
Gt	Gigaton
GtC	Carbon Gigatons

Abbreviation	**Explanation**
n	Sample/Sample Number In The Group
$\overline{X}$	Mean
SD	Standard Deviation
t	t-test Score
p	Level of Significance
r	Coefficient of Correlation
d	Cohen’s d statistics (Effect Size)

1. INTRODUCTION

Today's problems are more complex and demand various solutions. Education that was "good enough" for us in the past cannot be sufficient to meet the challenges faced by the world citizens of tomorrow (Lyneis, 2000). Today's suggestions might be the challenges of tomorrow, so learners should be skilled in solving complicated problems (Chandi, 2008). In the 21st century, science is regarded as a necessity to address complicated, interrelated issues on the earth and to generate feasible alternatives (Capra and Luisi, 2014). Students need systems-thinking abilities to address the problems of the current world and to create a sustainable future. System thinking also offers unique alternatives to scientific education in order to enhance students' learning of the complex universe.

Systems learning is crucial to enhance our understanding of today's problems in our culture, create alternatives and, more broadly, act as worldwide people (Sweeney and Sterman, 2007). Forrester (2007b), one of the pioneers of system dynamics, draws attention to the lack of an equivalent of programs in science and biology in kindergarten through 12th-grade education that will make students ready for more advanced study at the university level. With innovations in the sector of science, science teaching has become vitally important for education. System dynamics assists new science and technology curriculum to fulfill students' vision (Nuhoğlu and Nuhoğlu, 2007). It helps to enhance the deficiencies in the complex and dynamic universe. For example, science education could assist learners to comprehend the systems' complexity (Assaraf and Orion, 2010). For this reason, people's thinking skills must be altered. Students should emerge from the education system as persuaded that the current puzzling conduct of private, social, economic and company circumstances can be understood much better (Forrester, 2016).

The current research aimed to design an alternative way of instructing the global carbon cycle with stocks and flows to study the effects of the systems-based intervention on the carbon reduction strategy. Students were instructed two lessons on system dynamics. The research was carried out in biology classes. Students used the carbon cycle model to explore how carbon transfers throughout the Earth system, how different pools and fluxes interact, and how the human actions impact the global carbon cycle. Students learn how to set up the carbon cycle model with stock-flow networks. The study included data collection tool, and teaching materials to teach the basics of dynamic environmental issues on the carbon cycle for tenth-grade biology courses.

2. PURPOSE OF THE STUDY

The carbon cycle has a large effect on our planet. In the Climate and The Carbon Cycle website (2016), globally, the carbon cycle plays a key role in regulating the Earth's climate by controlling the concentration of carbon dioxide (CO2) in the atmosphere. It continues that the burning of fossil fuels and deforestation increase CO2 as a greenhouse gas, this increase is believed to be causing a rise in global temperatures. This is the key cause of climate change and is the main reason for increasing interest in the carbon cycle. Asshoff, Düsing, Winkelmann, and Hammann (2019) emphasize that it can be categorized as a main element of ecology, as learners can comprehend significant ecological characteristics such as ecosystem dynamics by examining the carbon cycle. Also, they add that the significant of carbon cycle is exemplary as it represents other flows of matter. Therefore, it contributes to the basic understanding of biology.

Students at different grades are not properly informed about dynamic ecological problems even though teachers may believe that students find ecological subjects as simple (Grotzer and Basca, 2003). When the subject is teaching environmental sustainability, learning of facts about environmental issues is insufficient to "develop sound decision-making abilities" related to the environment (Assaraf and Orion, 2005). Understanding the dynamics and complexity of the environment becomes more difficult for students. If students do not gain a concrete understanding of carbon's role in climate and energy they will not be able to successfully tackle global problems and develop innovative solutions in the future (Silverberg et al., 2009). In this research, our purpose is to design an intervention to learn the carbon cycle with the help of stock-flow network as a system dynamics approach. Thus, students could have a better understanding of the carbon reduction strategy in the long term period. In addition, the study hypothesized that thinking in the stock-flows network might prevent students from sketching the stock trajectory diagram false and help them identify components of the carbon cycle more correctly.

Systems thinking can be a key to the doors and a source of motivation to go deeper into the study of systems (Forrester, 2016). By taking the literature review and purposes of the study into consideration, the main purpose is to answer the question; whether system learning approach provides efficient means to teach dynamic global carbon cycle and the atmospheric CO2 reduction strategies to tenth-grade students?

Through the intervention, students will be able to:

- Diagram the major stocks and fluxes of the carbon cycle.
- Explain how carbon is stored in and passed between living and non-living things in terrestrial, air and ocean ecosystems.
- Make predictions on atmospheric CO_2 concentrations under different biomass burning and forest plantation scenarios.

System dynamics based course and the coal substitution test in this study with the objectives contribute to the biology curriculum. A system dynamics approach give an alternative way to deal with environmental problems based on the carbon cycle. Also, system dynamics approach leads students to develop strategies rather than solely storing knowledge and thus it helps students develop a more holistic understanding of the topic. Since students develop holistic approaches, this will better enable them to deal with complex decision-making tasks they are likely to encounter in their life.

3. LITERATURE REVIEW

3.1. System Dynamics in Education

The field of system dynamics was developed by Jay Forrester at Sloan School of Management at Massachusetts Institute of Technology in the 1950s with a view to studying the structure and functioning of the complex systems in which we are fixed, inventing effective policies that ensure sustained improvement, and accelerating successful implementation and change (Sterman, 2000). System dynamics can be defined as a methodology with which complex feedback systems, which are generally found in business and social systems, are investigated and managed (Forrester, 1994). Barlas (2002) indicated that the term system refers to "reality" or some aspects of reality and he added a system may be defined as a "collection of interrelated elements, forming a meaningful whole." A system dynamics model is designed to make sense of a system of forces which have paved the way for a "problem" and continue to sustain it (Albin, 1997). Groff (2013) indicated that system dynamics methodology facilitates the way we develop models about the major dynamics in each system, by using tools to:

- Make a representation of a system feedback framework to comprehend why a system behaves as it is;

- Test and prepare a plan for policies before they are applied; and

- To improve the probability that they generate the required results.

System dynamics started in the world of industry and business but now affect education and many other fields (Nuhoğlu and Nuhoğlu, 2007). Applications have extended to include project management, supply chains, instructional issues, energy systems, politics, sustainable development, medicine, psychology, healthcare and many more fields since the early 1980s (Forrester 2007a). Fisher (2011) asks why we do not teach our kids this analytical technique and questions whether system dynamics and system thinking have been implemented effectively to many system-related issues.

Forrester (1994) in his article named Learning through System Dynamics as Preparation for the 21st Century mention that the aims of a system dynamics education could be divided into five headings:

1. Personal abilities development,
2. Economic behavior learning,
3. Shaping a perspective and character that fits into the 21^{st} millennium,
4. Understand the nature of systems in which we work and live,
5. Achieve the advantages of education in schemes.

Meadow, Sweeney, and Mehers (2016) define system thinking is a wide word used to describe techniques focused on the collections and interconnections of components rather than on individual parts. They add that system thinking offers a framework to define and solve complicated issues and thus promotes more efficient teaching and layout. They offer that students should increase consciousness of a system thinker's mind patterns because community confronts a major instructional task in the 21st-century: to learn how to assist individuals to understand and cope with increasingly complex systems.

They describe the characteristics of the system thinkers:

1. Looking at the entire picture
2. Changing views in complex systems thanks to seeing new leverage points
3. Searching for interdependence
4. Considering how mental models (beliefs, thoughts, hypotheses of how the world operates) build our future
5. Paying attention to the long-term
6. Going broad to see complicated interactions between cause and effect
7. Finding out where unforeseen implications arise
8. Focusing on structure (system interrelationships)
9. Making systems visible through causal maps and (which demonstrate how different actions affect other actions and outcome) computer models
10. Searching for the stocks and time delays and inertias (accumulations of materials and information in a system)

11. Watching for fixed/ growth mindsets, knowing that in highly interdependent circumstances they generally make matters worse
12. Seeing themselves in the system, not outside.

One of the pioneers of system dynamics, Sterman (2000) explains that system dynamics is a view and collection of educational instruments that allow us to comprehend complex system design and dynamics in a Business Dynamics book. System dynamics is also a strict modeling approach that allows us to develop formal software models of complicated structures and use them to develop strategies and organizations that are more efficient. He adds that these instruments enable us to quickly learn, to develop knowledge of complicated systems and to layout policies for higher success, to encounter long-term adverse impacts of policy choices.

System dynamics can also be seen as a field which assists us in dealing with policy resistance and human limitations. The goal of system dynamics is to understand the structure and interconnections that create the behavior of a defined system. Groff (2013) mention that the tools of system dynamics show and uncover the complexity of a system that otherwise we would not recognize. A model of system dynamics represents the structure of a system. Moreover, he points out that the tools of system dynamics provide us with a way to employ the knowledge behind our mental models to represent the complexity of the system more precisely. Systems are our world's fundamental structure. Simple systems are nestled within larger complex systems that are nestled in larger, more complex systems. Groff (2013) described the four type of general tools found in system dynamics. These are behavior-over-time graphs, computer simulation models, causal loop diagrams, stock/flows maps.

Behavior-over-time graphs displays system to change data in line graph format, where time on X-axis is plotted. Causal loop diagrams show that explains why the behavior which takes place over time requires an understanding of system dynamics. Causal loop diagrams help us visually map loops and show how they interact. Its accuracy can be best tested by a computer simulation once a system has been diagrammed. While no one could simultaneously determine the interdependent time system relationships that cause trouble, a computer model can (Groff, 2013). Sterman (2000) in his book named Business Dynamics indicates that stocks and flows, along with feedback, are the two central concepts of systems dynamic theory. Accumulations are stocks. He explains that stocks characterize the state of the system and provide information on the basis of decisions and actions.

He added the notation of stock and flow diagramming (originated by Forrester, 1961) was based on a hydraulic metaphor, namely the flow of water to and from reservoirs. Indeed, inventories can be thought of as water baths. The amount of water in your bath at any time is the accumulation of more water. More water that flows from the tap than water that flows into the drain (assume no splash or evaporation). Similarly, the amount of material in any stock is the accumulation of more material that flows in than material that flows out.

System dynamics employs a specific diagram notation for stocks and flows as shown in Figure 3.1. Stocks are shown as rectangles. Flows are illustrated with pipes filling (inflow) and draining (outflow) the stocks. Valves control flows. Clouds are the infinite sources and sinks of the flows, hence sources and sinks are supposed to have the endless capacity and can never limit the supported flows. These elements comprise the structure of all stock and flow structures. It can be exemplified that, the inventory of a towel company is a stock that accumulates production inflow and reduces selling outflow. The only flows considered are these: other possible flows into or out of the stock, such as inventory decrease or damage, shall not be assumed to be zero unless it is explicitly shown. The clouds show that the raw material stock never runs out of production and that the product bought by customers never increases so high that it hinders the buying rate.

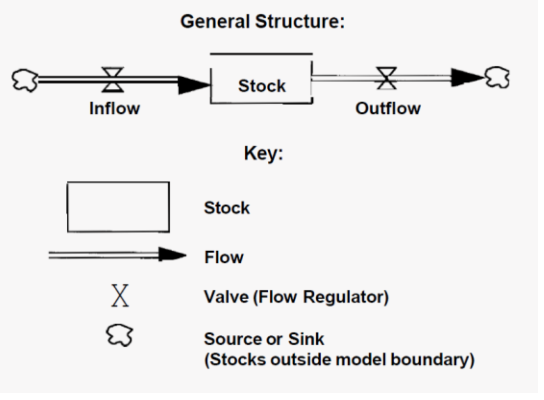

Figure 3.1. The general stock-flow structure (from Business Dynamics book of Sterman, 2000)

Formal education reduces the natural tendency of children to think about systems and needs to call for more radical reforms (Sweeney, 2007). Moreover, a special way of thinking is needed to interpret the world. Systems thinking is described as a discipline for the comprehension of the system as a framework for acknowledging the system's relations and the values and methods for understanding interrelationships (Senge, 2006). Systems thinking attracted educators ' attention and were seen as a critical strategy to education (Hmelo, Holton and Kolodner, 2000).

It is important to remember how different things can mean to different people under the term "systems thinking." System thinking is more than just a set of tools and methods–it is at the same time a philosophy. Goodman (2018) stressed that too many beginners are fascinated by tools such as causal loop diagrams and flight management simulators with the hope that they will help them overcome continuing business problems. However, system thinking also means a sensitivity to the circular disposition of the world in which we live; a recognition of the structure's part in creating our conditions; an understanding of the powerful laws of operating systems that we do not understand and an awareness that there are consequences for our actions that we do not know about.

Systems thinking is necessary for science, technology, and everyday life, according to Senge (1990). Science and technology are the keys to designating the path of a nation to make future generations ready for being scientifically literate and capable of transformational thinking as it is today in the 21st century (Schunn, 2009). Forrester (2009a) emphasizes that we should give students a better way to interpret the world around them. This approach helps students gain a scientist's discipline and sensitivity. This allows students to actively observe their surroundings, to detect new problems, to model and to scientifically examine these problems (Nuhoğlu and Nuhoğlu, 2007). Hogan (2003) suggests that in this century students should be trained as system thinkers to be effective problem solvers and decision-makers.

3.2. Importance of The Carbon Cycle

Sterman (2012) indicates: "Our society is not sustainable. We use up renewable resources faster than they regenerate, we create pollution and wastes faster than ecosystems can break them down into harmless substances, and we are, in the words of former U.S. President George W. Bush, 'addicted to oil' and 'other nonrenewable resources'." He adds that unfortunately, our manner is unsustainable and it's getting worse. People significantly rely on nonrenewable resources, particularly including fossil fuels, and the greenhouse gas (GHG) emitted, as a result, is quickly changing the climate. In terms of the warming the atmosphere and oceans, it has been found out that human agency accounts for variations in global water cycles, decreases in snow and ice, increases in the global mean sea level, and alterations in some climate extremes (IPCC, 2013). It is not hard to see why these events take such attention in teaching and learning science. Earth systems, as a new disciplinary area, has garnered greater attention than traditional topics in biology, chemistry, and physics. I have new topics such as global climate systems, the curriculum of which includes the carbon cycle and interactions that take place among the biosphere, lithosphere, hydrosphere, and atmosphere, and understanding how human agency influences the global climate system (Jacobson, Markauskaite, Portolese, Kapur, Lai and Roberts, 2017). For example, public discussions on carbon sequestration strategies make little sense if it is not admitted that all these strategies would depend on transferring carbon into very stable molecules and sites, often starting with photosynthesis in long-lived, woody plants. (Schramm, 2018). It is crucial that science curricula continue to enhance the way students comprehend vital processes.

Environmental education arose from the need to react to emerging environmental crises in the early 1960s (Wals, Brody, Dillon, and Stevenson, 2014). Its main objective of environmental education is to demonstrate environmental change and establish a connection with human behavior (Mosley, 2015). It attempted to do this by creating the economic and environmental literacy needed to comprehend the social and political environments, where environmental problems occur and need to be addressed (Wals, et al., 2014).

The field of interdisciplinary environmental science draws advantage from chemistry, physics, geoscience, and biology (Lindstrom and Middlecamp, 2018). Today, a considerable amount of studies on environmental schooling focuses on the circumstances and learning procedures that allow young and old people to (i) develop their own ability in critical, ethical and creative assessments of environmental circumstances; (ii) make informed choices on such circumstances; (iii) develop individual and group capacity and commitment to act in a manner that supports and improves the environment (Asshoff et al., 2019). Philipson-Mower and Adams (2010) emphasize that the role and mission of science teachers are not just restricted to a content-based understanding of environmental education. They stress that the primary goal of environmental education is to create worldwide environmental consciousness and science educators must also train their students in ecologically sustainable methods for building a sort of competencies and attitudes based on an environmental viewpoint.

