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Influence of Production Areas on Agri-foods Sustainability: A Carbon Footprint Comparison

Submitted by

Irtiqa Arif Makhdum

Student ID 2078651

Supervisor,

Dott. Francesco Marinello

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TABLE OF CONTENTS

ABSTRACT

The carbon footprint as a concept is the greenhouse gas emission resulting from human activities. There is the impact of human actions, from daily routines to industrial processes on Earth's resources and climate. Carbon footprint, quantified in tons of CO_2 or CO_2 equivalent, has become a prominent metric. It encompasses emissions from various sources including fossil fuel combustion, electricity generation, and production processes, encompassing not only CO_2 but also methane, nitrous oxide, and chlorofluorocarbons. The outline highlights the disparities in per capita carbon footprints among nations. Moreover, it underscores the significance of considering consumption related emissions from international trade and transportation, through statistical data and insights from international reports.

People are becoming aware of climate change demanding manufacturers to disclose the climate impact of their products which can be easily achieved through Life Cycle Assessment (LCA).

Food production results in greenhouse gas (GHG) emissions, comprising over one third of total emissions. Key stages including farming, manufacturing, and pre-production are major GHG emitters within the food industry. The farm stage contributes substantially to emissions through agricultural practices, livestock production, and land use changes. From farming to post-production, GHGs are emitted, with through processing, packaging, transportation, and waste disposal.

Food production involve improvements in agricultural techniques, development of new production methods, and the promotion of environmentally friendly products can result in carbon footprints reduction. Life Cycle Assessment (LCA), evaluates environmental impact. Shifting towards plant-based diets can lower GHG emissions compared to animal-based diets, as meat production emits more carbon. Effective communication with consumers is crucial for modifying behavior and reducing carbon footprints. Food waste contributes significantly to GHG emissions, nano packaging to extend shelf life and minimize spoilage. In countries like China reducing GHG emissions involves optimizing cropping methods, efficiently using chemical fertilizers, and adopting water saving irrigation techniques, diverse cropping systems, efficient fertilizer use, and soil sequestration, have the potential to significantly reduce carbon footprints while improving agricultural productivity.

There are different steps through which a particular food ingredient passes through to become and edible food such as pre harvesting, harvesting, post harvesting involving handling and storage, processing, manufacturing, distribution to retail and wholesale, household. All the steps through which a food ingredient passes through emit certain amount of carbon footprint.

Different countries grow or produce different products with in their own country and import some products from other countries as well. There are many food products that are traded around the whole world and among those important food products include coffee, mango, rice, wheat, chocolate, palm oil, grapes and salmon.

Coffee production depends upon land characteristics, ecological factors, fertilizers and pesticides, all these factors influence carbon footprint. Coffee is produced through both dry and wet methods. If the coffee is dried using a machine instead of sun then it requires fuel and electricity which emits carbon hence contributing to carbon footprint. In wet method, during the processing stage of coffee, electricity and natural gas is used for roasting. So weather its dry method or wet method at the end coffee is packed and transported which contributes to carbon footprint on its own. If we talk about the actual data for example in Vietnam carbon footprint of coffee production through conventional technique is 16.04 kg co2eq/kg-1 whereas in case of sustainable techniques it is 3.46 kg co2eq/kg-1 respectively. Similarly in case of Brazil it is 14.61 kg co2eq/kg-1and 3.37 kg co2eq/kg-1 respectively.

Mangoes the king of all fruits is usually grown in countries with hot climate. Countries which grow and harvest mangoes are required to use fertilizers containing nitrogen, phosphorus, potassium and other micronutrients these compounds definitely contributes in carbon footprint. Similarly packaging and transportation weather in the home country or any other country through air or sea, contributes in carbon footprint but to our relief mangoes sequester carbon as well. As far as figures are concerned Mango has carbon footprint of 0.21 kg co2e /lb.

Similarly rice and wheat both our considered a staple crop around the world both requires land preparation, water management, use of fertilizers and pesticides in case of wheat it is transported to flour mills which definitely requires electricity and natural gas for the process after which its packed weather normally or through vacuum packaging, paper pouches or in polypropylene bags or mesh bags and then transported, all this contributes to increase in carbon footprint. If we talk about the rice figures according to a research on two different types of rice in Northeast area of Thailand. The first type was conventional jasmine rice and the second type was organic jasmine rice. As a result, the GHG emission was 37.42 kg co2eq/kg for conventional jasmine rice while 38.36 kg co2eq/kg for organic jasmine rice. In India a study was conducted on conventional rice production and as a result the carbon footprint was 6720.46 kg

co2eq/ha of rice. During the production stage, the carbon footprint emitted was 4869 kg co2eq/ha. The harvesting stage emitted carbon footprint of 770 kg co2eq/ha and different processes like drying, storing and milling contributed 959.6 kg co2eq/ha of carbon footprint. The packaging of these rice emitted carbon footprint of 5.7 kg co2eq/ha. Similarly for wheat a LCA case study was conducted on organic and conventional wheat in USA and according to this study the carbon footprint for 0.67 kg of conventional wheat flour is 190 kg co2eq while in case of organic wheat is 160 kg co2eq of 0.67 kg of wheat.

Chocolate is considered as a world's most delighted confectionary that is liked by everyone. It is made up of beans of cacao tree. It usually have carbon footprint towards higher side. It was estimated that the carbon footprint of chocolate ranged from 2.9-4.2 kg CO2eq/kg of chocolate. It is estimated that a bar of milk chocolate that is of 100 grams have carbon footprint of 580 g of CO2eq. According to report on production of chocolate, the GWP for milk chocolate is 3.6 kg CO2eq/kg, for dark chocolate is 1.9 kg CO2eq/kg and for white chocolate is 4.1 kg CO2eq/kg. Dark chocolate does not contains milk powder so values are toward lower side while white chocolate contains extra milk powder so its values are towards higher side.

Palm oil is extracted from fruit of palm trees. The demand of palm oil has been increased as it is not just used in making of many foods like pizza, doughnuts, chocolate but also used in making of nonfood items like deodorant, shampoo, toothpaste and lipstick. According to a study, a typical palm oil mill that does not utilize bio gas or methane produces GHG emission of 637-1131 kg CO2eq/t of crude palm oil. This value was compared with the mill that requires an external power supply and found out that the self-sufficient palm oil could potentially reduce emission by 457 kg CO2eq/t of crude palm oil compared to mill that requires external power supply.

Grape is a berry of deciduous woody vines of plant genus Vitis. They can be eaten as a fruit or can be processed into wine, jam, juice, jelly, grape seed extract, raisin and vinegar and grape seed oil. The steps which are involved in grape farming include placing the grape vine on land, mulching the ground, cultivating the field, and pruning, applying the fertilizer, harvesting the grapes and lastly storing them before transporting them to market of factories for their transformation into other products. Grapes are transported to different countries in the form of food or in the form of food products. All of this emits certain amount of carbon footprint. According to an article by Teresa Mersereau, the carbon foot printing emit during grapes production is mainly from their irrigation, high pesticides use, refrigeration requirement during transportation and high level packaging. The carbon foot print for grapes is 0.64 kg CO2eq/lb of grapes.

Salmon name is given to certain species of fish family Salmonidae like Atlantic salmon, Pacific salmon and among them only Atlantic salmon is farmed. Farming of salmon is done in large nets in sheltered waters like fjords or bays. Salmon is considered a popular food and a healthy option as it contain high amount of protein and omega fatty acids. A thesis was submitted on the carbon footprint of the production of salmon which are growing on different types for feeds from 2010 and 2012. The feeds included marine oil, marine protein, vegetable oil, vegetable protein, vegetable starch and micro ingredients. So the sum for the carbon footprint form the 2012 diet but no land use GWP from soy was included was 2.61 kg CO2eq/kg of edible salmon at salmon farm gate, the sum for carbon footprint for 2012 diet was 4.03 kg CO2eq/kg of salmon while for 2010 diet the sum was 3.69 kg co2eq/kg of edible salmon.

Chapter 1
INTRODUCTION

1.1 What is Carbon Footprint?

Every activity of human beings have impact on Earth and its resources which causes harmful effects to Earth as well as human beings. Whatever activity human beings are performing is emitting carbon dioxide in environment. For example, making breakfast in the morning or just making a cup of coffee or driving to the workplace or working on laptop or even listening to music on mobile phone is emitting carbon dioxide in environment. Carbon footprint is expressed measure of weight in tons of CO_2 or CO_2 equivalent.

Carbon footprint is the measure emission of greenhouse gas from different activities. It is expressed in tons of CO_2 equivalent. These days carbon footprint is immensely popular due to increase in public awareness about the environmental issues and climate change. The word "Carbon Footprint" is now commonly being used in media, government, and commercial world and even in households drawing a connection with an increase levels of CO_2 in environment. It is believed that if there is a constant increase in emission of CO_2 in the environment, it can alter earth's climate (IPCC 2007). It includes emission from fossil fuel combustion in manufacturing, heating and transportation and emission required to produce the electricity associated with goods and services consumed.