The carbon is a key greenhouse gas (GHG) that drives global climate change, although it plays an essential role in our lives. We are made of carbon, we consume carbon, and our civilizations— our economies, home, transportation — are constructed with carbon (NASA Earth Observatory, 2011). We need carbon, but that need is also connected to one of the most severe issues of today:

worldwide climate change. Most significantly, human activity has contributed to increasing the atmospheric carbon dioxide concentration, which is commonly considered as a leading cause for worldwide warming since the Industrial Revolution (Asshoff et al., 2019).

How do emissions continue to grow despite increasing concerns about climate change? Dennis Meadows et al. (2016) in the playbook of the environment indicate that one significant cause is the behavior of the climate systems is not understood by individuals. They add that because individuals do not know how climate systems operate, they make mistakes that are possibly fatal. They also point out that methods that have caused harm will cause even more harm in the future. The projections of scientists have not changed people's attitudes, as warnings and discourses are poor teaching methods.

Mauritsen and Pincus (2017) said that current climate commitments in nations, limit in, at any rate, suggesting that existing domestic policy on emissions is severely insufficient. The implementation of an efficient mitigation strategy is a two-stage task in a democracy: policymakers need to develop suitable measures and then obtain political and electoral approval (Dreyer, Walker, McCoy, and Teisl, 2015). Both tasks involve the understanding of the CO2 system by policymakers and citizens. Unfortunately, most people lack that understanding and thus underestimate action needed to mitigate climate change (Sterman and Sweeney, 2002; Guy, Kashima, Walker, & Neill, 2013).

Fu (2016) indicates that atmospheric carbon is the most significant constitution and has a leading role in the world carbon cycle. Research into the terrestrial carbon cycle provides the basis for predicting atmospheric CO2 concentrations. Measuring carbon source and sink level is not only useful in understanding the evolution of CO2, but it also provides theoretical foundations for worldwide climate change regulation and control. It also adds to all countries ' financial and social growth strategies and environmental diplomatic policies.

Xie (2018) highlights the need for implementing an energy policy for carbon emissions and adds that how these CO2 emissions contribute to climate change has to be understood by an individual. He presents an example to someone who follows a scientific consensus: (1) recognizes the increase in the global temperature, (2) attributes it to increasing emissions of anthropogenic CO2 and (3) predicts more CO2 emissions will heat up the Earth further.

The understanding of the system structure of environmental issues and dynamic behavior patterns is relevant to system thinking abilities development (Doğança and Saysel, 2017). Skills related to systems thinking are a fundamental part of science education that is necessary for teaching complicated phenomena (e.g., ecosystems, the formation of moons, water cycles, carbon cycles, and energy transfers), as well as competencies and behaviors (Evagorou, Korfiatis, Nicolaou, and Constantinou, 2009). In order to comprehend a complicated subject such as the carbon cycle, both its component procedures and interactions must be understood (Waheed and Lucas, 1992). Students, therefore, need a comprehensive understanding of many parts and procedures to clarify how the carbon cycle operates and which mechanisms actuate carbon flows (Asshoff et al., 2019). By allowing students to formulate the framework and policies which cause the conduct under research, a system-dynamics modeling curriculum will assist to maintain and restore the creative prospects (Forrester, 2009). Students will need interdisciplinary training in order to make sense of the carbon cycle, and while the documents on standards in science education have long supported interdisciplinary understanding, our existing science education structure is still aligned with learning based on a single discipline (You, Marshall, and Delgado, 2018).

3.3. Challenges in Understanding the Dynamics of Carbon Cycle

Forrester (1961) stresses that every decision is based on designs, usually mental models. Mental models are developed using intuitive beliefs and long-term knowledge of people (Newell, Mcdonald, Brewer and Hayes, 2014). Through our feelings and our body, we continuously build (model) our universe. The keynote of system dynamics is to analyze problems from a variety of perspectives and to broaden the horizons of our mental models including the long-term effects of our behaviors with economic, social and personal implications (Meadows, Richardson and Bruckmann, 1982).

It is crucial to understand people's mental models in order to interpret environmental decision making. One approach is to encourage improved mental models of stock-flows via analog training (Newell et al., 2014). The work of Moxnes and Saysel (2009) demonstrates that analogy can help individuals comprehend the accumulation of carbon. The participants were expected to estimate emission rates. The objective of the study was to stabilize CO2 at a given concentration between 2040 and 2100. In addition, two conditions contained analogies to solve the issue more easily. In the first test, the dynamic of stock-flow was determined to stabilize the flow in an air mattress. No mention was made of atmospheric CO2 in this situation. The other participants were asked to think of the atmosphere as a balloon with two-openings, one allowing air in and the other air out. In decreasing overestimations, the air mattress condition was the most efficient. The results show that individuals need assistance in developing appropriate CO2 accumulation mental models and that individuals need encouragement to re-think inappropriate heuristic decision making (Moxnes and Saysel, 2009). In pedagogical terms, a system-thinking strategy allows students to view processes, issues, and occurrences more fully than traditional teaching methods. (Lee, Jones, and Chesnutt, 2019).

In the real environment, understanding stocks and flows is an essential method (Cronin et al., 2009; Fischer et al., 2015). Cronin, Gonzalez, & Sterman (2009); Dutt and Gonzalez (2011) provide examples to explain stock-flow interactions. For instance, we retain our bank accounts (stock) due to our earnings (inflows) and expenditures (outflows). We maintain the body's weight (stock) by handling our diet (inflow) and the exercise (outflows) of our body. It is known that people find it hard to comprehend the dynamics of stock-flow problems (Cronin et al., 2009; Dutt and Gonzalez 2011). Kumar and Dutt (2018) note such problems to cite the failure of stock-flow like the people from the system dynamics community. Even for extremely trained individuals with a powerful mathematical background, stock-flow issues, even easy ones that include one stock and two flows (inflow and outflow), are hard. For instance, Sweeney and Sterman (2000) gave graduate students at the Massachusetts Institute of Technology with a bath image and diagrams showing the water flow and outflow, then asked them to trace the water stock in the tub. Although the patterns were easy, less than half replied properly. The heuristics we use to attribute causal issues often do not eliminate, but often strengthen misconceptions (Sweeney and Sterman, 2000).

The climate system of Earth is another place where stock-flow failure has been observed (Dutt & Gonzalez, 2011). It is hard for individuals to draw up the emissions and absorption form that corresponds to a trajectory for the concentration of CO2. Why is the carbon cycle difficult for students to comprehend? The subject is generally complicated. Its knowledge requires the integration of perspectives from different fields in different phases. Asshoff and his colleagues (2019) point out that first, there is an interconnection of trophic levels (producers, consumers, decomposers), and second, that students need to know what physiological processes are involved in the transformation of carbon compounds (e.g., photosynthesis, cellular respiration). In the latest years, both science and environmental policy have put a premium on the carbon cycle. Unless students get a real conception of the part carbon plays in climate and energy, they will not succeed in solving global issues and developing innovative solutions for the future (Hausfather, 2010).

Many researchers in system dynamics have turned their attention to the stock-flow error, which covers apparent problems that people have to derive from information on flows that add or drain stocks (Sweeney and Sterman, 2000; Cronin and Gonzalez, 2007; Cronin, Gonzalez & Sterman, 2009). Sweeney and Sterman (2007) mention that stock-flow relationships in the carbon cycle and the principle of mass balance govern the quantity of CO2 in the atmosphere at any time. They interpret this situation as the stocks will continue to increase if the emission rate is higher than the natural absorption rate. The basis of mass balance is that the influx rate must be equal to the outflow rate in order to stabilize the concentration. The conclusion is that even extremely trained people find the method of CO2 accumulation and stability very difficult to understand.

The correlation heuristic and violation of the mass balance are two of the common misconceptions in the climate stock-flow issues (Dutt and Gonzalez, 2012). In line with the correlation heuristic, individuals wrongly conclude that the accumulation (CO2 concentration) and the inflow (CO2 emissions) have the same direction. This misconception assumes the concentration would be stabilized rapidly by stabilizing emissions and emission reductions would rapidly decrease concentration and harm from climate change. This argument is wrong because dependence on the correlation heuristic considerably miscalculates the time delays between CO2 emission cuts and their CO2 impact (Sterman, 2008; Dutt and Gonzalez, 2012). According to the violation of the mass balance, the second misconception in climate stock flow issues, individuals wrongly assume that the concentration of atmospheric CO2 can be maintained even if emissions surpass absorptions. People believe that the emissions double absorptions of the current Earth's climate does not constitute a problem for the future stabilization (Sterman, 2008; Dutt and Gonzalez, 2012).

Kumar and Dutt (2018) point out that prior study has tested for the misconceptions of the correlation heuristic and mass balance violation with a Climate Stabilization task. In the task, the starting value of the concentration in 2000 and its historical trend from 1900 through 2000 are given on paper. The respondent is told to draw shapes of CO2 emissions and absorptions that would reflect the expected 2001-2100 scenario of carbon concentration. Regardless of education backgrounds, individuals rely heuristically on correlation and the violation of mass balances in their

Climate Stabilization assignment drawings (Sterman and Sweeney, 2007; Sterman, 2008; Dutt and Gonzalez, 2012). In general terms, the task assignment was used as a measure to evaluate public misconceptions of stock-flow issue about climate change (Sterman, 2008; Fischer and Rucki, 2017).

Even if there are a number of factors caused by people's wait-and-see preference for action against climate change (McCright and Dunlap, 2011), recent studies have indicated that misunderstandings about climate change can also have an effect on such preferences (Dutt and Gonzalez, 2011). Kumar and Dutt (2018) add that the correlation heuristic contributes to wait-and-see preferences because individuals think that stabilizing CO2 emissions is adequate to stabilize the concentration of CO2. Violation of mass balance thinking also contributes to wait and see decisions because individuals think that CO2 concentration can be stable even where CO2 emissions are double of the absorption level (Sterman, 2008; Dutt and Gonzalez, 2012).

Kumar and Dutt (2018) indicate that people's wait-and-see preferences for climate change action arise from various variables, including conceptual misunderstandings. They add that by using simulation tools, these misconceptions about the Earth's climate could be reduced. However, they emphasize that it is still uncertain whether the learning from these instruments consists of the surface characteristics of the problem (emission and absorption dimensions) or the structural characteristics of the problem (how emission and absorption cause the CO2 concentration to alter according to CO2 concentration scenarios). The heuristics utilized for making causal attributions often fail to deal with these issues, and instead generally strengthen erroneous beliefs (Sterman, 2000). Little is also known about how the difficulty of these instruments (the shape of the path of CO2) and the use of these instruments as aids in decision making affect learning efficiency (Kumar and at Dutt, 2018).

Environmental problems have taken the lead in the global political agenda and present a huge challenge for humanity today and the future (Mosley, 2006). Not only the public but the negotiators themselves are afflicted by poor knowledge of complex systems (Sterman, Fiddaman, Franck, Jones, Mccauley, Rice, Sawin, Siegel & Lori, 2012). In response to emerging problems, efforts to interconnect the skills needed for future science teachers in the 21st century and the empirical conditions proving the environmental sciences is still dominated by mastery in teaching materials are becoming very important (Afandi, Akhyar & Suryani, 2018). Students should perceive modeling and systemic knowledge as a way to reduce social and political problems (Forrester, 2016).

4. MATERIALS AND METHODS

4.1. Sample of Study

The study was conducted at a foundation school in Istanbul. This school is Turkey's first non-governmental educational organization, which provides free and quality education for the orphans and gives them a chance to change their lives in a positive manner. Its mission is to change lives through education by offering state-of-the-art education since 1863 Therefore, the school applies the exam to the fourth-grade orphaned students all over Turkey. First 120 students who are successful in the entrance exam become entitled to attend the school. Students who pass the entrance exam prove that they have a good educational background. The school aims to become one of the best and most prestigious schools both in Turkey and around the world for the education of underprivileged and talented children. The sample consists of 25 tenth-grade students who voluntarily agreed to be a part of this research (15 male and 10 female students). They attended the classes and took the Coal Substitution Tests. Ages of the subjects ranged from 16 to 17. The samples' grade point average of mathematics and biology in the first term are respectively 82.28 and 86.76 over 100.

4.2 Design of the Study

The study was conducted in the last week of May 2019 in İstanbul. The study was applied to the 10th-graders. "Ecosystem, Ecology and Current Environmental Issues" unit is taught in the second academic term according to Biology Curriculum. The students first took their eight regular instructions focusing on the objectives of the unit in the curriculum. The objectives contained the following issues: matter flow, carbon cycle, sustainability, greenhouse gases, climate change. After completing the objectives, the students took Coal Substitution Test. Following this, they were given two hours system dynamics lessons about the global carbon cycle. After the intervention they completed the Coal Substitution Test.

The method of research is a case study. Yin (1994) maintains that the case study method is an empirical investigation which explores a modern phenomenon in its context of actual life. This case study was carried out with a course teaching the carbon cycle with the system-based approach and evaluating 25 students' understanding of the atmospheric carbon reduction strategy. Thanks to the

Coal Substitution Test applied before and after the intervention, the progress of the subjects was measured and evaluated. The system dynamics content of the lesson materials and the data collection tool were controlled by an expert in systems dynamics field and the language used was controlled by one Turkish Linguistic expert to keep the validity of the overall study. The sequence of the instruments and the design of the overall research is presented in Table 4.2. One lesson is forty minutes.

Table 4.2. The research design of the study

Topics	**Time**
Demographic Information Paper Coal Substitution Test	1st lesson
Stock-Flow Relationships Modeling The Carbon Cycle	2nd lesson
Modeling The Carbon Cycle The Bathtub Activity	3rd lesson
Coal Substitution Test	4th lesson

4.3. Instruments

4.3.1. Demographic Information Sheet

Demographic Information Sheet and Coal Substitution Test were given in the first lesson. In total, tenth-grade students were able to complete the overall test within the one-lesson period (40 minutes). Demographic Information Sheets were used to collect personal information about the subjects such as: gender, age, biology and mathematics grades (see Appendix A). This information sheet aids to define the sample in detail.

4.3.2. Intervention

In this study, 10th-grade students take regular biology courses about "Ecosystem, Ecology and Current Environmental Issues" units. Their biology courses are designed according to objectives of the biology curriculum approved by the Ministry of Education. Their objectives (Ministry of Education, 2017) related to the global carbon cycle is that students will be able to:

- analyze the flow of matter and energy in the ecosystem.
- comprehend the topics of matter flow, sustainability, nitrogen, carbon, and the water cycle.
- establish a relationship between matter flow and the sustainability of life.
- evaluate the causes and possible consequences of current environmental problems.
- question the role of the individual in the emergence of environmental problems.
- suggest solutions to eliminate environmental pollution in a local and global context.
- give examples to works which have been done to eliminate environmental pollution in the local and global context.
- discuss human activities that harm the environment on the local and global scale.
- explain the importance of the sustainability of natural resources.
- exemplify successful practices across Turkey for the sustainability of natural resources and emphasize the importance of environmental awareness.

The traditional instruction is restricted to the plan for "Ecosystem, Ecology and Current Environmental Issues" unit of the biology curriculum. The lesson activities and content knowledge were taken from both the coursebook and student workbook. The biology teachers also prepared presentations, experiments, and worksheets about the unit. These activities are directly related to the objectives of the unit. The curriculum proposes to teach in this part of the unit a number of environmental problems such as greenhouse gases, climate change, air pollution, acid rain, and deforestation during eight lessons.

As verified by the corresponding biology teacher, the students had a basic knowledge of the carbon cycle and related photosynthesis, respiration and decomposition concepts, from their previous lessons.

The two-hours systems-based instruction aims the support the traditional plan and additional objectives about dynamic global carbon cycle. The introduction also aims to enhance the lerners to gain a more holistic point of view towards the dynamic global carbon cycle.

Introductory system dynamics lessons include teaching about systems in general, stock-flow diagrams, construction of simple models of the carbon cycle. The detailed worksheet for students is shown in Appendix C. The researcher began the lesson as an engagement part with the figure 4.1., Blind Men and the elephant which is inspired by the famous poem of John Godfrey Saxe (1816-1887). In this caricature, every blind man produces his own version of reality from the restricted knowledge and viewpoint. The aim to use this caricature is showing the importance of seeing the whole picture. Meadow and et al (2016) point out one of the characteristics of the system thinkers is looking at the entire picture.

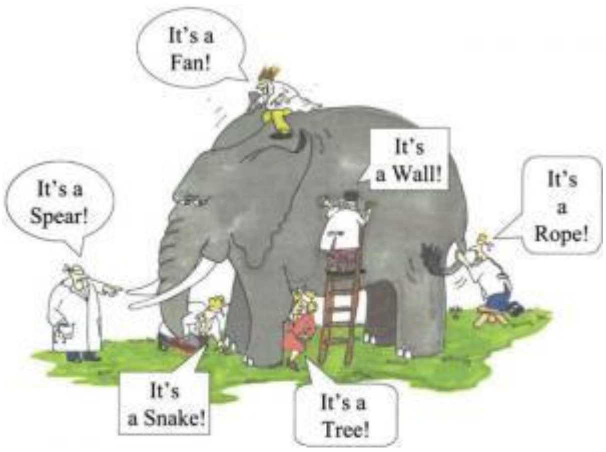

Figure 4.1. Blind Men and the elephant (Penman, 2018).

Then, the bathtub analogy was introduced as an exploration part for understanding stock-flows relationships on the worksheet (see Appendix C) since stocks and flows are essential for systems dynamics (Forrester 1961; Sweeney and Sterman, 2000). In systems of all kinds, stock and flow are prevalent and the stock and flow concept is essential in all the fields ranging from accounting to epidemiology (Sweeney and Sterman, 2000).

Students and the teacher discussed various examples to identify the stock, inflow, and outflow. Richmond's (2008) examples were used in the lesson. Some examples of accumulations are water in the cloud, the weight of the body and anger. The corresponding flows are evaporation/precipitation, gain/loss, and building/venting. In cases where the difference between stocks and flows is ignored and any other scenarios in which a dynamic pattern of behavior must be inferred by mental simulations, there is a considerable risk of drawing incorrect conclusions (Richmond, 2008). Therefore, students analyze the first question conditions (see Appendix C) using bathtub analogy on the worksheet.

The second question is about the carbon cycle diagram as an explanation part to determine the stocks and flows. The biology curriculum mentions examining ecosystems by taking some external and internal environmental factors into account. However, there are no structured carbon cycle activities with any graphs or any other form of data. For systems-based intervention, the global carbon cycle is an important dynamic issue to teach. In the website of The Network for Business Sustainability, Sterman (2013) points out that the system structure must be widely understood, including physical components (e.g., carbon dioxide concentration in the atmosphere and time lags in the supply chain), institutions (e.g. markets and governments), human conduct (e.g. decision-making) and mental model designs that make up the world's perception and interpretation. In that question, subjects were expected to develop a simple stock-flow diagram about the global carbon cycle. The difference of that activity from the one in the traditional lesson is that subjects were expected to indicate relationships between stock-flow networks and the compartment of the global carbon cycle.

Bralower and Bice (2017), in his course modules of modeling earth systems, mention that the global carbon cycle is a comprehensive process system that moves carbon in varying forms to different areas of the earth. The carbon in the environment as CO2 does not remain in the environment for a prolonged time— it goes from there to another place and has various types. He states that plants use atmospheric CO2 in photosynthesis for the production of carbohydrates and other organic molecules and that they can go back to the atmosphere as CO2 or to the soil as a various compound that contains carbon. Some carbon is accumulated in the sedimentary rocks of the oceans and this carbon can return to the atmosphere much later. So, carbon travels - it flows - everywhere. He emphasizes that since CO2 is a significant greenhouse gas, how the carbon cycle works is essential to the worldwide climate system's operation.

The second question (see Appendix C) not only triggers students to work with a carbon cycle stock-flow model that will help them understand how it operates but also assists them to have an overview of the carbon cycle from the systems perspective. What does a systems perspective mean? According to Bice (2017), it means that students concentrate on the locations where carbon dwells (the reservoirs, in the terminology of systems), how it travels from reservoir to reservoir, how much of it moves from location to location and how these motions are controlled.

First, let's consider the primary carbon reservoirs in the second question’s diagram in which each box corresponds to a different reservoir and carbon is in very different forms in each of them (see Appendix C). Students used Gigaton (Gt) which means one billion tonnes or 1015 grams while studying human carbon dioxide emissions.

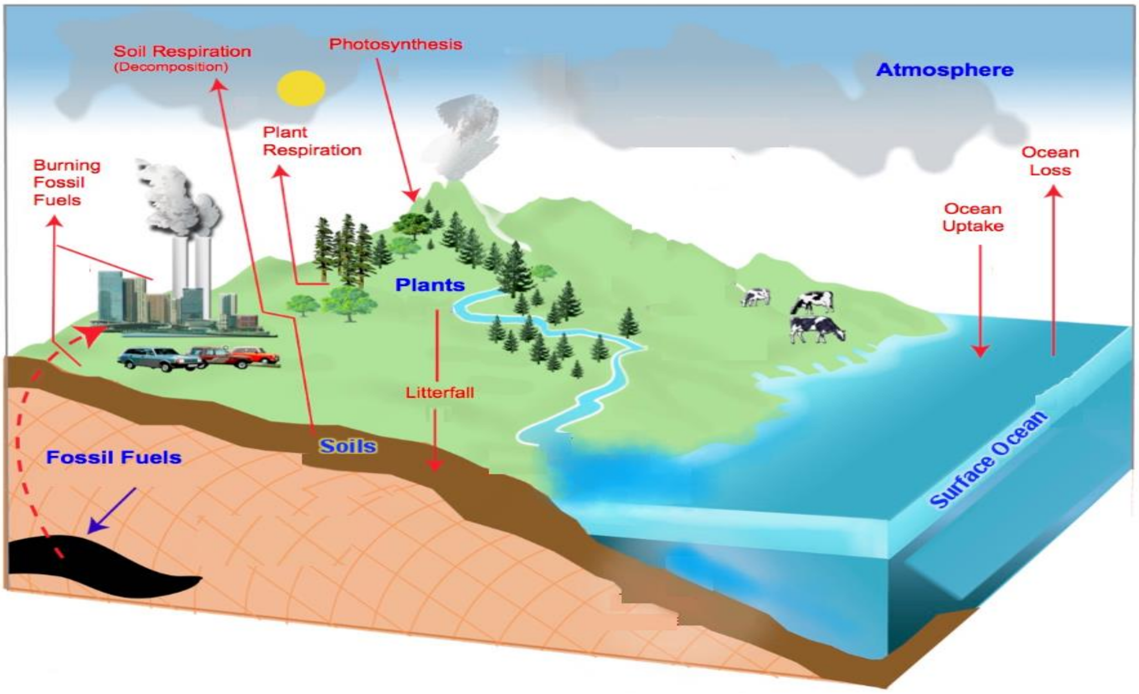

Figure 4.2. A simplified diagram of the global carbon cycle. (adapted from “Global Cycle Model”, 2017).

This diagram illustrates the Earth's carbon cycle. The size of the pools (atmosphere, plants, soils, ocean, and fossil fuels), is displayed in blue. Fluxes are displayed in red. Sterman (2000) states that measuring units can help learners distinguish between stocks and flows. Stocks represent a quantity such as the amount of inventory widgets or the number of employees in an office. The corresponding volumetric flows such as the number of widgets added to the stock per week, the monthly recruitment rates per person or the account expenditure rate in percent/hour need to be measured over an interval of time.

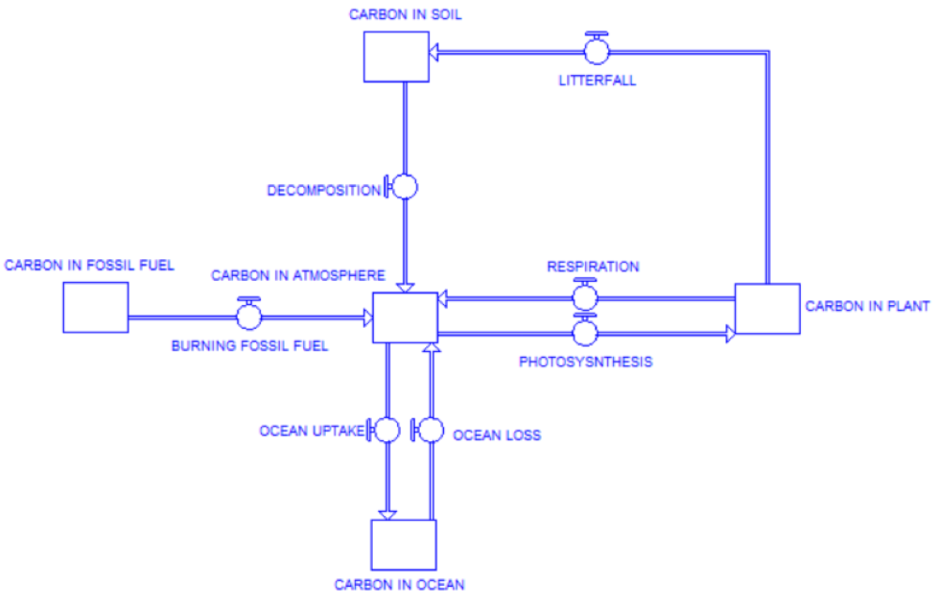

Figure 4.3. Stock-flow network of the global carbon cycle

The figure describes the way carbon atoms 'flow' between different 'reservoirs' in the Earth system. Rectangular blocks and arrows represent reservoirs and flows between reservoirs, respectively. Reservoir sizes are given in units of carbon gigatons (GtC) while flows between reservoirs are in units of carbon gigatons per year.

The Global Learning and Observations to Benefit the Environment (GLOBE) Program (University of New Hampshire, 2008) emphasizes on its website that to comprehend the way carbon is being cycled and atmospheric CO2 will alter in coming years, researchers must thoroughly study the areas in which carbon (pools) is stored, its duration and the procedures in which it is being transferred from one pool to another (fluxes). All the main carbon pools and flows on Earth together constitute what we call the global carbon cycle.

The website of The Globe Carbon Cycle (University of New Hampshire, 2008) describes the global carbon cycle, showing that the Earth's atmosphere, soils, oceans, and plants also contain carbon. When considering the Earth as a structure, these parts can be called carbon pools (also known as stocks or reservoirs) as big quantities of carbon storehouses. Any carbon movement between those reservoirs is known as a flux. It explains that fluxes connect reservoirs in any embedded scheme to generate cycles and feedback. An instance of such a process is shown in Figure 4.3. for intervention, where carbon is used in the atmosphere to produce a new plant material in photosynthesis. On a worldwide basis, big quantities of carbon are transferred from one pool (atmosphere) to another (plants). These plants die, decline over time, are harvested by people, ar destroyed in forest fires or burned for electricity. All these procedures are fluxes which can cycle carbon between different pools in ecosystems and finally release it back into the atmosphere. When the Earth is viewed as a whole, individual cycles are connected to oceans, rocks and so forth on a range of space-time scales to create an embedded global carbon cycle on Figure 4.3.

In The Global Carbon Projects' article (University of New Hampshire, 2008), it is explained that on the shortest period of time scales, from seconds to minutes, plants photosynthesize and release carbon from the air back to the atmosphere by respiration. It is then stated that on the longer period of time scales, carbon from dead plant material can be absorbed into soils where they could stay for years, decades or hundreds before being disintegrated and released into the atmosphere by soil microorganisms. Carbon was gradually converted into deposits of coal, petroleum and natural gas, the fossil fuels utilized today and were buried into deep sediments (and protected from decomposition) on still longer time scales. When these substances are burned, the carbon stored in the atmosphere for millions of years is again emitted in the form of CO2.

The article named Introduction to The Global Carbon Cycle from The Globe Program webpage (University of New Hampshire, 2008) emphasizes that keeping CO2 constant in the atmosphere plays a role in sustaining stable average temperatures around the world. Due to the rise of CO2 inputs into the air during fossil-fuel combustion and deforestation, the size of the atmospheric carbon pool expands without corresponding increases in natural sinks that remove CO2 from the atmosphere (oceans, forests, etc.). This is what resulted in the current CO2 increase and is thought to have led to the observed trend of rising global temperatures. According to the article, the answer depends on the level of CO2 released by humans and the future amount of carbon intake and storage of the Earth's natural sinks and reservoirs. It depends, in short, on the carbon cycle.

The carbon cycle means the ongoing motion of carbon, the most abundant component of the planet, through the oceans, earth, atmosphere, fossil fuels and life on the Earth. Learning about the carbon presence at each of these environmental levels makes us realize how important it is to stabilize the cycle and the consequences of an unbalanced cycle (LaPan, 2011).

The third question on the worksheet is taken from "Bathtub Dynamics: Initial Results of a Systems Thinking Inventory" (Sweeney and Sterman, 2000). The Bathtub question measures subjects' understanding level of stock and flows relationships by giving flow rates into and out of the stock and asking them to calculate how the amount in stock will change over time. An understanding of the dynamics of complex systems relies mainly on this capability, which is referred to as graphical integration (Sweeney and Sterman, 2000).

Cronin (2009) emphasizes that all stock-flow systems have the same structure. The level of resource (stock) stores the influxes less than the outflows. Though the relationship between stocks and flows is an essential calculus concept, computational knowledge is not required in order to make sense of the behavior of stocks and flows. Any stock can be considered as the quantity of water in a bath. Therefore, this question strengthens the understanding of the stock and flow system of the global carbon cycle in the previous question.

The third question shows that the amount of water flowing into the bath (the inflow) accumulates less than the flow out of the drain (the outflow). The rate of water shift is the net flow, due to the distinction between the inflow and the outflow. As everyday experience shows, the amount of water only increases if the influx surpasses the outflow, it only falls if the outflow surpasses the inflow and only stays the same if the inflow equals the outflow. Many system dynamic scientists have focused on the 'stock and flow error', which covers apparent problems resulting from people's misinterpretation of information about flow adding to and draining out of stocks (Sweeney and Sterman, 2000; Cronin and Gonzalez, 2007; Cronin, Gonzalez & Sterman, 2009). Analyzing the third question provides students with the advantage of eliminating misconceptions.

4.3.3. Coal Substitution Test

Coal Substitution Test was designed and administered for this study (see Appendix B for English and Appendix E for Turkish). The questions were developed so that a natural system thinker can answer questions without having any knowledge of the system's terms, such as stocks and flows specific to the field. The descriptive text and graphs about biomass scenarios were inspired by Sterman, Siegel and Rooney-Varga's (2018) article "Does replacing coal with wood lower CO2 emissions? Dynamic lifecycle analysis of wood bioenergy". Some part of the text and graphs in test were quoted or paraphrased from the article.

The Coal Substitution Test primarily provides subjects with a brief non-technical summary of climate change and the use of biomass instead of fossil fuel to reduce GHGs. After the informative text, there are two graphs about the change in the quantity of CO2 in the atmosphere under two different conditions. First, the text clearly illustrates the graph about that the change in the amount of carbon dioxide in the atmosphere under certain equilibrium conditions if a forest is totally cut down and not reforested instead of using fossil fuels to get only one unit of it (1x 1018) when t=0. Secondly, the text describes the graph about that the change in the quantity of carbon dioxide in the atmosphere when the wind energy and the solar energy are used instead of fossil fuels, under the same equilibrium conditions, in order to get 1018 joule of energy at the initial time. After general information, there are two questions about the scenarios about oak-hickory trees and shortleaf loblolly trees respectively.