Carbon footprint not only includes the emission of CO_2 but also the emission of other greenhouse gases like methane, nitrous oxide and chlorofluorocarbons (CFCs). Every country have their own per capita emission of carbon footprint. According to the report of United Nations Framework Convention on Climate Change (UNFCCC), carbon footprint is not only associated with emission of GHG from the production but also associated with the emission of GHG from consumption. It also includes the emission of GHG from import and export including international transport and shipping. According to the Carbon Dioxide Information Analysis Center (CDIAC) and United Nations Development Program in 2004, USA has highest per capita carbon footprint emission. The average resident of USA had per capita carbon footprint of 20.6 metric tons of CO_2 equivalent, which is five to seven times the global average. Generally it is found that developed countries have higher carbon footprints like France had a per capita carbon footprint of

0.6 metric tons of CO_2 equivalent while Brazil had 1.8 metric tons of CO_2 equivalent and lastly Tanzania had 0.1 metric tons of CO_2equivalent.

1.2 Invention of Carbon Footprint

The word Footprint was first developed by William Rees and Mathis Wackernagel at University of British Columbia in early 1990s. In 1996, ecological footprint was defined by Rees and Wackernagel as tool used to measure the consumption of resources and waste assimilation requirements of defined human population or economy in terms of corresponding productive land area. According to Global Footprint Network 2007, the concept of ecological footprint is still commonly used as a resource management tool. The word carbon footprint was derived from ecological footprint but in past few years, it has gained its own power as there is difference between carbon footprint and ecological footprint. Carbon footprint is process related to emission of greenhouse gases while ecological footprint is impact of human activities on ecosystem. Another difference can be that carbon footprint measures the physical quantity of carbon or equivalent gases resulting from human activities while ecological footprint is measure of regenerative capacity of environment. Although carbon footprint and ecological footprint are different from each other but still both are connected with each other.

1.3 Emission of Carbon Footprint in Food Production

Now a day's public has become well aware of how manufacturing of different products is causing climate change and because of that they are demanding that manufacturers should declare the climate impact of the product. The carbon footprint of food products describe the emission of GHG from manufacturing to delivery of the food product. The carbon footprint is the complete set of GHG emission caused by product and is expressed as CO_2 equivalent (CO_2 eq). Carbon footprint is assessed by Life Cycle Assessment (LCA) in which GHG emission is measured from the production process till its final use and disposal. The main food processing activities which contributes in the emission of GHG are pre-production, production, transport, storage, cooking and wastage of food (IPCC 2007, Garnett 2008, Chakrabatri et al. 2015). Carbon footprint not only provide information about the emission of GHG but also can help companies to evaluate their operations and making them more energy and emission efficient. According to UNEP 2008, it was found in recent studies that food, drink, transportation and construction sectors are most important contributors of GHG emissions. Animal based products have higher carbon footprint as compared to plant based products. Usually food items emit three GHGs that are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Kling and Hough 2010). During agricultural practices, CO_2 is released when fossil fuels

are burnt to generate energy, CH_4 is released from paddy fields, livestock digestion and during decomposition of food waste in landfills while N_2O emits from application of fertilizers for growing crops. Every country have different component emitting majority of carbon footprint. Like in UK, food emits one fifth of all GHG emissions (Berners-Lee et al.2012, Garnett 2008). In Asia, food and drink, transportation and construction contribute between 70-80% of total GHG emission (UNEP 2008). In USA packaging of food contributes for 10% of all food production emissions with cartons and aluminum packaging, being the major contributors (Kling and Hough 2010). Roos et al. 2010 performed a study on potatoes from Sweden using detailed LCI method with global warming potential. Monte Carlo Simulation was used to quantify overall carbon footprint uncertainty. According to study, the mean carbon footprint for producing 1 kg of potatoes in 2 kg paper bag is 0.12 kg CO_2 equivalent. A study was performed on production of pig using good agricultural practice and organic agricultural practice to determine carbon footprint value using LCA method. It was found that good agricultural practices emitted CF of 2.06 kg co2eq/kg while organic agricultural production emitted 3.97kg CO_2eq/kg.

1.4 Policies to Reduce Carbon Footprint in Food Production

Food production is one of the most important component in GHG emissions as it contributes to over one third in it. Farm, manufacturing and pre-production stages are Main emitters of GHG in food industry. Although farm stage is the most overlooked phase in food industry yet it is one of the main stage to contribute most of the emission. Food system comprising of stages from farming to post-production is greatly involve in emitting man made GHG. At farm level, emission arises from agricultural and livestock production and land use changes while at manufacturing level majority of emission comes from food manufacturing processes like processing, packaging and transportation whereas during post-production stage, main contributors to the GHG emission are the retail, consumer travel, household consumption and food waste disposal. United Nations Framework Convention on Climate Change (UNFCCC) plays a notable role in conveying climate change and its global impact. Conference of Parties 26(COP26) in 2021, decided upon Glasgow Climate Agreement. According to this conference, many discussions on environmental impacts of food industries were done and deciding upon their capable remedies and as a result of it, specific attention has been given to the food industries to reduce GHG emission. UNFCCC have made two agreements that are Kyoto Protocol (1997) and Paris Agreement (2015). Kyoto Protocol was made on 11th December 1997 but was ratified on 16th February 2005 and currently 192 countries are part of it. According to this protocol, countries should work on limiting and reducing the GHG emissions according to the goals set. While Paris agreement was signed at COP 21 on 12th December 2015. In this

agreement, all nations are involved to strengthen against threat of global change by keeping global temperature rise this century below 2 degrees Celsius above pre industrial levels and make sure to limit temperature increase even further to 1.5 degrees Celsius.

Greenhouse Gas Protocol (GHG Protocol) is globally recognized standard for measuring and controlling GHG emissions. GHG Protocol was initiated in 1990 due to increase in reports of greenhouse gas. Presently, GHG Protocol is working jointly with governments, industries, NGOs and corporations and other organizations to provide guidelines to calculate emission. GHG Protocol consists of scope1, scope2, and scope3 to classify emission. Scope 1 and scope 2 are obligatory to report while scope 3 is optional to report as it is hardest to monitor. Scope 1 emissions are from controlled and company owned resources that are directly being emitted into the environment from different activities. Scope 2 emissions are indirect emissions generated from purchased energy from utility provider. They are emitted in the environment from consumption of purchased electricity, steam, cooling and heating. Scope 3, also known as value chain emission, includes all indirect emissions that occur in reporting company's upstream and downstream supply chain. It is divided into 15 categories including business travel, waste disposal and purchased goods and services. Besides GHG Protocol, there are other standards also that are used to measure and report greenhouse gases. ISO 14064 provides guidelines to organizations to quantify and report their GHG emissions and removals.

1.5 Reducing Carbon Footprint in Food Production

In order to reduce carbon footprint, agricultural techniques are being improved, new food production methods are being developed and environmentally friendly products are being preferred by customers (Shabir et al. 2023). Carbon footprint of a product is assessed using Life Cycle Assessment (LCA) which calculate environmental effects like toxicological stress, climate change, acidification, eutrophication and resources to evaluate products suitable for climate change stages (Xu et al., 2020). GHG emission can be lowered by consuming plant based diet as compared to animal based diet as meat emit more carbon foot print as compared to fruits and vegetables. Communication will play an important role in reducing carbon footprint as consumers are already aware of approach to reduce carbon footprint and communication can help to modify consumer behavior according to the approaches to reduce carbon footprint (Kause et al. 2019). According to Waste and Resources Action Program (WRAP) 2011, in UK food waste is responsible for 20 million tons of GHG emission. So to reduce this food waste emission, nano packaging is considered as possible method to preserve food and extend the shelf life of food and minimize the emission as nano particles have antimicrobial properties which decrease the spoilage and improve the quality and safety of

food (Zhang et al. 2019). According to Huang et al. 2017, China has world's largest agricultural sector, because of which there is great emission of greenhouse gas. Chemical fertilizer contributes most to the emission of GHG and also the electricity utilized for crop irrigation was heavily contributing in emission. Therefore to reduce the GHG emission grain should be produced by optimizing cropping spatial layout and using chemical fertilizers efficiently and cutting down the use of power through water saving irrigation. Opting certain methods can help in reducing carbon footprint like use of diverse cropping systems, increase the use of N fertilizer will generate 36-52% of total emission, implementing intensified rotation with reduced summer fallow will lower carbon footprint up to 150% and improving soil sequestration can help in reducing carbon footprint, reduced tillage combined with crop residue retention has been shown to improve soil organic carbon and minimize carbon footprint while integrated essential agricultural practices may uplift crop productivity by 15% to 59% and decrease emission by 25% to 50% (Liu et al. 2016).

1.6 Food Products

Different countries produce different food products while some of the countries prefer to import different food products from other countries which they cannot grow. Like in case of coffee, there are many countries which cannot grow coffee so they import from other countries like Brazil as it is the largest producer of coffee. Countries usually prefer two conditions first, growing the food products in their own country but does not have all of the favorable conditions while on the other hand getting food products from other countries which have all of the favorable conditions but need to transport them to their country. There are many food products that are traded around the whole world and among those important food products include coffee, mango, rice, wheat, chocolate, palm oil, grapes and salmon.