In the first scenario (see Appendix B), it is assumed that we produce 1018 joules of energy by burning the oak-hickory and we afforest 130 hectares of open space with oak-hickory in order to neutralize the carbon dioxide released into the atmosphere. The scenario gives information that the amount of absorption of carbon dioxide by oak-hickory has increased as it is shown on the graphic, and under these circumstances, the carbon dioxide gas emitted to the atmosphere by burning biofuel will be photosynthetically absorbed approximately in 80 years. According to the oak-hickory scenario, it is expected from subjects to draw and explain a graph about how the change in the amount of carbon dioxide in the atmosphere through 120 years would be.

In the second scenario (see Appendix B), it is assumed that we produce 1018 joule of energy by burning the shortleaf loblolly and we afforest 130 hectares of open space with shortleaf loblolly in order to neutralize the carbon dioxide that we emitted to the atmosphere. The scenario gives information that under the circumstances where the quantity of carbon dioxide absorption by shortleaf loblolly initially increases and then stays stable as shown in the graphic, carbon dioxide emitted to the atmosphere by burning the biofuels is never totally photosynthetically absorbed by these short-lived trees. According to the shortleaf loblolly scenario, it is expected from subjects to draw and explain a graph about how the change in the quantity of carbon dioxide in the atmosphere through 120 years would be.

The Coal Substitution Test described two scenarios' graphs in which the amount of CO2 absorption rises and falls between -0.04 and 0.08 ppm for 120 years. These graphs show the behavior of the outflows. The burning of the trees at the initial time is inflow. The participants were then asked to describe the change of the quantity of CO2 in the atmosphere for the 120 years. That is the stock behavior. The two CO2 scenarios were developed between the predictions of pattern matching and those based on the understanding of the stock and flow structure. In the emission and absorption conditions in the test, the participants were notably directed to make their estimate of future CO2 level in the atmosphere, necessary to achieve the scenario for atmospheric CO2 they were given.

The answer sheet for The Coal Substitution Test, which presents six conditions for drawing an appropriate CO2 concentration pathway is presented in Appendix D. The six conditions for each answer were coded as 1 and 0. If it is the true answer, the student gets 1 point; if it is a false answer, the student has no point. All the questions on this test are open-ended questions and there are no partial credits for responses. The Coal Substitution Test consisted of two questions. Students were evaluated over 12 points in the test and each question was 6 points.

The first condition for the first question is “Increasing CO2 amount to the 0.033 ppm value at first” because oak-hickory trees are burned at the initial time. The second condition is “starting decrease at 0.033 ppm” because the amount of carbon dioxide in the atmosphere permanently increases by 0.033 ppm in order to get only one unit of it (1x 1018) when t=0. The third one is ‘‘declining linearly’’ because the amount of carbon dioxide absorption by oak-hickory has increased linearly at the beginning. The fourth one is “decreasing decreasingly” because the shape of oak-hickory tree graph continues increasing increasingly. The fifth one is “neutralizing at the 80th year” because the atmosphere created by burning oak-hickory tree as biomass will be photosynthetically absorbed approximately in 80 years. The last one for the first question is “Never reaching at the 0.04 ppm value” because the change in the quantity of carbon dioxide in the atmosphere is permanently decreased by 0.04 ppm when the wind energy and solar energy are used instead of fossil fuels, in order to get 1018 joule of energy. However, this decrease is not present in any case of biofuel use.

The first condition for the second question is “increasing CO2 amount to the 0.033 ppm value at first” because shortleaf loblolly trees are burned at the initial time. The second condition is “starting decrease at 0.033 ppm” because the quantity of carbon dioxide in the atmosphere is permanently increased by 0.033 ppm in order to get only one unit of it (1x 1018) when t=0. The third one is ‘‘declining linearly’’ because the amount of carbon dioxide absorption by shortleaf loblolly has increased linearly at the beginning. The fourth one is “keeping it stable or increasing the value” because the shape of shortleaf loblolly tree graph continues keeping the stable line. Also, the line may rise because of the growing trees. The fifth one is “changing the downward trend into neutral or upward one at the 20th year” because shortleaf loblolly initially increases and then stays stable graphic in 20th year (see Appendix B). The last condition for the second question is “never reaching at the level of 0 ppm” because the carbon dioxide emitted by burning the biofuels is never totally photosynthetically absorbed by these short-lived trees.

There are two questions addressing to stock-flow network on The Coal Substitution Test. The theme and content of the question were simplified for the test. In this design, this instrument has two aims. Firstly, it seeks to determine whether system-based intervention would lead to increase understanding of the global carbon dynamics. Secondly, this tool was intended to decrease the correlation heuristics for long term carbon reduction policies to diminish environmental problems. There are sample of students’ papers in this study (see Appendix F)

5. RESULTS

In this chapter, the results of the study are presented in two main sections. Firstly, descriptive statistics about the mean, standard deviation, minimum and maximum values before and after intervention are presented. Secondly, statistical inference is introduced. Each result is also presented in the tables.

Coefficient of skewness is used in the test of normality for test before and after the intervention. The scores obtained from a continuous variable remaining within ±1 limits of the coefficient of skewness that is used in normal distribution can be interpreted as showing no significant deviation from a normal distribution (Büyüköztürk, 2011). Because the total scores of test before and after intervention show normal distribution, paired t-test (t-test for related samples) is used in the comparison. The paired t-test is used to test whether the difference between the two-sample means is significantly different from zero (Büyüköztürk, 2011). Significance level was taken as 0.05. When there was a significant difference between the before intervention test and after-intervention test scores of group, Cohen’s "d” statistic is used to determine the effect size of the intervention. Cohen's standardized effect size index "d" provides the opportunity to interpret the number of standard deviations of the averages compared to each other. Regardless of the sign, the "d" value is 0.20; 0.50 and 0.80. In Cohen’s "d” statistics, the range 0 to 0.20 is “small effect size”; 0.20 - 0.50 is “medium effect size”; 0.50 and above is considered as “large effect size” (Büyüköztürk, 2011). The following formula is used in the calculation of Cohen’s "d".

$$d = \frac{\overline{X}_1 - \overline{X}_2}{(SS_1 + SS_2)/2} \tag{5.1}$$

5.1. Descriptive Statistics

Table 5.1. presents the descriptive statistics of the test scores. According to the results in Table 5.1., the scores of the tests show normal distribution. According to Table 5.1., test-after intervention 1, 2 and total scores are higher than test- before intervention 1, 2 and total scores.

Table 5.1. The descriptive statistics of the test scores.

Test Time	Test Question	n	Min.	Max.	$\overline{X}$	SD	Mod	Skewness	Kurtosis
Test-before intervention	1	25	0,00	6,00	2,60	1,38	2,00	0,49	0,30
	2	25	1,00	5,00	2,84	1,07	3,00	-0,10	-0,53
	Total	25	2,00	9,00	5,44	2,10	4,00	0,06	-1,02
Test-after intervention	1	25	1,00	6,00	3,48	1,29	3,00	-0,14	-0,41
	2	25	2,00	6,00	3,96	1,24	5,00	-0,20	-0,99
	Total	25	3,00	11,00	7,44	2,24	9,00	-0,05	-0,82

5.2. Statistical Inference

Table 5.2. shows whether the difference between test before and after intervention scores is statistically significant. Test 1 and test 2 refers to question 1 and 2 in the Coal Substitution Test. In Table 5.2., a statistically significant difference is found between Test1 before and after intervention scores (t (25) = -3,47; $p<0,05$). Test 1 score after the intervention (3.48 ± 1.29) is significantly higher than Test 1 score before intervention (2.60 ± 1.38). A positive and significant effect of the intervention on Test 1 score is determined and this effect size is found to be “large” (d = 0.66> 0.50).

According to Table 5.2., a statistically significant difference is found between Test 2 before and after intervention scores (t (25) = -3.85; $p <0.05$). Test 2 score after the intervention score (3.96 ± 1.24) is significantly higher than Test 2 score before intervention (2.84 ± 1.07). A positive and significant effect of the intervention on Test 2 score is determined and this effect size is found to be “large” (d = 0.97> 0.50).

Table 5.2. Paired t-test results for comparison of the test scores

Test No	**Test Time**	**n**	$\bar{X}_1 - \bar{X}_2$	$SD_1 - SD_2$	**t**	**p**	**d**
1	Test-before intervention Test-after intervention	25 25	-0,88	1,27	-3,47	**0,002**	0,66
2	Test-before intervention Test-after intervention	25 25	-1,12	1,45	-3,85	**0,001**	0,97
Total	Test-before intervention Test-after intervention	25 25	-2,00	2,40	-4,17	**0,000**	0,92

According to Table 5.2., a statistically significant difference is found between the before and after intervention test total scores (t (25) = -4.17; p <0.05). The total score after the intervention (7.44 ± 2.24) is significantly higher than the total score before intervention (5.44 ± 2.10). A positive and significant effect of the intervention on the test total score is determined and this effect size is found to be “large” (d = 0.92> 0.50).

6. DISCUSSION

Sterman (2000) shows that we tend to create choices using static, narrow and simple mental models in the dynamic and interconnected world. Students often have misunderstandings about the global carbon cycle and are often unable to reason at all levels of the biological organization, which is essential for detailed explanations of these complex events (Asshoff et al., 2019). Based on the literature, this study hypothesized that students participating in the intervention would have difficulties and misconceptions drawing a graph about carbon dioxide (CO2) in the atmosphere if biomass were used to substitute coal burning. Therefore, this study aimed is to design an intervention to teach global carbon cycle dynamics based on the stock-flows network as the system dynamics approach for 10th-grade biology curriculum. Moreover, the study aimed to investigate the improvement in 10th grader’s understanding of the dynamics of carbon cycle before and after the intervention. Following the intervention, it is expected that students will become more aware of the fact that the carbon cycle forms part of the interconnected system.

The research method is a case study. This case study was conducted for teaching 25 students the carbon cycle with the system-based approach and assessing their understanding of the atmospheric carbon reduction strategy. The progress of the subjects was measured and assessed thanks to the coal substitution test. The results of t-test before and after intervention were statistically important. In addition, Cohen d statistics show a positive and significant effect on the overall test and the effect size was found to be "large". In the light of the results, our study showed that implementing system dynamics models in the teaching of a complex subject, in this case, global carbon cycle, enhances students’ understanding of the global carbon dynamics. Also, exercising on carbon reduction strategies on simple dynamic models can provide more valuable insight into the efficacy of carbon sequestration approach to climate protection. In addition, the results show us the materials in this research can be defined as helpful and applicable in addressing biology curriculum.

The global carbon cycle is a crucial topic for environmental education. System dynamics approach in this study is an alternative way to simplify the global carbon cycle by the stock-flow network. The intervention is based on eliminating misconceptions of the global carbon cycle as a result of the structured stock-flow network of the global carbon cycle and bathtub activity. Also, activities construct the definitions, and relationships between the stock and flows for the students. The topics of the traditional curriculum facilitated understanding of the system-based instruction since students have an idea and information on the basic environmental problems. After the intervention, learners were able to define stock-flows and associated ideas, and explain how carbon is stored in compartments of the earth. Furthermore, they were able to estimate atmospheric CO2 concentrations under different conditions.

This study gives an alternative way to deal with dynamic environmental problems such as the carbon cycle. In addition, the system dynamics approach provides students to develop plans rather than storing data. Thus it helps students develop a holistic understanding of the environmental problems based on carbon cycle.

7. CONCLUSION

Traditional schools strongly suppress innovative tendencies (Forrester, 2011). K-12 education is a large organization with established resistance to change (Lyneis, 2007). However, people live in an increasingly dynamic and complicated globe. While the world around them is progressively complicated and interdependent, colleges continue to divide and divide, strengthening the idea that knowledge consists of many unrelated components, and offering learners with little chance to see reoccurring behavioral patterns across fields and topics (Sweeney, 2007). One of the methods is the system dynamics that provides an overview of micro to macro worlds. This method makes it possible for learners to deal with the complex social, financial, technological and environmental challenges they will encounter in the future in an efficient manner (Lyneis, 2000).

There are many more environmental issues in the world. Environmental education plays a key role in understanding environmental dynamics in this regard. However, the Biology Curriculum has its own environmental content deficiencies. In addition, dynamic environmental issues are described with restricted representation. The materials we developed for this study enrich the existing biology curriculum. The study also aimed to achieve additional objectives about system dynamics. These are diagramming the major stocks and fluxes of the carbon cycle; explaining how carbon is stored in and passed between living and non-living things in terrestrial, air and ocean ecosystems and making predictions on atmospheric CO2 concentrations under different biomass burning and forest plantation scenarios.

A significant challenge for the next decade is to design and establish academic organizations that can meet the growing need for system dynamics and systematic-thinking education (Barlas, 2002). There are limited educational materials (Zaraza and Fisher, 1999) and limited system dynamic measures (Plate, 2010) that support the development and systems thinking skills of students. In the future, further research may be carried out to determine whether this strategy to learning is advantageous over alternative learning techniques. If the students receive system dynamics education before becoming future leaders, they will better adapt their environmental politics when they become new decision-makers.

8. LIMITATIONS AND FUTURE RESEARCH

Actually, the design does not help us eliminate the fact that the students can be using pattern matching or correlation heuristics, as they deal with the problems. The reason for this is that in each question, the decrease in atmospheric carbon dioxide concentration correlates with the carbon held by the forests. However, when students learn the stock-flow network, they incline to draw the stock-flow model to understand the problems easily (see Appendix F). Also, in the intervention, there is bathtub activity from the Sweeney and Sterman's (2000) study that breaks the heuristic correlation in students' mental models in the system based lessons.

Secondly, one can design between-subject experimental studies to better measure the effectiveness of alternative systems learning interventions. However, most schools do not allow this as they deem it unethical to give an enriched lesson plan to one class and a traditional one to another class. Therefore, Coal Substitution Test was administered one week after the first test. The students did not see the questions again after the first time. The students were not given the answers of the test. Thus, we tried to minimize the impact of the test before intervention.

System dynamics is a strict modeling approach that allows us to develop formal software models of complicated structures and use them to develop strategies and organizations that are more efficient (Sterman, 2000). For future research, this study may be develop with the adjustment of the causal loop diagrams, modeling with STELLA, simulation of C-ROADS or alternative simulations. All related educational materials, mainly biology curricula and textbooks, may be prepared from this holistic perspective.

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APPENDIX A: DEMOGRAPHIC INFORMATION PAPER

DEMOGRAPHIC	ANSWERS
Name surname:	
Class:	
Gender:	
Age:	
What's your first term biology note?	
What's your first term mathematics note?	

APPENDIX B: COAL SUBSTITUTION TEST

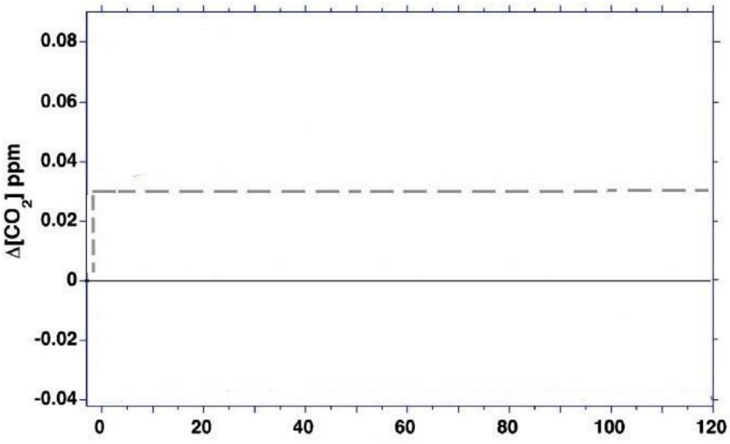
When the emission of greenhouse gases, such as carbon dioxide, to the atmosphere, creates a gradual increase in the temperature, this is called global warming. The use of fossil fuels (coal, natural gas, petrol) which supply a great part of our energy need causes the global warming by emitting the carbon that has stayed underground for millions of years to the atmosphere.