Chapter 2
EMISSION IN DIFFERENT PHASES OF FOOD PRODUCTION

Food processing involves set of techniques consisting of equipment, energy and tools to transform agricultural products into food ingredients or prepared food. Processing step is one important step involved in food manufacturing. In past centuries heating was the only process which was involved in food processing, to cook food, preserve food and food's organoleptic and nutritional properties and increase the shelf life of the food. In late 19^{th} century, the focus shifted from home cooking to more industrialized processing with aiming on better preservation, microbial safety, improving quality of food and enhancing nutritional qualities of food. With passing years, new technology were discovered like steam and use of microwave. Because of these new techniques, the style of cooking in homes have been changed and instead of home cooked food people are preferring semi-finished processed foods. As people are favoring semi processed foods, industrialists are focusing more on quality and safety and nutritional properties of food. There are different steps through which a particular food ingredient passes through to become and edible food such as pre harvesting, harvesting, post harvesting involving handling and storage, processing, manufacturing, distribution to retail and wholesale, household. All the steps through which a food ingredient passes through emit certain amount of carbon footprint.

2.1 Foods going through different processes

Coffee

A study was performed by Roberta Salomone on coffee production in Sicily, Italy. The first step in coffee production is cultivation. Coffee production depends on the type and characteristics of land and ecological factor as well as age of plant. All these factors influence carbon footprint and emission of carbon footprint also depends on use of fertilizers and pesticides. Coffee beans are processed by two methods that are dry method and wet method. In dry method, coffee beans are sun dried or dried using machine. Use of machine requires fuel and electricity which emits carbon footprint whereas sun drying emits zero

carbon footprint. In wet method different resources are involved which results in emission of carbon footprint. During the processing stage of coffee, electricity, natural gas for roasting and packaging materials are used and as result there is roasted coffee in packaging and coffee waste like dust and scraps from cleaning and roasting. Every company uses different types of packaging like aluminum cans, paper filter, glass bottles etc. Every packaging have its own carbon footprint. After packaging, coffee is transported to markets or coffee is transported to different countries through different means of transportation. Consumption is considered difficult to measure the footprint as it depends on consumer nationality and taste and method of how coffee is prepared for consumption. All these steps coffee go through emits carbon footprint.

Mango

It is considered as one of the most important fruit. It is consumed in raw as well as fully ripped form. Growing mangoes require certain type of weather condition like area with good rain fall, and dry summer. Windy areas and areas with cyclones should be avoided as it can shed the flower of fruit and can break the branches. There are countries that cannot grow mangoes as they do not have favorable weather conditions, so they import from countries that grow them. For mango farming, firstly land is chosen with good sunlight exposure and from where any waste must be removed. Then pits are prepared and mango samples are grafted into pits. During the first few years, use drip irrigation or sprinkler to provide water to the plants. Fertilizers are added containing nitrogen, phosphorus and potassium and other micronutrients. Pruning is done to give a well-balanced structure to branches. Then harvesting is done and are transported to the market. Mangoes are exported to other countries through different means of transportation in different packaging as most common in cardboard boxes. All of this procedure emits carbon footprint but towards lower side because the trees of mangoes sequester a lot of carbon and irrigation and use of pesticides in minimal quantity and use of dense land help to reduce it.

Rice

Rice is considered as one of the important staple food for many countries as it is considered as the second most grown cereal crop and more than half of the world consume it as staple food. It can be grown in variety of climatic, soil and hydrological conditions in the world. There are different steps involved in the cultivation of rice like firstly variety of rice and quality of seed is selected then land is prepared and planting is done. Water management is done and fertilizers and pesticides are added. Harvesting is done when rice are ready and then rice are dried and stored under suitable temperature. Then milling is done

during milling rice is cleaned, hulled, polished, graded, sorted and packed and send to retailers and markets. Rice is one of the important food that is traded around whole world. It is imported to different countries by different means of transport in packaging like modified atmosphere packaging or vacuum packaging or paper pouches or in polypropylene bags. All of these process emits certain amount of carbon footprint.

Wheat

Wheat is one of the important cereal crop as it is an essential staple food for many countries. It is highly adaptable crop and can be grown in variety of climate and soil types. Wheat is considered as key ingredient as it is used in variety of dishes because of that its demand is increasing day by day depending on population growth and dietary preferences. It is not just consumed by humans but it is also considered as an important feed for livestock. The steps involved in wheat cultivation such as soil preparation, planting, watering, addition of pesticides and harvested. After harvesting, the wheat is send to mills for its conversion into flour. The wheat is cleaned and conditioned, wheat is milled into to flour, flour is stored and packed and send to market. These steps requires electricity and will emit carbon footprint. Wheat is also among the food that is transported to other countries through different way of transport as not every country have suitable conditions to grow wheat. Wheat is packed is mesh bags or cardboard boxes.

Chocolate

Chocolate is considered as a world's most delighted confectionary that is liked by everyone. It is made up of beans of cacao tree. Cacao trees were originated in rainforest of South and Central America. Chocolate is consumed in many ways like in drink form or eating as a candy, in deserts etc. It is not only consumed as a food but they are also used in manufacturing of cosmetics, ointments and coating of pills. Not all countries grow cacao trees so export of cacao trees was started where the all the conditions for growth were favorable to increase the production. Making of chocolate is a complex process which involves so many chemical reactions. The production of chocolate involves many steps like harvesting, fermentation, drying, roasting, grinding of beans, conching, tempering and mixing of all ingredients like cocoa mass, sugar, cocoa butter, emulsifiers, aroma, milk components. Fermentation, drying, roasting and conching are important processes as development of flavor and aroma depends on these steps (Barisic et al. 2019). All these steps involve usage of energy and electricity and emits greenhouse gases, because of this chocolate emits higher amount of carbon footprint. After the completion of process, chocolates are packed in either boxes, foil or paper wrapping and are transported to market. Chocolates are transported

to other countries by different means of transport as not all countries can produce chocolates, emitting carbon footprint.

Palm oil

It is a vegetable oil that is extracted from fruit of palm tree and its scientific name is Elaeis guineensis. From this fruit, crude palm oil is produced by squeezing the flesh from the fruit where palm kernel oil is also produced by crushing the kernel or the stone of fruit. The demand of palm oil has been increased as it is not just used in making of many foods like pizza, doughnuts, chocolate but also used in making of nonfood items like deodorant, shampoo, toothpaste and lipstick. In many countries of the world it is used as animal feed and as biofuel. Palm is extracted from the mesocarp of the fruit. The fruit undergoes much processing for the production of the oil. When the mesocarp of fruit is fully ripened, it contains around 56-70% of edible oil. The extraction of oil is categorized into traditional method, small scale mechanical units, medium scale mills and large industrial mills depending on their level of complexity (Poku, 2002). The primary steps involves in processing of palm oil include fruit sterilization, fruit loosening or stripping, digestion, oil extraction and clarification. Extraction of oil is divided into wet and dry extraction. In wet extraction, usually water is used as liquid, to extract oil from the fruit already milled. Hot water or stream is used to leach out oil from ruptured oily cells of fruit (Obibuzor, Okogbenin & Abigor, 2012; Poku, 2002). In dry extraction, hydraulic press or screw press or centrifugation techniques are used (Poku, 2002). All of these steps require electricity because of which there is carbon footprint emission. The crude palm oil is packed in bottles and transported to the market. For international trade, crude palm oil is transported in tankers with stainless steel or coated tanks. All of this emits certain amount of carbon footprint.

Grapes

A grape is a berry of deciduous woody vines of plant genus Vitis. They can be eaten as a fruit or can be processed into wine, jam, juice, jelly, grape seed extract, raisin, and vinegar and grape seed oil. Grape are non-climatic type of fruit that occurs in the form of clusters. Its skin contains yeast which is the earliest domesticated microorganisms. The steps which are involved in grape farming include placing the grape vine on land, mulching the ground, cultivating the field, and pruning, applying the fertilizer, harvesting the grapes and lastly storing them before transporting them to market of factories for their transformation into other products. Grapes are transported to different countries in the form of food or in the form of food products. All of this emits certain amount of carbon footprint.

Salmon

Salmon name is given to certain species of fish family Salmonidae like Atlantic salmon, Pacific salmon and among them only Atlantic salmon is farmed. Salmon are anadromous which are born in freshwater and migrate to ocean and then return to fresh water to reproduce. Farming of salmon is done in large nets in sheltered waters like fjords or bays. Salmon is considered a popular food and a healthy option as it contain high amount of protein and omega fatty acids. In 2008 according to FAO, Norway and Chile are the biggest producers of Framed raised salmon having supply of two third of world's salmon. Farming to salmon is divided into three stages that are eggs hatch in freshwater tanks, young salmon are raise is tanks or channels of running water for 12 to 18 months and finally they are transferred to cages along seashore where they are grown till matured. In this cage, salmon feed on small bait fishes. After maturing, salmon are harvested. Salmon are stopped getting fed a week before the harvest so that their digestive system get empty from waste. Salmon are then taken out using net and are placed in water with carbon dioxide to anesthetize them to cut their gill arches. Cutting of gills will cause blood loss and then salmon are placed in ice cold slurry to stop the spreading of enzymes and maintain their color and flavor. Salmon are packed in air tight plastic or foil wrap and are then transported to markets and even to other countries. These process emits carbon footprint.

2.2 Carbon Equivalent in different stages of processing

Every stage of food processing emits certain amount of carbon footprint and it also depends on the type of food and the process it is undergoing. The emission of carbon footprint depends even on the place where that particular food item is produced. Not all countries produce every type of food item and there are many countries which prefer to import food from other countries even though they have favorable conditions to grow particular food product. Import and export is one of the biggest step which emit great amount of carbon footprint, also depending on the mean of transport. Every step that a food is gone through emits certain amount of carbon footprint.

Coffee

The overall carbon footprint emitting from the production of coffee is different for every country and also depends on the agricultural method used for the production. Like in Vietnam, when conventional technique is used to produce the coffee, the overall carbon footprint is 16.04 kg co2eq/kg-1 and in the case of sustainable technique to produce coffee in Vietnam, emits carbon footprint 3.46 kg co2eq/kg-1.

In case of Brazil, the use of conventional technique to produce coffee emits carbon footprint is 14.61 kg co2eq/kg-1 while in case of sustainable coffee production in Brazil emits 3.37 kg co2eq/kg-1. In the case of Costa Rica, the overall carbon footprint for the production of coffee was 4.98 kg co2eq/kg and as for the milling of coffee contributed to 0.64 kg co2eq/kg of green coffee of carbon footprint and exportation of green coffee from Costa Rica to Europe emits carbon footprint on 0.27 kg co2eq/kg. the transportation depends on the mean of transport, as for in this research the if the export carbon footprint value is broken down , then 0.185 kg co2eq/kg of carbon footprint was emitted from sea transportation, 0.041 kg co2eq/kg of carbon footprint was emitted from transportation by land from port to storage destination, 0.033 kg co2eq/kg of carbon footprint was emitted from transport by land from mil to port and finally some administrative activities emitted carbon footprint of 0.006 kg co2eq/kg. After the coffee reach Europe, coffee undergo processing which emits carbon footprint of 3.05 kg co2eq/kg of green coffee including roasting, packaging, distribution, grinding, purchasing, consumption and disposal. Coffee production was done in Karnataka in India using techniques like conventional and organic emitted carbon footprint in between 0.26-0.67 kg co2eq/kg in conventional coffee while 0.12-0.52 kg co2eq/kg in organic coffee. A research was done in Aceh province of Indonesia, comparing production of Gayo Arabica coffee in two different years of 2015 and 2016, according to this study, the overall carbon footprint for the years 2015 was 1.48 kg co2eq/fu while in 2016 the carbon footprint was 1.93 kg co2eq/fu. The production and processing of coffee require use of electricity which can emit a certain amount of carbon footprint. So as for this research the carbon footprint for use of electricity in 2015 was 0.374 kg co2eq/kg of green beans and in case of 2016, the carbon footprint for 2016 coffee production was 0.536 kg co2eq/kg of green beans A research was done in East Java, Indonesia comparing the production of Arabica and Robusta coffee and according to which the total GHG emission for the processing of coffee was 98.7 kg co2eq/kg-1 for Arabica coffee and as for Robusta coffee, the total GHG emission was 119.6 kg co2eq/kg-1. The emission for the use of pesticides in Arabica coffee production was 16.4 kg co2eq/ha-1 of coffee and while in case of Robusta coffee, the emission for the use of pesticides was 102.53 kg co2eq/ha-1 of coffee. As for the milling stage the carbon footprint for Arabica coffee was 98.7 kg co2eq/ha-1 of coffee and as for Robusta coffee milling stage, the emission was 119.6 kg co2eq co2eq/ha-1 of coffee. The transportation is done of coffee harvest to Sukorejo village form coffee processing which is done on motorbike. So to transport Arabica coffee for processing almost travel for 15 km on motor bike emitting of 9964.69 g co2eq t-1 and as for Robusta coffee, the emission for traveling for 9 km on motor bike emitted 10643.62 g co2eq t-1. A study was conducted in Klungkung Province of Indonesia on production of organic Arabica coffee and according to this study, the GWP was 18.0589 kg co2eq/15 kg of ground organic Arabica coffee. A

research was carried out in in Yunnan China and comparing it with other regions of China so according to this research, the carbon footprint was 3.59 kg co2eq/kg of coffee beans, among which 2.94 kg co2eq/kg. The coffee production consists of stages of planting, processing, roasting, grinding and transportation and among them plantation emitted carbon footprint of 2.94 kg co2eq/kg with transportation to distributers emitted the lowest of 0.09 kg co2eq/kg. To compare Yunnan region with other regions, the carbon footprint for Lincang city was 3.18 kg co2eq/kg, for Baoshan City was 3.04 kg co2eq/kg, for Peur City was 2.90 kg co2eq/kg and for Dehong Prefecture was 2.65 kg co2eq/kg. A study was carried out in Satipo, Junin, Peru, in which two different techniques were used to roast the coffee that include solar and local electricity grid. As for comparing the carbon footprint emitted from both of the techniques, the roasting of coffee through solar power emitted carbon footprint of 0.318 kg co2eq/kg of roasted coffee which in the case of roasting from electricity from local grid emitted carbon footprint of 0.744 kg co2eq/kg of roasted coffee. A research was performed in Piracicaba, Sao Paulo, Brazil to determine the emission of carbon footprint in harvesting of coffee. To harvest the coffee, a coffee harvester with 3 cylinder diesel engine with 40 KW and weighted 5600 kg was used which resulted in GHG emission of 4.75 kg co2eq/kg-1 of coffee.

Mango

According to an article which is written by Teresa Mersereau, 2012, Growing mangos have low carbon footprint because the tree sequester a lot of carbon, irrigation and use of many pesticides is minimal and the land use is dense. Mango has carbon footprint 0.21 kg co2e /lb. The main factors that contributes in carbon foot printing during mango production includes harvesting, processing and packaging as they require electricity and chemicals is there production and use of more packaging. Harvesting stage has zero carbon footprint emission but use of electricity and excessive packaging like use of cardboard or Styrofoam, boost overall carbon footprint. Mangos are perishable fruit so they have to be transported by air which means there will be an increase in carbon foot printing but it also depends of the distance of transport. Generally mangoes are transported in refrigerated containers through air transport so refrigerated containers not only emits more carbon than no refrigerated but air travel also increases carbon footprint as compared to if transported through truck or ship. Mangoes can be imported from neighboring countries or can be produced domestically but mean of transport can have an impact on carbon footprint. Disposal of mangoes has high waste carbon footprint because their packaging is non-recyclable or non-biodegradable which end up in landfilling. According to a report on mangoes produced in Mexico and exported to USA, the carbon footprint of mangoes from Mexican production to USA retail

distribution is average 0.4556 kg co2e/kg of mangoes. In Mexican farms, operation gives an average of 0.229 kg co2eq / kg of mangoes while packaging gives 0.066 kg co2eq/kg and transportation give average of 0.126 kg co2eq/ kg of mangoes. For the exportation of mangoes from Mexican border to USA distributers emits carbon footprint of 0.008751 kg co2eq/kg. A research was done on different fruits in India among which the carbon footprint for mangoes was 2.86 kg co2eq/kg. A study was carried out in UK for the production of mangoes and among which the carbon footprint was 2.2 kg co2eq/kg of mangoes. In Southeast region of Iran, mango farming emits 181.99 kg co2eq/kg of overall carbon footprint. A research was carried out in Sao Francisco Valley, Brazil in which mangoes are grown using conventional technique which emitted carbon footprint of 0.139 kg co2eq/kg. A study was conducted to find the environmental effect on producing mango pulp in Tamil Nadu, India. According to this study, the plantation of mango emits 2.163 kg co2eq/ha of GWP100a, the use of fertilizer emitted 14.232 kg co2eq/ha and the use of pesticides emitted 2.413 kg co2eq/ha.