Intergovernmental Panel on Climate Change (IPCC) by United Nations has declared on 2014 that the global warming must stay below 2 ◦C, and to achieve that, the consumption of fossil fuels must be decreased to a large extent quickly before the year 2050. The governments promote the use of biofuels instead of fossil fuels in order to decrease the emission of greenhouse gases. It is declared that the biofuels are carbon-neutral, in the other words they absorb the same amount of carbon dioxide from the atmosphere as they emit to. For example; even if the wood has the potential of creating a short-term rise in the quantity of the carbon dioxide in the atmosphere when it is burnt, this carbon can be slowly absorbed from the atmosphere by afforestation. And this situation influences the rise of the use of wood which is a biofuel for the heat and the electricity.

However, do biofuels really decrease the emission of greenhouse gases? Whether the carbon dioxide in the atmosphere comes from the coal or the biofuels does not create any difference for global warming. According to researches, when a forest is completely cut for biofuels and then re-afforested, it takes between 44 to 104 years depending on the forest type to recover the carbon emitted to the atmosphere before.

Related to the information above, some of the important information and graphics in the works of leading scientists in their field are given below.

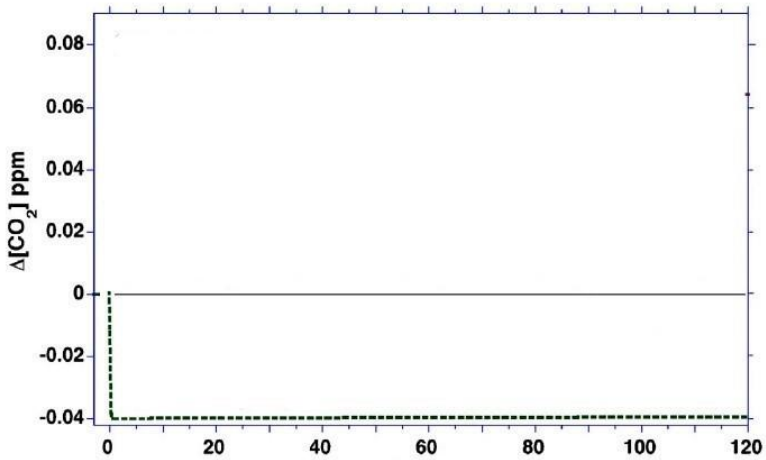
The change of the quantity of CO_2 in the atmosphere



Years

Global energy consumption on the earth today is approximately 500 x 1018 joule. The graphic above shows the change in the quantity of carbon dioxide in the atmosphere under certain equilibrium conditions if a forest is totally cut down instead of using fossil fuels in order to get only one unit of that (1x 1018) when t=0 and reforestation is not done. Graphic shows that the quantity of carbon dioxide in the atmosphere is permanently increased by 0.03 ppm.

The change of the quantity of CO_2 in the

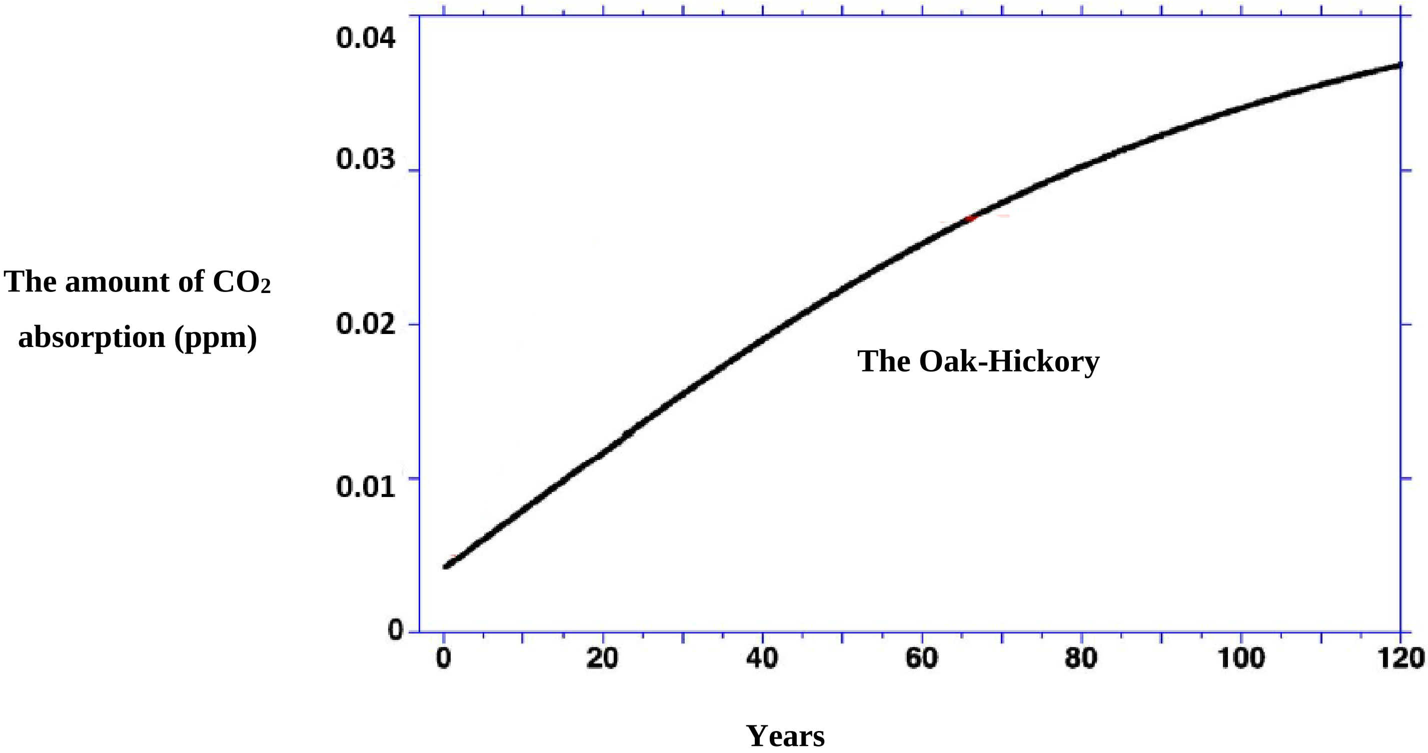


Years

This graphic shows the change in the quantity of carbon dioxide in the atmosphere when the wind energy and the solar energy are used instead of fossil fuels, under the same equilibrium conditions, in order to get 1018 joule of energy when t=0. Graphic shows that the quantity of carbon dioxide in the atmosphere is permanently decreased by 0.04 ppm when t=0. Also, this decrease is not present in any case of the use of biofuels.

*On the graphics, the point that we see when the change of the quantity of carbon dioxide in the atmosphere is zero is the initial moment. And all the other factors that affect the quantity of carbon dioxide in the atmosphere are assumed to be in equilibrium.

1)

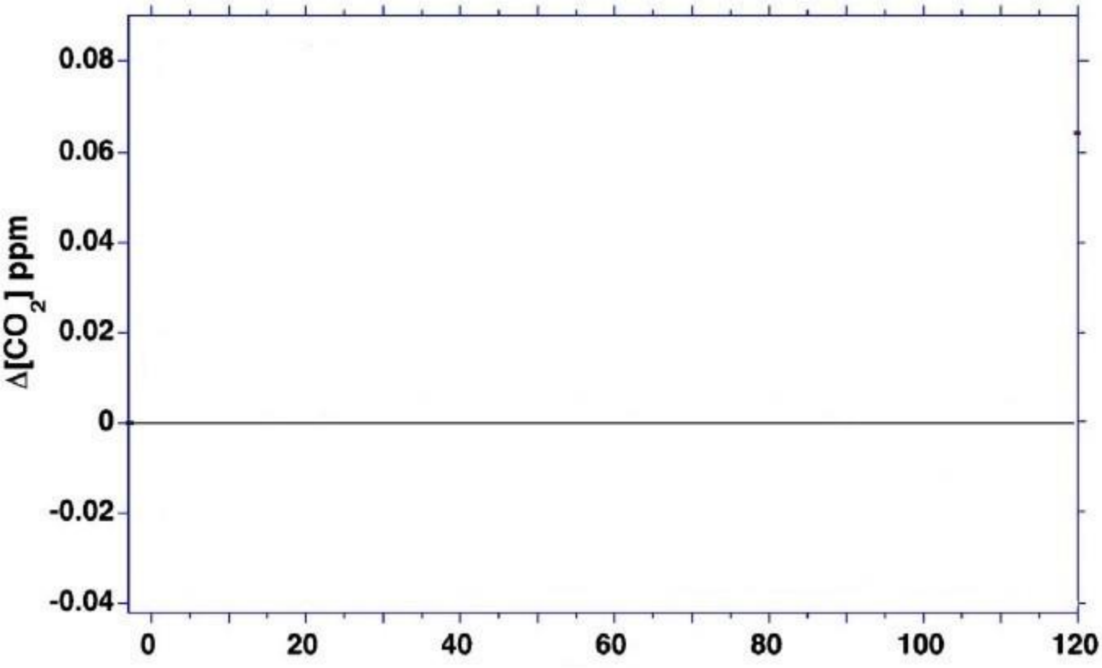


Let's assume that we produce 1018 joules of energy by burning the oak-hickory and we afforest 130 hectares of open space with oak-hickory in order to neutralize the carbon dioxide released into the atmosphere.

It is known that the amount of absorption of carbon dioxide by oak-hickory has increased as it is shown on the graphic, and under these circumstances, the carbon dioxide gas emitted to the atmosphere by burning biofuel will be photosynthetically absorbed approximately in 80 years.

According to the scenario above, how would be the change in the quantity of carbon dioxide in the atmosphere through 120 years? Draw on the graphic below and explain.

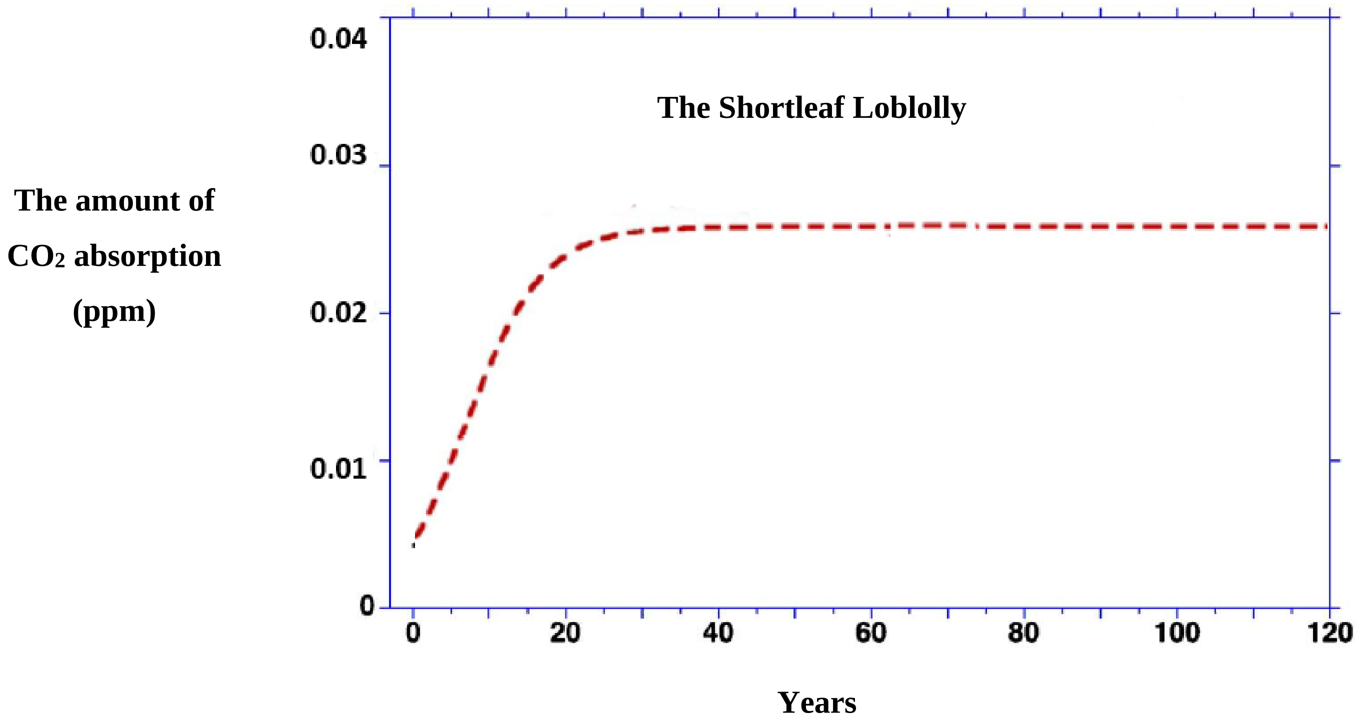
The change of the quantity of CO_2 in the atmosphere



Years

Explanation:

2)

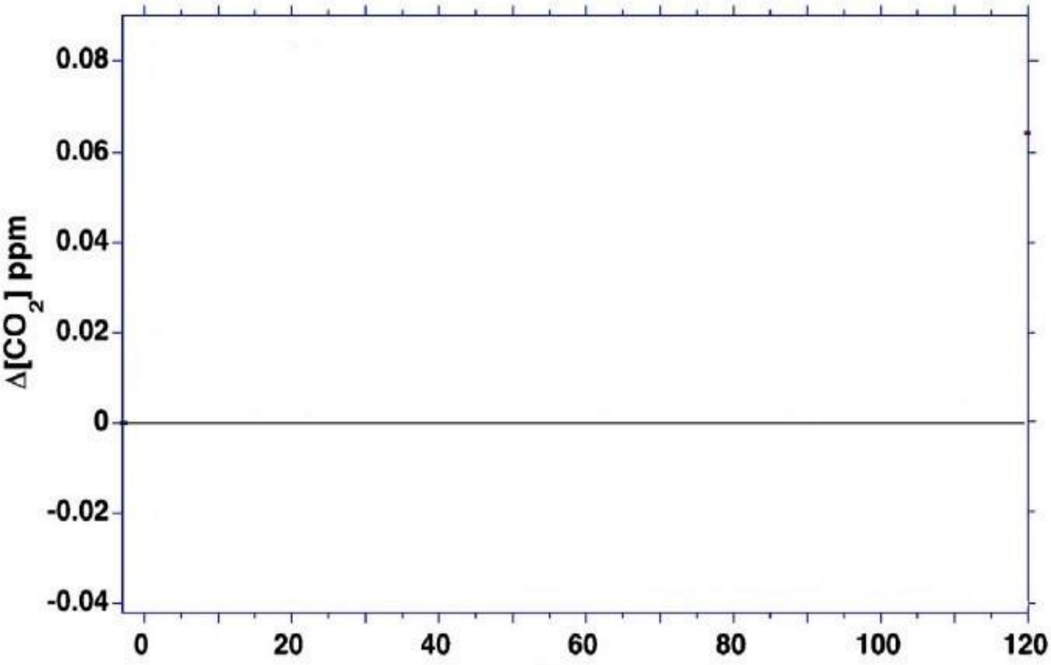


Let’s assume that we produce 1018 joule of energy by burning the shortleaf loblolly this time. And in order to neutralize the carbon dioxide emitted to the atmosphere, we afforest 130 hectares of open space with shortleaf loblolly.

It is known that under these circumstances where the quantity of carbon dioxide absorption by shortleaf loblolly initially increases and then stays stable as shown in the graphic, carbon dioxide emitted to the atmosphere by burning the biofuels is never totally photosynthetically absorbed by these short-lived trees.

According to the scenario above, how would be the change in the quantity of carbon dioxide in the atmosphere through 120 years? Draw on the graphic below and explain.