Rice: A study was conducted in Malaysia on conventional unmilled rice and according to which the GHG impact was 1.39 t co2eq/ton. A research was conducted on two different types of rice in Northeast area of Thailand. The first type was conventional jasmine rice and the second type was organic jasmine rice. As a result, the GHG emission was 37.42 kg co2eq/kg for conventional jasmine rice while 38.36 kg co2eq/kg for organic jasmine rice. After harvesting, the transportation of both conventional and organic jasmine rice was 1.3540 kg co2eq/kg. A study was conducted on rice production in which different techniques and different variety of rice were grown in different regions of Thailand. In Chiang Mai Region, the GHG emission for organic KDML (KhaoDawk Mali) 105 paddy rice was 2.39 kg co2eq/kg and for the organic KDML 105 brown rice with packaging was 3.57 kg co2eq/kg. In Nang Kai Region, the GHG emission for GAP (Good Agricultural Practices) KDML 105 paddy rice was 1.52 kg co2eq/kg and GAP KDML 105 brown rice with packaging was 2.58 kg co2eq/kg. In Phattalung Region, the GHG emission for GAP sangyod paddy rice was 1.34 kg co2eq/kg and for GAP sangyod coarse rice with Packaging was 2.29 kg co2eq/kg. A study was conducted in Thanjavur District of India on conventional rice production and as a result the carbon footprint was 6720.46 kg co2eq/ha of rice. During the production stage, the carbon footprint emitted was 4869 kg co2eq/ha. The harvesting stage emitted carbon footprint of 770 kg co2eq/ha and different processes like drying, storing and milling contributed 959.6 kg co2eq/ha of carbon footprint. The packaging of these rice emitted carbon footprint of 5.7 kg co2eq/ha. A research was carried out on irrigated rice production system in Ghana. The total carbon footprint emitted was 1520.1 kg co2eq/ha-1 while as for the use of fertilizer emitted carbon footprint was 632 kg co2eq/ha-1 and for the use of

pesticide was 94.2 kg co2eq/ha-1 of rice. Carbon footprint for the harvesting of rice was 178 kg co2eq/ha-1. A study was conducted to assess the carbon footprint of upland brown rice in the area of Karen and Lawa in Thailand from the stages planting to harvesting of rice. In Lawa, the GHG emission assessed was 0.19 kg co2eq/kg of unmilled upland brown rice while in Karen, the GHG emission assessed was 0.13 kg co2eq/kg of unmilled upland brown rice. A research was carried out to estimate the greenhouse gas mitigation in rice production system without using any agricultural chemicals in Jeonbuk province of South Korea. The total carbon footprint emitted was 2.21 kgco2eq/kg-1. A study was done in Hubei province of China to estimate the carbon footprint of rice production, according to which the emission was 6.81 t co2eq/t of polished rice. According to a research which was done on rice production using lifecycle inventory analysis in Philippines in either rainfed area or irrigated area, the GHG emission for irrigated area was 3920 kg co2eq/ha-1 of rice and for rainfed area the emission was 138 kg co2eq/ha-1 of rice. In Egypt a study was conducted on carbon footprint for paddy rice production. As a result of this study, 1.90 kg co2eq/kg of paddy rice was recorded as carbon footprint. A study was conducted in between organic and conventional rice production in Southern region of Brazil. As a result the GHG emission for the organic rice was 0.21 kg co2eq/kg while for conventional rice the carbon footprint was 0.32 kg co2eq/kg. A research was carried out in Dargaz region of Iran on Greenhouse gas emission in two type of rice production system. As a result of this study, the GHG emission was 813.17 kg co2eq/ha-1 for semi traditional rice and 968.31 kg co2eq/ha-1 for semi mechanized rice. Another study was conducted in Iran in Mazandaran region on paddy rice production which resulted into GWP of 2666 kg co2eq/ha-1 of paddy rice field. A study was conducted on rice production in five typical districts in China and all five districts and different carbon footprint depending on parameters setting of the calculations of boundaries, material or energy consumption. Guangdong province generated 2504.20 kg co2eq/t rice of carbon footprint, Hunan province generated 2326.47 kg co2eq/t rice of carbon footprint, Heilongjiang province generated 1889.97 kg co2eq/t rice of carbon footprint, Sichuan province generated 1538.90 kg co2eq/t rice of carbon footprint and lastly Jiangsu province generated 1344.92 kg co2eq/t rice of carbon footprint.

Wheat

A study was conducted in which carbon footprint was determined for producing wheat with different farming practices. Although use of fuel, inorganic fertilizers and pesticides in wheat production have negative impact on environment but the purpose if this study was to see whether using different farming practices will improve yield as well as reduces carbon emission. The four farming practices used in this study were Fallow-flax-wheat, Fallow-wheat-wheat, Continuous wheat and Lentil- wheat. It was found

that spring wheat which was produced using improved farming practices has negative carbon footprint that is averaging -256 kg co2eq ha-1 per year. For each kg of wheat grain produced a net 0.027-0.377 kg co2eq is sequestered into soil. Among the four framing practices, Lentil-wheat system had lowest carbon footprint at -552 kg co2eq ha-1 per area. A LCA case study was conducted on organic and conventional wheat in USA and according to this study the carbon footprint for 0.67 kg of conventional wheat flour is 190 kg co2eq while in case of organic wheat is 160 kg co2eq of 0.67 kg of wheat. These values do not contain transport factor. After production of wheat flour, it is transported further to area where it is baked, packed and distributed so the wheat flour is transported by both truck and rail. According to this study, it is assumed that is transported 2000 km to the shipping destination where it is further processed. According to the analysis, the transport value for both organic and conventional wheat that transported for 2000km will be same of 140 g co2eq of 0.67 kg of wheat that is more than four times the difference between the two systems. A research was conducted in Punjab state of India according to which the carbon footprint for the wheat production was 0.28 kg co2eq/t-1 of wheat. According to a study on the greenhouse gas emission of wheat production in Bangladesh, the carbon footprint emitted was 3043.43 kg co2eq/ha-1 of wheat and the use of fertilizer emitted 712.771306 kg co2eq/ha-1 and in the case of harvesting the emission was 15.825836 kg co2eq/ha-1 of wheat. A research was done in the Shangdong, Hebei and Henan province in Northern China using different farm scale like small, medium and large farm. The small farm size was <3.3 ha, the medium was 3.3-16.7 ha while the large was >16.7 ha. The carbon footprint for the small farm was 5350 kg co2eq/ha-1, for medium farm was 5235 kg co2eq/ha-1 and for large farm was 4169 kg co2eq/ha-1 of wheat. It was also observed that the carbon footprint value decreases with the increase of farm area. A study was carried out in Khuzestan province in Iran and according to which the GHG emission was 7541.04 kg co2eq/ha while the use of fertilizer emitted 719.45 kg co2eq/ha of wheat. Another study was conducted in Iran in Esfahan province and according to which the GWP was 2620.86 kg co2eq/t-1 of wheat. A study was conducted on the 15 farms in Wielkopolska, Poland on winter wheat production using three tillage system that are conventional tillage, reduced tillage and direct sowing. So as a result the carbon footprint recorded were 309.9 kg co2eq/t for conventional tillage winter wheat, 393.5 kg co2eq/t for reduced tillage winter wheat and lastly 397.1 kg co2eq/t for direct sowing winter wheat. A research was done in Kohgilouye-Boyer Ahmad, Iran on wheat production and according to which the GHG emission was 280.57 kg CO2eq/ha-1 of wheat. A research was conducted in Agroindustry Company of Iranian Novin Frams in Golestan Province, Iran and the GWP for wheat production was 841 kg CO2eq/t due to diesel fuel consumption. A study was conducted in Northern area of Iran and according to which the GWP was 1164.12 kg CO2eq/ha of irrigated wheat while 805.46 kg

CO2eq/ha of rain fed wheat. Another study was conducted in Antalya in Turkey on production of rainfed wheat and as result of it, the GHG emission was 592.12 kg CO2eq/ha of wheat. This emission was mainly due to diesel use followed by use of fertilizer seeds and chemicals. A study was conducted in Finland according to which the GHG emission for spring wheat production was 2330 kg CO2eq/ha-1. According to a survey, the average carbon footprint for the wheat export from 2015 to 2019 is 0.8 kg CO2eq/kg and by 2040 it will be 0.7 kg CO2eq/kg. According to YEN ZERO, the carbon footprint of wheat crop range from 5.658 kg to 625 kg CO2e/ha. It also depends on the cultivation strategy like in plough based technique the carbon footprint will be 2,965 kg CO2e/ha while in case of direct drill technique, its 1,756 kg CO2e/ha .

Chocolate

Chocolate usually have carbon footprint towards higher side. It was estimated that the carbon footprint of chocolate ranged from 2.9-4.2 kg CO2eq/kg of chocolate. According to a study, cocoa from Millot plantation in Madagascar generated 0.57kg CO2/kg of cocoa. It is estimated that a bar of milk chocolate that is of 100 grams have carbon footprint of 580 g of CO2eq. A study was conducted in UK and according to that study, GWG of chocolate production ranges from 2.9 to 4.2 kg CO2eq/kg.

A study was conducted on Ecuadorian chocolate and according to that study, the carbon footprint of storage, manufacturing and transportation phases ranged from 1.20 to 2.76 kg CO2eq/kg depending on number of days of storage, distance travelled etc. The carbon footprint for storage of chocolate is 0.10 kg CO2eq kg-1 while for manufacturing is 0.55 kg CO2eq kg-1, for packaging is 0.27 kg CO2eq kg-1 and for transportation is ranged between 0.28 and 1.84 kg CO2eq kg-1 depending on transportation distance.

A study was conducted in which there was comparison between Peru's chocolate and Ivory Coast's chocolate. In Peru, to produce chocolate organic agriculture and fair trade practice was used and it was transported to France. The GWP for ingredients production was 1.24kg CO2eq/kg of chocolate, GWP for cocoa paste production was 0.37kg CO2eq/kg of chocolate, GWP for packaging and transport was 1.01 kg CO2eq/kg of chocolate, GWP for chocolate bar fabrication was 0.56 kg CO2eq/kg of chocolate and GWP for transport for retail distribution was 0.19 kg CO2eq/kg of chocolate and the overall GWP was 3.37 kg CO2eq/kg of chocolate. While in Ivory Coast, to produce chocolate conventional agriculture practice was used and was transported to Spain. The GWP for ingredients production was 4.41kg CO2eq/kg of chocolate, GWP for cocoa paste production was 0.19 kg CO2eq/kg of chocolate, GWP for packaging and transport was 2.38 kg CO2eq/kg of chocolate, GWP for chocolate bar fabrication was 0.71 kg CO2eq/kg of chocolate and GWP for transport for retail distribution was 0.22 kg CO2eq/kg of chocolate and the overall GWP was 7.90 kg CO2eq/ kg of chocolate. A study was conducted on the production of chocolate in Ghana

using life Cycle Assessment. The GWP100 for Extra dark chocolate (EDC) was 1.65 kg CO2eq/kg while for Flavored milk chocolate (FMC) was 4.21 kg CO2eq/kg. According to report on production of chocolate, the GWP for milk chocolate is 3.6 kg CO2eq/kg, for dark chocolate is 1.9 kg CO2eq/kg and for white chocolate is 4.1 kg CO2eq/kg. Dark chocolate does not contains milk powder so values are toward lower side while white chocolate contains extra milk powder so its values are towards higher side. In milk chocolate more cocoa butter than cocoa liquor is used and in white chocolate only cocoa butter. According to a study dark chocolate has low environmental impact of 1.67 kg CO2eq/kg and as for white chocolate is 4.1 kg CO2eq/kg while for milk chocolate is 4.19 kg CO2eq/kg. According to Escribano et al. milk included into milk chocolate emits higher impact as dairy farming and milk powder product plays an important contribution into carbon emission. It is said that milk production alone emits carbon emission from 1.77 to 4.09 kg CO2eq/kg.

Palm oil

According to a study, a typical palm oil mill that does not utilize bio gas or methane produces GHG emission of 637-1131 kg CO2eq/t of crude palm oil. This value was compared with the mill that requires an external power supply and found out that the self-sufficient palm oil could potentially reduce emission by 457 kg CO2eq/t of crude palm oil compared to mill that requires external power supply. According to an article"Carbon Emissions and Palm Oil" by efeca: A study which was cited by European Commission calculated that growing and refining 1 metric ton of crude palm oil emits average 0.86 tons of CO2eq. It was also stated that carbon footprint of 5.69 t co2eq-1/ ton of palm oil was produced on converted peat soil. It was estimated that the average emission of export of palm oil to Europe is 0.13t CO2e t-1. A research was performed in Malaysia/Indonesia as inventoried country/region and according to which the GHG potential was 2024 kg CO2eq/t of palm oil (including iLUC and biogenic CO2 uptake) and to compare the carbon footprint was 1418 kg CO2eq/t of palm oil (excluding iLUC and biogenic CO2 uptake). A study was conducted in Riau, Indonesia according to which the total emission was 1405.83 kg CO2eq/kt /year. A study was carried out in Aceh, Indonesia on palm oil mill and according to which the planting of palm oil emits 0.0187 kg CO2eq, use of fertilizer can emit 148 kg CO2eq and harvesting of plant can emits 3.50 kg CO2eq and the overall carbon footprint for processing palm oil into crude palm oil in 9.6 kg CO2eq.

Grapes

According to an article by Teresa Mersereau, the carbon foot printing emit during grapes production is mainly from their irrigation, high pesticides use, refrigeration requirement during

transportation and high level packaging. The carbon foot print for grapes is 0.64 kg CO2eq/lb of grapes. Grapes production emits methane, nitrous oxide and chlorofluorocarbon. The growth and end of life have most significant impact on grapes carbon foot print. Each stage of production of grapes have different carbon footprint. The growing stage of grapes have moderate carbon footprint because of use of high amount of pesticides and use of irrigation. The harvesting, processing and packaging stage of grapes have moderately high carbon footprint because of use of packaging material like Styrofoam or plastic which mainly contribute in increase in carbon footprint. The carbon footprint of transporting grapes produced in California to other parts of America is low because they do not have to travel in refrigerated trucks. The carbon footprint of end of life of grapes is fairly significant as plastic and Styrofoam have low recycling rate. According to a study the carbon footprint for Mediterranean table grape variety Soultanina was 0.85 kg CO2eq/ kg of grapes while carbon footprint of Cabernet Sauvignon was 0.56 kg CO2eq/kg of grape and carbon foot print of indigenous white variety Xynisteri was 0.28 kg CO2eq/kg of grape. A study was performed in Zanjan Province of Iran on to determine energy efficiency and CO2 pattern of grape production according to which the overall carbon emission was 1207.37 kg CO2eq/ha-1 while the use of fertilizer emits 229.94 kg CO2eq/ha-1 and the use of pesticide emits 584.01 kg CO2eq/ha-1. A study was conducted in Italy on production of different varieties grapes, according to which GWP100 was 3383.41 kg CO2eq/ha of VCWNO(vine grapes cultivation for common wine production based on nonorganic agriculture practices), 1282.81 kg CO2eq/ha of VCWO(vine grapes cultivated for common wine production based on organic agriculture practices), 2464 kg CO2eq/ha of VQWNO(vine grapes cultivated for quality wine production based on nonorganic agricultural practices) and 1630.70 kg CO2eq/ha of VQWO(vine grapes cultivated for quality wine production based on organic agricultural practices). A research was conducted in Sughd, Tajikistan on grapes production using different systems like system A is trunk height < 30cm, system B is height 80 cm, system c is 120 cm, one sides multi arm paired planting, system D is 120 cm and system E is 140 cm as a result GHG was 556.34 kg co2eq Mg-1 grapes for system A,B and C while 306.23 kg co2eq Mg-1 of grapes for system D,E. A study was performed in Lazio region of Italy according to which the total GHG emission for grape production was 0.297 kg CO2eq/ha of grapes. A research paper on calculation of carbon footprint of Austrian wine, according to which the total GHG emission was 1733 kg co2eq/ha of grapes.

Salmon

A thesis was submitted on the carbon footprint of the production of salmon which are growing on different types for feeds from 2010 and 2012. The feeds included marine oil, marine protein, vegetable

oil, vegetable protein, vegetable starch and micro ingredients. Components included other than these ingredients to find the carbon footprint were pallets production, smolt production and salmon farming and reduction to marine oil. So the sum for the carbon footprint form the 2012 diet but no land use GWP from soy was included was 2.61 kg CO2eq/kg of edible salmon at salmon farm gate, the sum for carbon footprint for 2012 diet was 4.03 kg CO2eq/kg of salmon while for 2010 diet the sum was 3.69 kg co2eq/kg of edible salmon. The carbon footprint from 2010 to 2012 increased from 3.7 to 4.0 kg CO2eq/kg of edible salmon due to increase in feed efficiency and the changes in feed increased the final GWP. The reason behind the increase is increased use of vegetable ingredients. In feed, soy replaced pelagic fisheries so this change in feed from marine to vegetable have higher carbon footprint as growing soy is associated with land use change. According to (Burg van Den, 2012; Pelletier, 2012; Aubin, 2009; Iribarren, 2010; LCA DK Food), the GWP of salmon in Norway was 1.8 kg CO2eq/kg of fillet, the GWP for the salmon in UK was 3.3 kg CO2eq/kg of fillet, the GWP for the filleting of salmon was 0.15 kg CO2eq/kg of fillet while the GWP for freezing of salmon was 0.03 kg co2eq/kg of fillet. A research was done on Carbon footprint of Norwegian seafood product on global seafood market among which fresh gutted salmon that was airfreight from Norway to Tokyo showed 14 kg CO2eq/kg. A study report on LCA of Atlantic salmon harvested at indoor RAS farm in Northern China. RAS is Recirculating Aquaculture System, which is used to deal with the environmental challenges associated with conventional cage culture system, so it resulted in 16.7 t co2eq/t of salmon production. It was found in the report of European Commission, that the carbon footprint for the salmon meat is low to 2 kg CO2eq/kg of salmon, (according to Winther and al., 2009) while according to Pelletier et al, 2009), the carbon footprint for live weight salmon is 1.8 kg CO2eq/kg. According to a research, the GHG emission for the Norwegian Produced salmon was 1.78 kg CO2eq/kg of whole weight while for the UK produced salmon is 3.27 kg CO2eq/kg of whole weight, (Pelletier et al., 2009). The difference among the values of Norwegian produced and UK produced salmon is due to the difference in feed ingredients and higher use of marine by products by UK. According to a study, GWP for the salmon production is 6.6 kg CO2eq/kg because of long distance transport and refrigeration. A study according to which fresh and frozen whole salmon and salmon fillet were shipped to the markets of Europe, USA and Asia through truck, sea or air from Norway. According to this study the overall carbon footprint for this ranged from 4.8 to 28 kg CO2eq/kg edible salmon among which 75% contributed for transport and feed production while less than 2% for slaughtering and processing and 1-5% for packaging. According to a study conducted on Norwegian salmon and US Salmon farmed on two different system that are ONP System and LBCC-RAS system, the carbon footprint for Norwegian salmon feed was 2.5 kg CO2eq/kg of feed. In case of LBCC-RAS system in which US salmon is farmed and is

transported to retailer on truck on electricity generated by mix of coal, gas, nuclear, wind and hydropower. In this case the carbon footprint for the use of electricity was 0.64 kg co2eq/kWh. In case of LBCC-RAS system in which US salmon is farmed and is transported to retailer on truck on electricity generated 90% from hydropower and 10% from coal and in this case the carbon footprint was 0.09 kg CO2eq/t/km. For ONP system, salmon was transported from Oslo to Seattle by air on Boeing 747-400 so carbon footprint was 1.18 kg CO2eq/t/km. For ONP system, salmon was transported from Alesund, Norway to Seattle through Panama Canal by cargo ship, so carbon footprint was 0.004 kg CO2eq/t/km.