The change of the quantity of CO_2 in the atmosphere



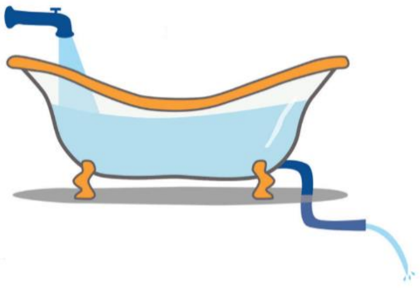
Years

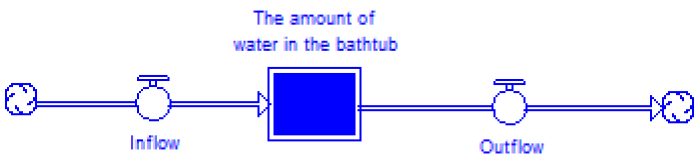
Explanation:

APPENDIX C: WORKSHEET

Name and Surname:

Class:





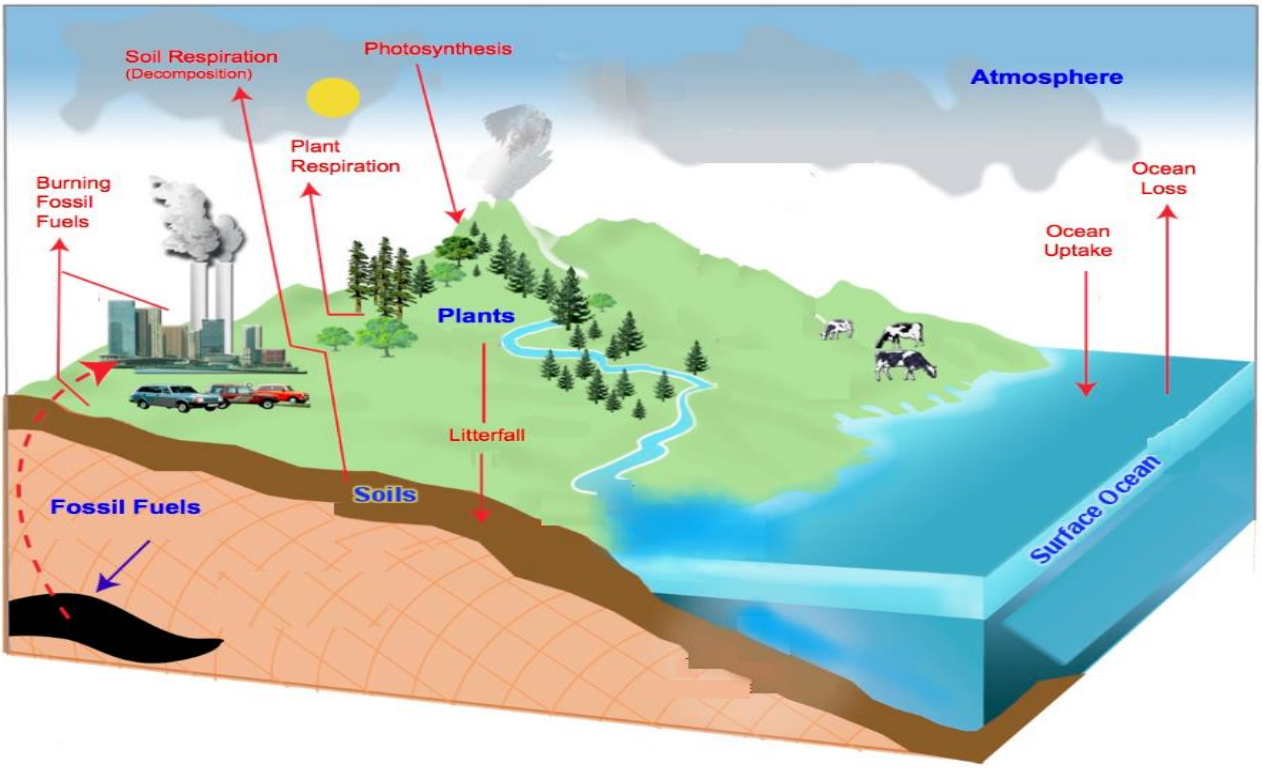
1.

a. What condition is necessary for keeping the amount of water in the bathtub at the same level within a specific time interval?

b. What condition is necessary for the increase in the quantity of the water in the bathtub within a specific time interval?

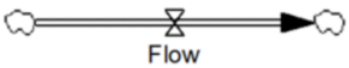
c. **What condition is necessary for the decrease in the quantity of the water in the bathtub within a specific time interval?**

2. **a. Write the stocks and the flows according to the diagram.**

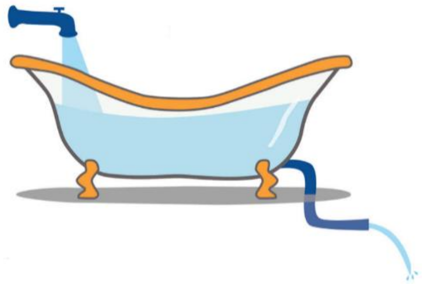


STOCKS	FLOWS

b. With the help the carbon cycle diagram, illustrate a carbon cycle using the symbols below which shows the carbon stocks and how carbon flows between those stocks.

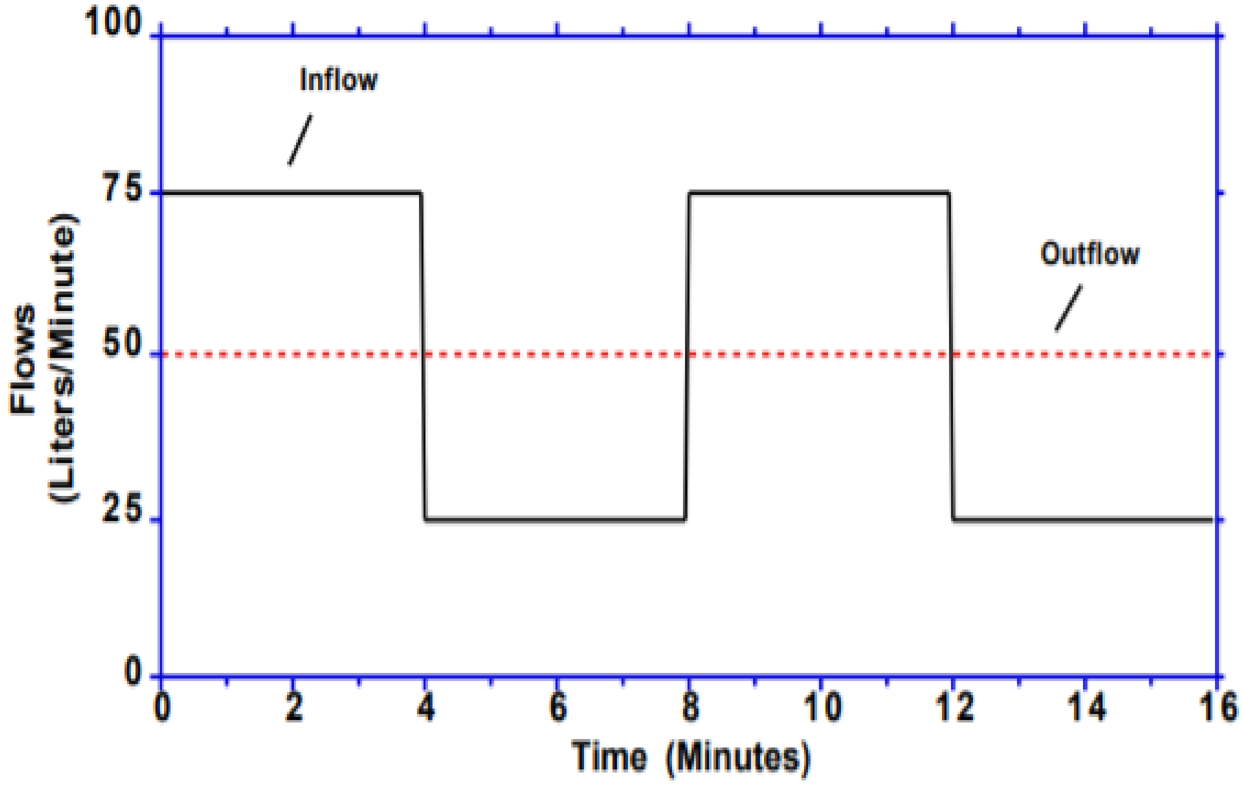
Stock:  **Flow:** 

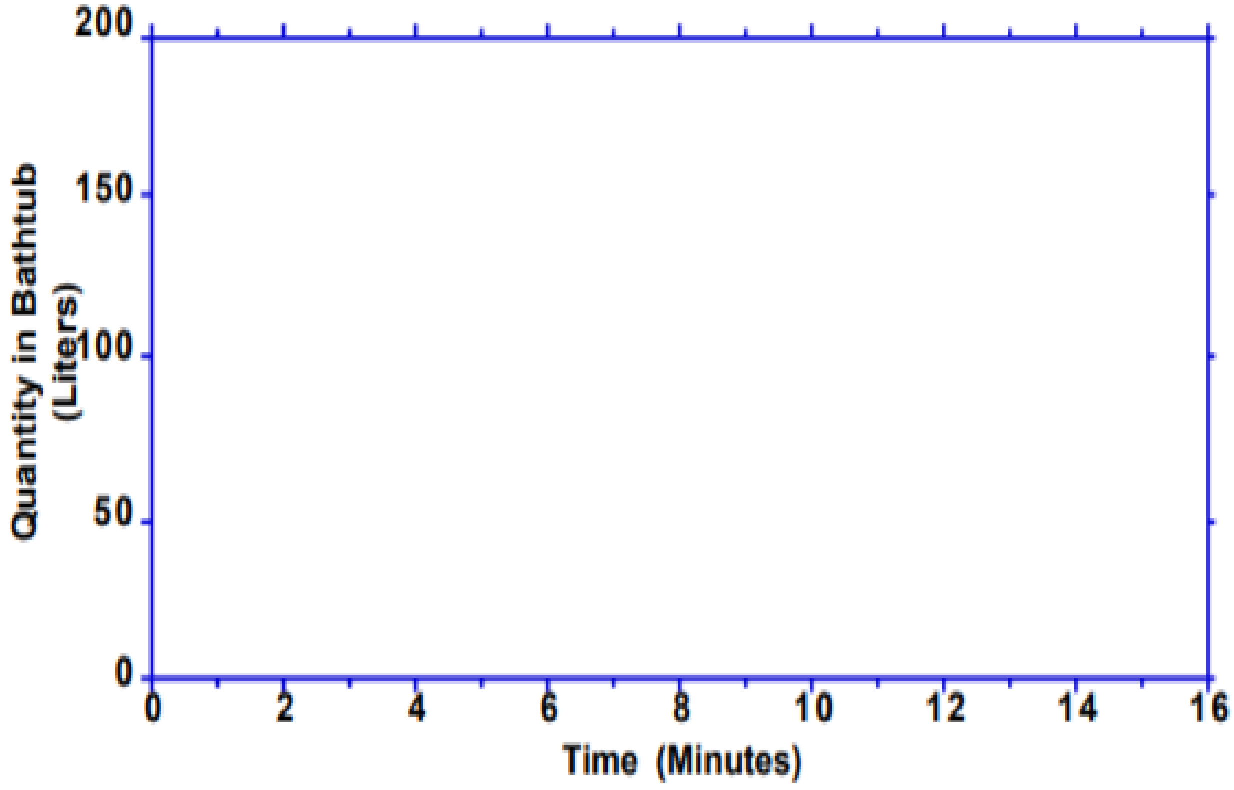
3. Consider the bathtub shown below. Water flows in at a certain rate, and exits through the drain at another rate:



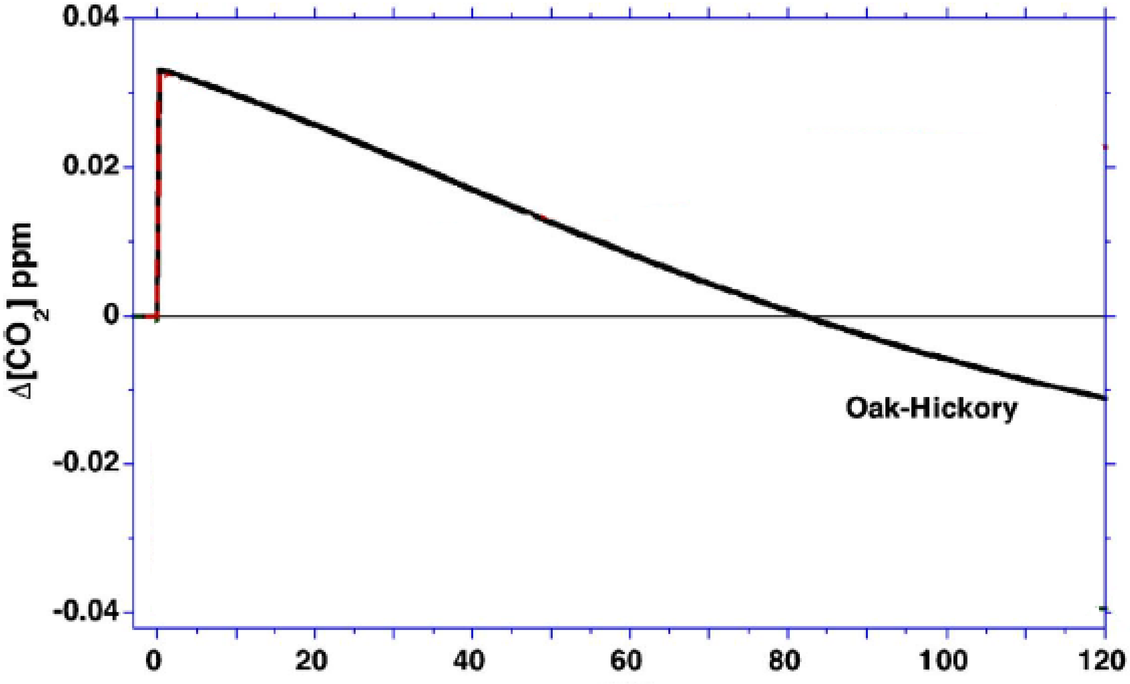
The graph below shows the hypothetical behavior of the inflow and outflow rates for the bathtub. From that information, draw the behavior of the quantity of water in the tub on the second graph below.

Assume the initial quantity in the tub (at time zero) is 100 liters.