Chapter 3
GEOGRAPHY OF DIFFERENT FOODS

Every country have their own special food item that they own like Thailand's chilies and Italy's tomatoes. There are many cases in which a certain food belong to a particular country but that country does not produce that food item instead they import from other countries. So it was revealed in a study that more than two third of crops that are considered as a national diets of a particular country, basically come from some other country and in majority of cases, somewhere far away. According to Colin Khoury, a plant scientist at CIAT (International Center for Tropical Agriculture) and US Department of Agriculture, "our entire food system is completely global". It is said that a country's food supplies and farm production is made up of 69 percent of foreign crops. As an example, in US people's diet mostly consist of food from Mediterranean and West Asia like wheat, barley, chickpea, almonds and more and they get soya bean from East Asia and maize from Mexico and Central America. World widely, there is wide range of crops making a diverse agricultural production system and giving variety of food supplies from different regions of world. It represents that all of global food system is interconnected with each other with respect to the geographical origins of food plant (Khoury et, al 2016).

3.1 Countries of Import and Export

Exporting countries for coffee are Brazil, Vietnam, Colombia, Indonesia and Ethiopia while on the other hand the importing countries include USA, UK, Germany, France, Italy and Japan. Many of the countries import coffee in fully prepared form but there are countries which only import green beans and process them by themselves like Germany. Germany imports coffee beans and process them and further export them to other European countries because of which Germany has an enormous roasting industry. As transportation is one of the important part in exporting a product so it is important to take all measures properly for transportation. The transportation of coffee is done by sea or by air. Transportation by ship can be cheaper as compared to air transport and it will have larger capacity to carry coffee while on other hand air transport takes less time to reach and more reliable but air pressure should be maintained. Coffee beans are packed into hermetic bag or grainpro bag as they should be remained air tight.

Exporting countries for mangoes are India, China, Thailand, Indonesia, Philippines and Pakistan whereas the importing countries include USA, Germany, France, Netherland, Belgium, UK, Canada, UAE, Saudi Arabia, Japan, China, Russia, Australia and South Korea. Mango is a perishable fruit so it is preferred to transport mango by air. If want to transport by ship then post-harvest treatment and care should be done as transport by ship takes time. Mangoes should be packed in an insect proof boxes.

Exporting countries for Rice are China, India, Indonesia, Bangladesh, Vietnam, Thailand, Myanmar, Philippines and Pakistan whereas importing countries include Nigeria, China, Bangladesh, Indonesia, Philippines, Iran, Saudi Arabia, Iraq, Brazil, USA, Germany, France, UK, Netherland, Belgium, Japan, South Korea and African countries. There are many countries that although produce their own crop and even export them to other countries but they even import that particular crop other countries to full fill the demand of their citizens. Rice is transported to other countries by ship, rail or truck by being packed in woven jute fabric bags or plastic bags or carton.

Exporting countries for wheat include China, India, Russia, USA, Canada, France, Australia, Pakistan, Ukraine and Argentina while importing countries include are Egypt, Indonesia, Algeria, Bangladesh, Brazil, Nigeria, Japan, Iran, Turkey, Philippines, Morocco, Saudi Arabia, Iraq, Mexico, USA, Italy, Spain, Netherland, Pakistan, South Korea and Vietnam. There are many countries that although produce their own crop and even export them to other countries but they even import that particular crop other countries to full fill the demand of their citizens. Wheat is transported by rail, trucks, ocean vessel or barge. Wheat is packed in jute bags or directly loaded into the containers but special care should be taken to avoid moisture.

Exporting countries for chocolate are Switzerland, USA, Germany, Belgium, Netherland, UK, Brazil, Poland and Italy while on the other hand the importing countries are USA, Germany, UK, France, Canada, Netherland, Japan, Italy, Belgium and Australia. There are many countries that although produce their own crop and even export them to other countries but they even import that particular crop other countries to full fill the demand of their citizens. Chocolates are packed in aluminum foil or plastic film or in cardboard boxes. It is transported to other countries by mean of sea as it gives cost and temperature stability. It can also be transported by air transport but there are chances of rapid change in temperature which can cause separation of the ingredients and can deformed the product.

Exporting countries for palm oil are Indonesia, Malaysia, Thailand, Colombo, Nigeria, Guatemala, Papua, New Guinea, Cote di Ivoire, Honduras and Brazil while on the other hand the importing countries are India, Netherland, Kenya, Italy, Mexico, China, USA, Spain and Philippines. Palm oil is transported to other countries by tanks but rarely by barrels or jerricans. It is transported by ship, trucks or by rail.

Exporting countries for grapes include Chile, Peru, South Africa, Spain, Italy, USA, China, France, Turkey, India, Argentina and Iran whereas importing countries include USA, Germany, UK, France, Netherland, Russia, Canada, China, Japan, UAE, Saudi Arabia, South Korea, Australia, Brazil, Mexico, Singapore, Malaysia, Thailand. There are many countries that although produce their own crop and even export them to other countries but they even import that particular crop from other countries to full fill the demand of their citizens. Grapes are packed into fruit crates or carton and are transported to other countries through ship, air, truck and rail.

Lastly the exporting countries for Salmon are Norway, Chile, Scotland, Canada, USA, Faroe Island, New Zealand and Australia while the importing countries include USA, Germany, France, UK, Netherland, Belgium, Japan, China, South Korea, Russia, Canada, Australia, UAE, Brazil, Chile, Switzerland, Sweden, Italy, Denmark and Taiwan. Salmon is rather transported alive or in frozen form. In the case of alive salmon, transportation is done in tankers containing water while in the case of frozen salmon, they are transported by air or road or rail transport in ice boxes or specialized isolated containers with dry ice or ice packs.

3.2 Different Places with Different Carbon Footprint

Every country produces different types of foods. It is not necessary that every food is produced by all the countries. Many food products are produced by more than one country. So every country has its own carbon footprint values for the same food product. Usually food goes through different stages like production, transport, roasting, distribution, consumption and export. These stages depend on that particular food product and on the stages the food has to go through as every stage emits different amount of carbon footprint value. If we take the example of salmon, when it is distributed in market, it is in the form of piece whole fresh or in the frozen form therefore, every form will have different emission value. Every country have their own practices and techniques to produce a certain food. It depends on the quantity of fertilizer and pesticide used or on whether any other chemical has been used during the cultivation of certain product or farming is done without the use of any chemicals. Every technique emits different carbon footprint. Some countries use production method that emits less carbon footprint while others use method that emits high carbon footprint as it depending on the technique used for the same product. Every country may be producing different variety of a certain food so this can also be reason of different carbon footprint values for same product. Countries have their own energy mixes which could be different from other countries, this can also influence the carbon emission which is mainly used in different food production, like processing, transportation and storage. Carbon footprint also depends on

the packaging of the food product. Every country have their own requirement for packing of the food products whereas the export is concerned every country prefer their own mean of transportation at every stages of food production, transportation can emit high amount of carbon footprint depending on the mean of transport and distance travelled. It also depends in what form a food is being transported. An example can be of coffee, many countries import coffee in roasted form while in case of Germany, it imports green coffee beans (not roasted) and they roast the coffee by themselves. Germany has vast roasting industry and after roasting it, they export to other European countries. There is great emission caused by the food wastage as every country have their way to deal with food waste from production or processing or after consumption. Every country have different carbon footprint values of same food as every country uses different growing method and processing method which will give different carbon footprint value for same food. Countries have their own cradle to gate approach. There are many countries which export the food that they grow by themselves but they import that same food from other countries to make up their requirements. Some countries while importing a food product give certain requirements to the importing country so it will also effect carbon emission. Land use change is also among the big factor for the emission of carbon footprint as every country have their own patterns of land use which are different from other countries. Each country go through different climate and weather conditions which can impact agricultural activities, productivities, water usage and energy needs. At the same time agricultural policies which shape their agricultural practices farming practices, food production (organic or conventional) and trading place an active role. The other reason can be that countries may use different methods or techniques to calculate carbon footprint resulting in differential values. These reason not only imply country to country but within a country in different regions. Every region within a country have their own land use practices, have their own farming techniques and agricultural practices, sources of transportation and their energy sources like renewable or nonrenewable energy sources.

3.3 How to calculate Carbon footprint

Carbon footprint is considered as an essential measure of environmental impact of supply chain and it indicates how different activities of humans can impact the global sustainability.