100
75
50
25
0
Flows
(Liters/Minute)
Inflow
Outflow
0
2
4
6
8
10
12
14
16
Time (Minutes)

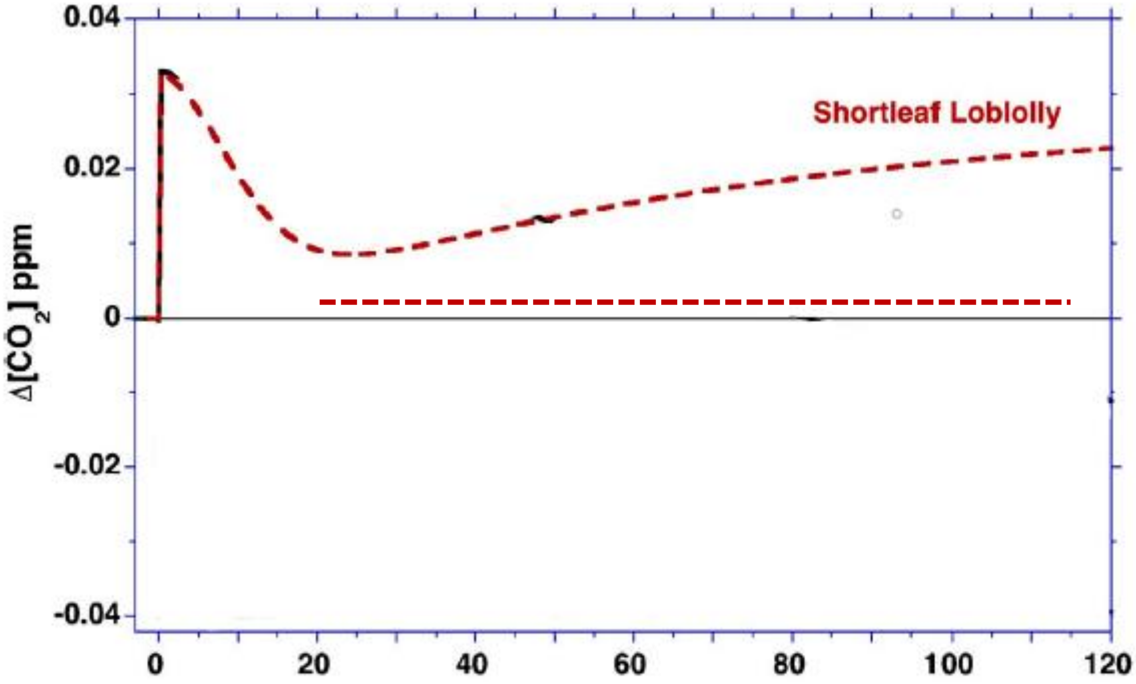

200
150
100
50
0
Quantity in Bathtub
(Liters)
0
2
4
6
8
10
12
14
16
Time (Minutes)

APPENDIX D: COAL SUBSTITUTION TEST ANSWER SHEET



1)

1. QUESTION	ANSWERS	POINTS
a	Increasing CO_2 amount to the 0.033 ppm value at first	1 point
b	Starting decrease at 0.033 ppm	1 point
c	First, declining linearly	1 point
d	Then, decreasing decreasingly	1 point
e	Neutralizing at the 80th year	1 point
f	Never reaching at the 0.04 ppm value	1 point



2)

2. QUESTION	ANSWERS	POINTS
a	Increasing CO_2 amount to the 0.033 ppm value at first	1 point
b	Starting decrease at 0.033 ppm	1 point
c	First, declining linearly	1 point
d	Then, keeping it stable or increasing the value	1 point
e	Changing the downward slope into neutral or upward at the 20^{th} year	1 point
f	Never reaching at 0 ppm value	1 point

APPENDIX E: COAL SUBSTITUTION TEST IN TURKISH

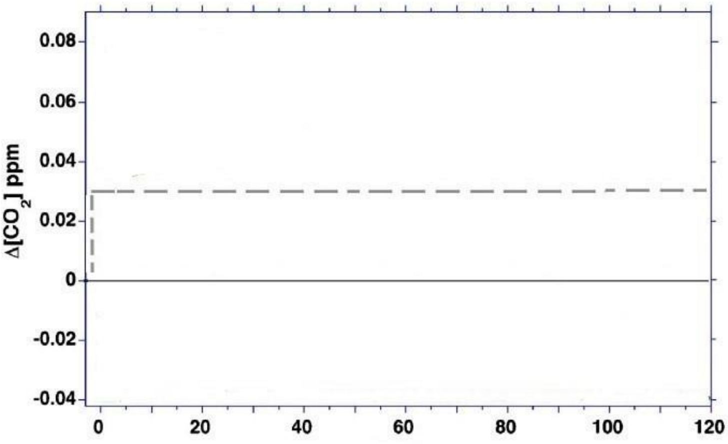
Atmosfere salınan karbondioksit gibi sera gazlarının; dünya atmosferinin sıcaklığında kademeli bir artışa neden olmasına küresel ısınma denir. Enerji ihtiyacımızın büyük bir bölümünü karşıladığımız fosil yakıtların (kömür, doğalgaz ve petrol) kullanımı milyonlarca yıl boyunca toprak altında tutulan karbonu atmosfere salar ve küresel ısınmaya neden olur.

Birleşmiş Milletler'e bağlı Hükümetler Arası İklim Değişikliği Paneli (IPCC), 2014 yılında yaptığı açıklamada küresel ısınmanın 2 ◦C'nin altında kalması gerektiğini duyurmuştur. Bunu başarabilmek için 2050 yılına kadar fosil yakıt tüketiminin hızlı ve büyük oranda azalması gerektiğini belirtmiştir. Sera gazı salımlarını azaltmak için hükümetler fosil yakıt yerine biyoyakıt kullanımını teşvik etmektedir. Biyoyakıtların karbon nötr olduğu yani atmosfere yaydıkları karbondioksit miktarı ile aynı miktarda karbondioksiti atmosferden aldıkları ilan edilmiştir. Örneğin; odun yakılarak elde edilebilecek enerji kısa zamanda atmosferdeki CO2 miktarını artırma potansiyeline sahip olsa da ormanlaştırma yoluyla bu karbon yavaşça atmosferden geri alınabilir. Bu da ısı ve elektrik için biyoyakıt olan odun kullanımındaki artışı tetiklemiştir.

Ancak biyoyakıtlar gerçekten sera gazı salınımını düşürüyor mu? Atmosferdeki CO2 molekülünün kömürden ya da biyoyakıttan gelmesi küresel ısınmaya olan etkisini değiştirmemektedir. Yapılan araştırmalar, biyoyakıt için bir ormanın tamamen kesilip sonrasında tekrar ormanlaştırma yapıldığında, atmosfere verilen karbonu geri almak için orman tipine göre 44 ile 104 yıl arasında zaman gerektiğini göstermektedir.

Üstteki bilgilerden de yararlanarak, kendi alanında öncü bilim insanlarının yaptığı çalışmaların senaryolarında yer alan bazı önemli bilgi ve grafikler aşağıda yer almaktadır.

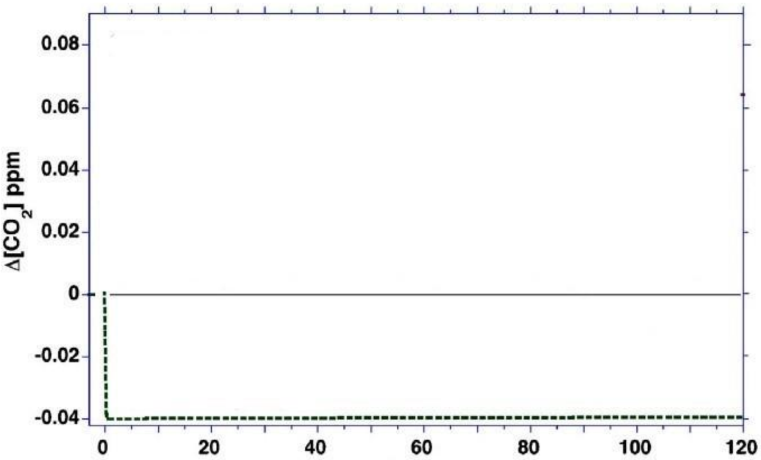
Atmosferdeki Karbondioksit Miktarındaki Değişim



Yıllar

Dünyada küresel enerji tüketimi bugün itibarıyle yaklaşık 500 x 1018 joule kadardır. Yukarıdaki grafik; başlangıç anında bunun sadece bir birimini (1x 10 18) elde etmek için fosil yakıt kullanmak yerine bir orman tamamen kesilir ve yerine ormanlaştırma yapılmaz ise atmosferdeki CO2 miktarının belli denge koşulları altında değişimini göstermektedir. Grafikte atmosferdeki CO2 miktarı kalıcı olarak 0.03 ppm artmıştır.

Atmosferdeki Karbondioksit Miktarındaki Değişim

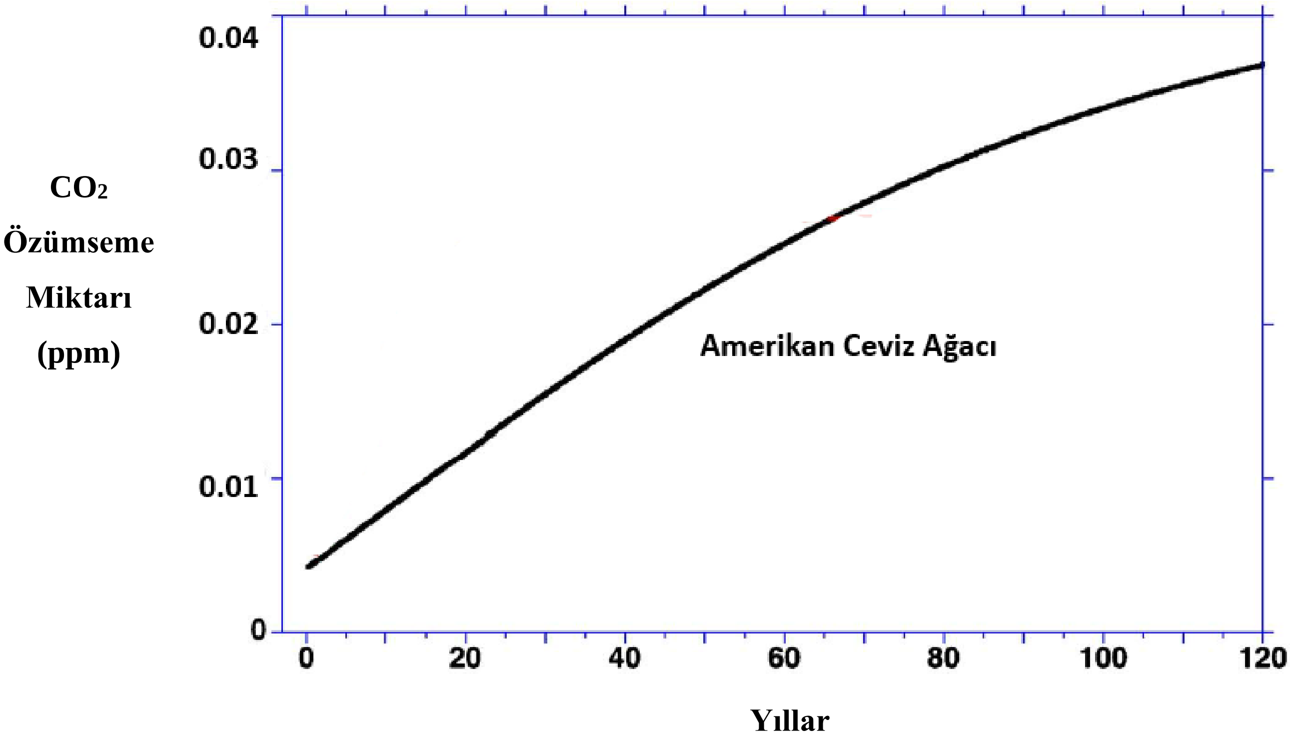


Yıllar

Bu grafik ise; başlangıç anında 1018 joule enerji elde etmek için, aynı denge koşulları altında, fosil yakıtlar yerine rüzgar ve güneş enerjisi kullanıldığında atmosferdeki CO2 miktarı değişimini göstermektedir. Grafikte başlangıç anında atmosferdeki CO2 miktarı kalıcı olarak 0.04 ppm azalmıştır. Ayrıca, hiçbir biyoyakıt kullanımında bu azalma yakalanamamaktadır.

* Grafiklerde, atmosferdeki CO2 miktarı değişiminin sıfır olduğu çizgi başlangıç anını göstermektedir ve atmosferdeki CO2 miktarını etkileyen diğer tüm unsurların dengede olduğu varsayılmaktadır.

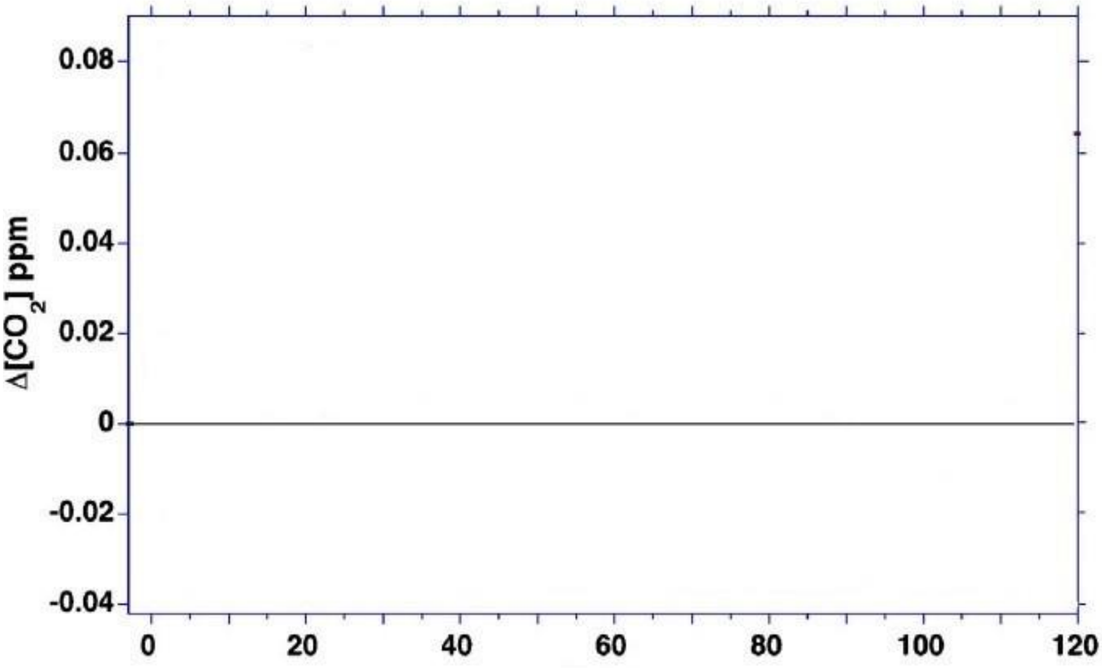
1)



Yukarıda kullandığımız başlangıç anında 1018 joule enerjiyi Amerikan ceviz ağaçlarını yakarak elde ettiğimizi ve atmosfere saldığımız CO2 gazını yeniden yakalamak (nötürleştirmek) için 130 bin hektar alanı Amerikan ceviz ağacı ile ormanlaştırdığımızı varsayalım. Amerikan ceviz ağacının CO2 özümseme miktarı grafikteki gibi arttığı ve bu koşullar altında, biyoyakıt yakılarak atmosfere verilen CO2 gazının yaklaşık 80 yıl içinde fotosentezle özümseneceği bilinmektedir.

Yukarıdaki senaryo altında, 120 yıl boyunca atmosferdeki CO2 miktarı değişimi nasıl olur? Aşağıdaki grafiğe çizip açıklayınız.

Atmosferdeki Karbondioksit Miktarındaki Değişim

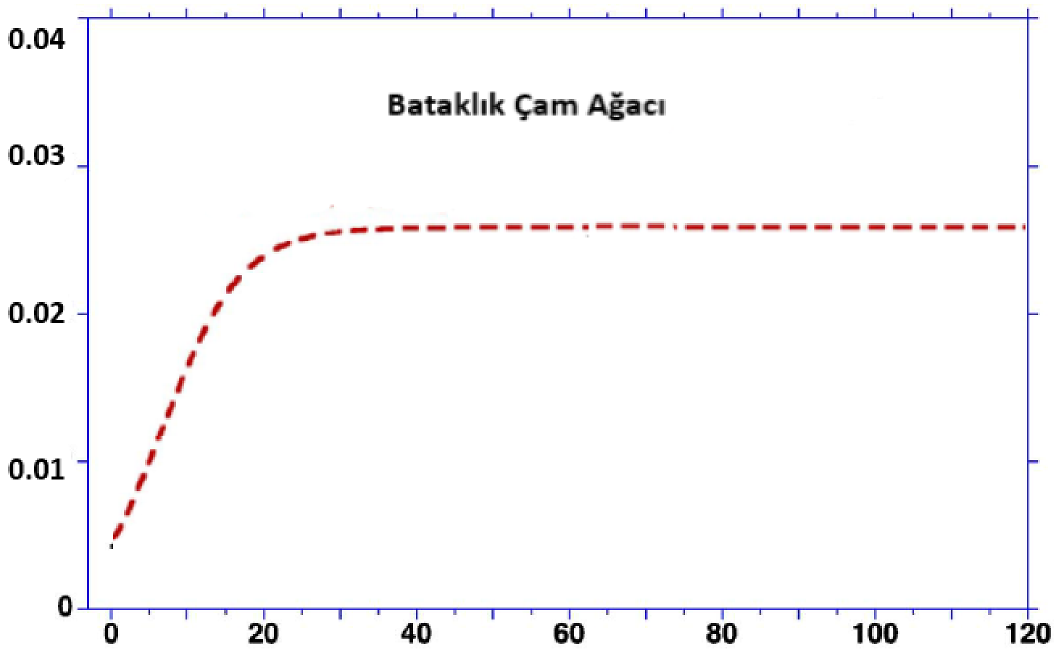


Yıllar

Açıklama:

2)

CO_2 Özümseme Miktarı (ppm)

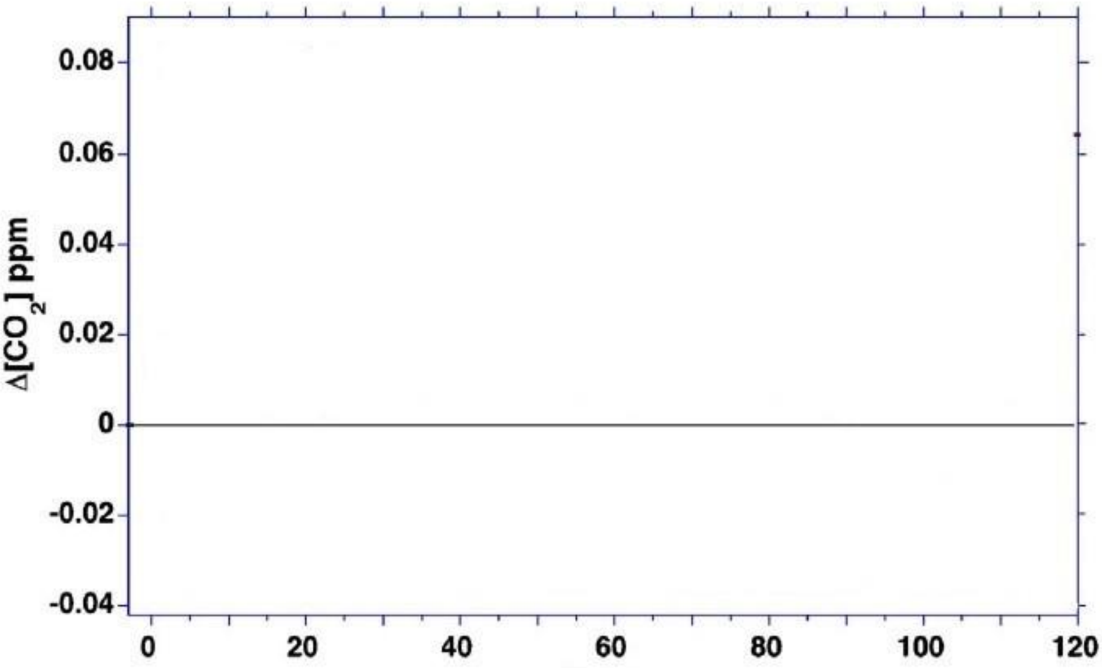


Yıllar

Yukarıda kullandığımız 1018 joule enerjiyi bataklık çam ağaçlarını yakarak elde ettiğimizi ve atmosfere saldığımız CO2 gazını yeniden yakalamak (nötürleştirmek) için 130 bin hektar alanı bataklık çam ağacı ile ormanlaştırdığımızı varsayalım. Bataklık çam ağacının CO2 özümseme miktarının grafikteki gibi arttığı ve sonra sabit kaldığı bu koşullar altında, biyoyakıt yakılarak atmosfere verilen CO2 gazının kısa ömürlü olan bu ağaç türünde hiçbir zaman tamamının fotosentez ile özümsenmediği bilinmektedir.

Yukarıdaki senaryo altında, 120 yıl boyunca atmosferdeki CO2 miktarı değişimi nasıl olur? Aşağıdaki grafiğe çizip açıklayınız.

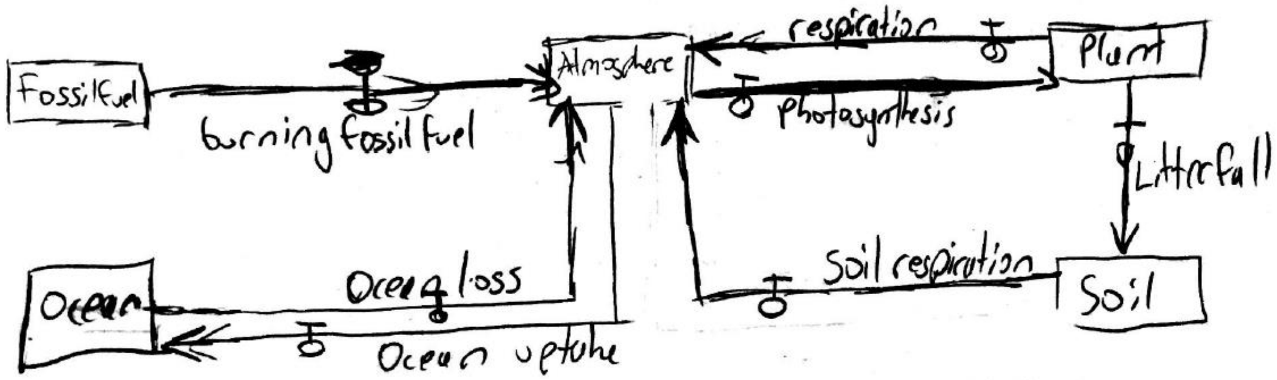
Atmosferdeki Karbondioksit Miktarındaki Değişim

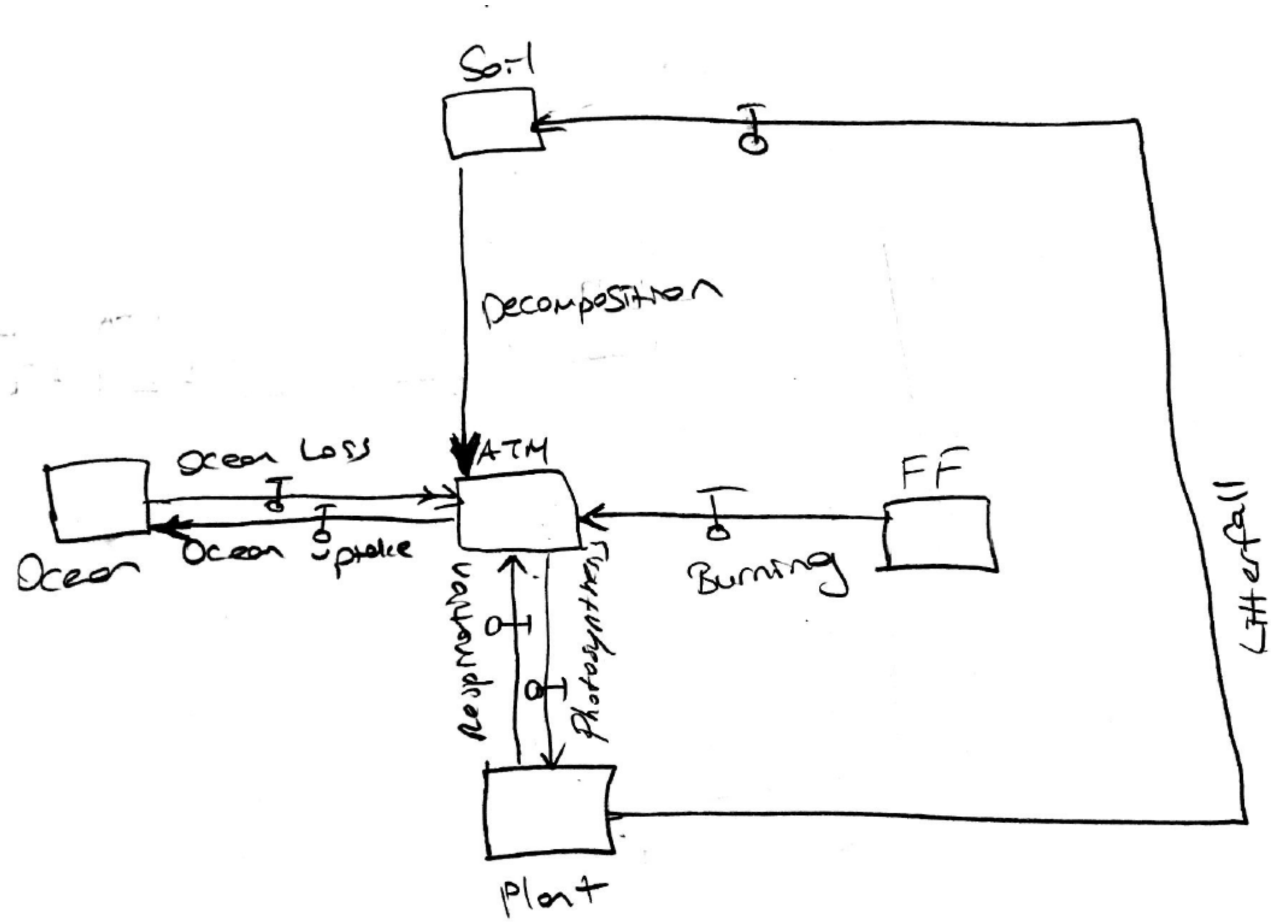


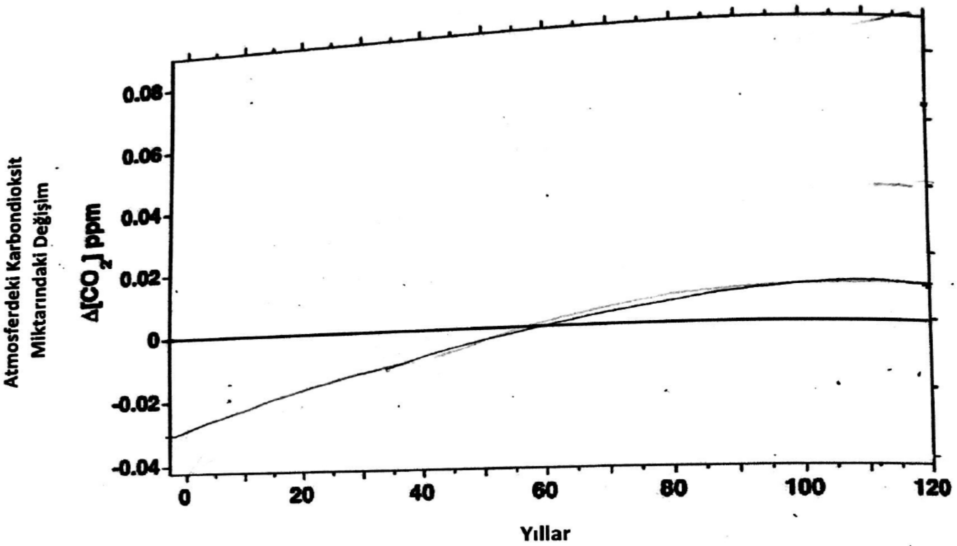
Yıllar

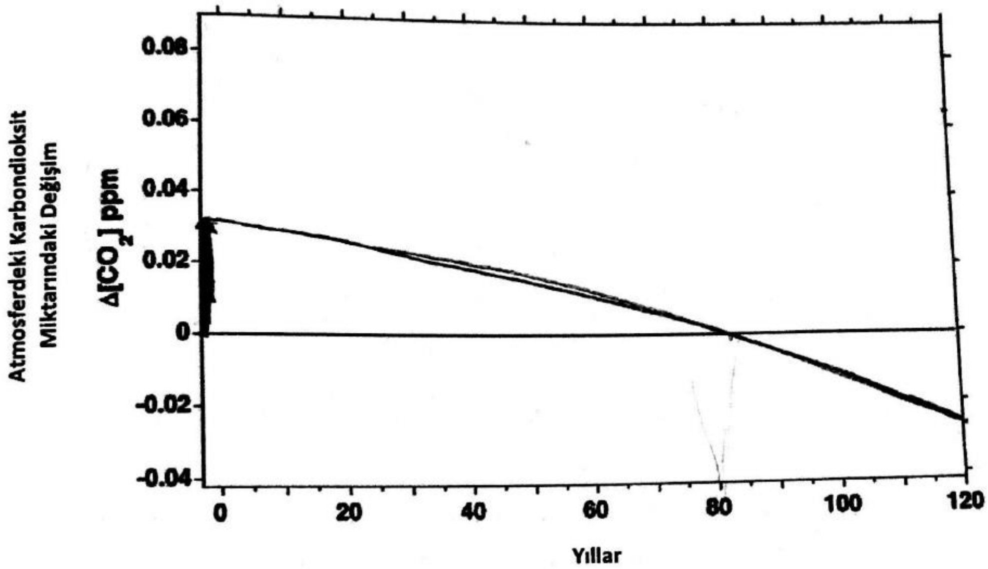
Açıklama:

APPENDIX F: SAMPLE OF THE STUDENTS' WORKING

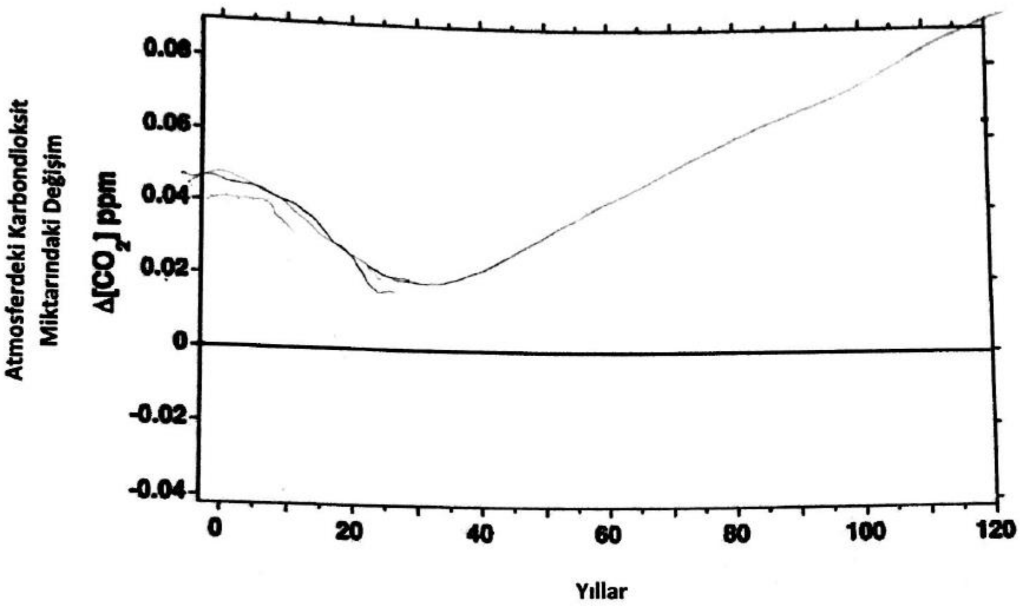




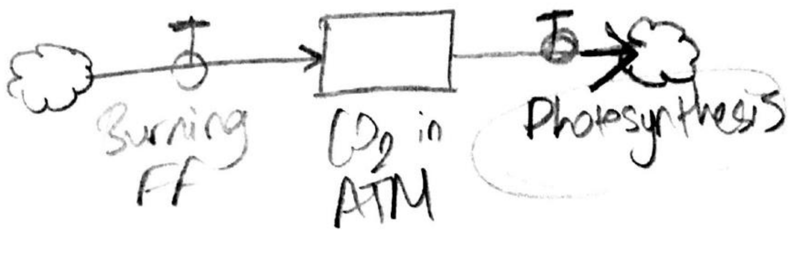




Açıklama: İlk başta yakılan ağaçlardan elde edilen CO_2 başlangıçta direkt olarak atmosferde asılı kalır. Daha sonraki 80 yılda zamanla azalır ve sonunda tükenir. Sonraki 40 yıl ise atmosferdeki CO_2 azalmaya devam eder.



Açıklama: Ağaç bir süre sonra öldüğü için özümseme duruyor ve karbondioksit artışı devam ediyor



Burning > Photosynthesis