To measure the carbon footprint of agricultural products, a comprehensive analysis of energy consumption in all stages of the production should be done. Total input energy in production is the sum of all components of energy used in different processes for the production of outputs. Carbon footprint is total amount of CO2 and other GHGs emitted in overall production process of product, because of this

it has become one of the significant environmental indicator. Global Warming Potential (GWP) is an indicator used to quantify carbon footprint which illustrates the quantity of GHGs that put up with the global warming and climate change. Carbon footprint is calculated using Life Cycle Assessment Methodology (LCA), as it is most perceived approach for the environmental assessment of products and their processes. To use LCA, large database with data on energy consumption by each activity and data on usage of fertilizer, annual product yield and plant protection product etc. are required. It also requires the calculations of GHGs from fuel consumption, use of fertilizers, plant protection products and transport of products to final consumer or food industry.

According to Plassmann et al, 2010, carbon footprinting is done by using different analytical methodologies. Calculations depends on the availability of data and uncertainty surrounding the value of key variable. Carbon footprint is estimation of total amount of GHGs emitted during life cycle of goods, from production of raw material to processing, transportation, storage and consuming and waste disposal. Carbon footprint is usually estimated by businesses, government and other stakeholders in order to get the idea of Emission of GHGs from products like food (Bolwig and Gibbon,2009). The results of carbon footprint can be used to reduce the emission further during different operations. The carbon footprint value can also be shared on the carbon labels on product to let consumers know about it (Bolwig and Gibbon, 2009; Sinden, 2009). Usually carbon footprint methodologies are sketched out in industrialized countries, but lack of scientific knowledge on GHGs emission from developing countries can cause risk of high carbon emission. Because of this, there are chances that low income countries may suffer from climate related consequences or reduction in export opportunities (McGregor and Vorley, 2006; Brenton et al., 2009; Kasterine and Vanzetti, 2010). According to some stakeholders, if international standards were developed, there will be more specific requirements but those will not be recognized internationally (BSI, 2008a,b; Sinden, 2009). The methodology for carbon footprint consider emission for all GHGs including CO2, N2O, CH4 and other gases like hydrofluorocarbons and perfluorocarbons and gas that is converted into CO2 equivalent value. GHGs are emitted from energy use, combustion processes, chemical reactions, refrigerant losses, land use change, livestock and other agricultural processes and waste. All these factors are included in analysis while non CO2 emission from livestock, their manure and soils are calculated through highest tier approach laid out by IPCC 2006 guidelines or highest tier approach guided by country. The issue between farms with or without land use change since 1990 showed two issues that are the forest land is converted to cropland in tropical countries so the emission from land will be very high while the tropical countries or individual farms which are enlarging their agricultural area will have very much higher carbon footprint using PAS 2050 as compared to countries or farm that do not convert

native vegetation. Absence of country or region specific emission factor can be a reason for problem in calculating the carbon footprint due to which the accuracy of the analysis is minimized. As no land use change can play a significant role in emission, other factors are also involved in impacting the final result of emissions. According to Hospido et al., 2009, carbon accounting and labelling are important for the understanding of impacts of activities on climate change but it is not necessary that they are good indicators of overall sustainability. There are many scenarios in which reducing GHG emission may have a negative impact on environment.

According to Greenhouse Gas Protocol, there are certain tools that are used to calculate the emission like Cross-sector tools, Country-specific tools, Sector-specific tools and Tools for countries and cities.

Chapter 4
RESULTS

According to the report by United Nations, every step of food production emits GHG that trap the sun's heat and can cause climate change. About a third of all human caused GHG emission is linked to food. The biggest contribution of food related GHG comes from agriculture and land use like methane from cattle's digestive process, nitrous oxide from fertilizers used for crop production, carbon dioxide from cutting down forests for the expansion of farmland and other agricultural emissions from manure management, rice cultivation, burning of crop residues, and the use of fuel on farms and smaller contribution is made by refrigeration and transport of food, industrial processes such as the production of paper and aluminum for packaging, the management of food waste. In order to reduce the carbon foot print, changes in each stage of production is required, from producers to consumers.

4.1 Emission in different stages

Every food undergoes different steps from farm to plate. Each step emits certain amount of carbon footprint. The emission depends on the area where food product is grown, type of technique used, storage method, transportation and export.

In case of coffee, majority of countries import coffee in roasted form. Coffee can be cultivated organically or conventionally, as result organic coffee emits less carbon footprint as compared to conventional coffee because in organic farming, compose and manure is used as fertilizer while in conventional farming, chemical fertilizers are used which emits high carbon footprint. According to co2eq values, Robusta coffee emits more carbon footprint as compared to Arabica coffee because Robusta coffee requires more fertilizer, water and processing and roasting. Among all stages of coffee, production stage emits most of carbon footprint which includes use of fertilizer, pesticides, irrigation and process that requires the use of electricity. So carbon footprint of coffee depends on type of coffee and technique used to produce coffee.

Mango is consider as carbon sequester as a mango tree grows, carbon sequestration starts. The mango tree absorbs carbon dioxide from environment. Mango is a fruit that take up carbon from environment rather than emitting it in environment. They are consider as super absorbers of carbon dioxide as Mexican

mango tress absorb more GHGs than that is emitted in environment by other processes like production or shipping, making it a positive crop to tackle climate change. Other reason for low carbon footprint emission from mango is that there production require less use of pesticides and irrigation. The main reason for carbon footprint contribution is harvesting, processing, packaging because of the use of energy during these stages and the material used in packaging is cardboard. When mangoes are exported to other countries, they are transported in refrigerators as mango is a perishable fruit due to which there is high carbon footprint emission.

There are different varieties of rice and different farming techniques are used to produce rice. So every stage of rice production emits certain amount of carbon footprint depending on the technique use like organic or conventional, cultivation including use of fertilizer, harvesting, storage, polishing, and transportation depending on the distance being travelled.

Production of wheat emits great amount of carbon footprint. Wheat can be produced by different farming techniques. There is spring wheat and winter wheat based on their growing season. Spring wheat crop duration is shorter than winter wheat and less water is required for winter wheat while winter wheat requires more fertilizer as compared to spring wheat. So carbon footprint emission depends on the variety of wheat and techniques used and packaging, transportation and exportation of wheat.

Chocolate emits carbon footprint towards higher side because of different process a cocoa goes through to transform it into a chocolate. One of the main factor for higher carbon footprint is milk in chocolate, that's the reason dark chocolate emits less carbon footprint as compared to milk chocolate while white chocolate emits the more carbon footprint as compared other chocolate due to addition of milk. Land use change can also be a factor for higher carbon footprint because presently, the demand of chocolate has been increased so more land are being turned to cocoa farming. In many countries, forest are being cleared for cocoa production. Then cocoa goes through many processes to transform into a chocolate and these processes require great amount of electricity due to which there is higher carbon footprint emission.

Palm oil is consider bad for environment. Palm oil is used in many products like shampoo, detergents, chocolate, cookies and producers are trying to eliminate palm oil from them as it emits high carbon footprint. Although it is more in use production oil but have a negative impact on environment mainly in Indonesia and Malaysia as they are the main and biggest producers of palm oil. As demand for palm oil is increasing globally there are two ways to do that are increase yield or expand the amount of land already being used, so this will emits carbon footprint as it is causing deforestation. A study suggested that palm oil contributed 2% in global forest loss.

Grapes farming emits high carbon footprint due to use of pesticides, fertilizers and use of packaging like Styrofoam or plastic. The highest emission is in growing stage while if grapes are exported, they are transported in refrigerators due to which emission can be high.

Salmon farming emits lower carbon footprint as compared with other animal protein sources. Salmon farming is considered more efficient farming as compared to other. The emission of carbon footprint depends how it is transported as some are transported in whole form or packed frozen fillet form.

4.2 Emission in different countries or region

There are different values for carbon footprint for every country or region for same food because of the difference in production method, energy sources, transportation distance and transportation methods, handling food waste and the land use change, food processing and packaging, climate condition, agricultural policies and each country have their own way to calculate carbon footprint.

There can be two conditions, first get food product from other countries as they have good and favorable conditions but involves transportation, and secondly grow food in your own country although does not have good or favorable conditions but does not involve transportation. Growing in bad condition with no transportation can reduce emission from transportation, encourages use of localized food but can lower yield and reduce the quality of crop due to unfavorable conditions and there can be chances of increased use of fertilizer or water and steps taken to make soil suitable for production. Whereas growing in good and favorable condition with transportation promotes higher yield and good quality of crops, proper use of resources but can cause emission due to transportation and have possibilities to support large scale industrial agriculture and contributing to global food system complexities. These both conditions can be favorable in their own ways as if bad conditions are not that extreme and it is still possible to grow yield with acceptable quality, so local production with no transportation can be an environment friendly option. On other hand, good conditions will improve the quality of yield and reduce the use of resources and minimize waste but if transportation is done by train or ship, then it can be a good choice. Although a detailed assessment of each stage of food production, from cultivation to transport and to consumption, will provide a better perception of environmental impacts.

4.3 Comparison of different foods from different countries

Every country have option whether to grow their own food or import from other countries. It is a hot topic these days, as in both cases there is emission of carbon footprint, but emission depends on different factors like soil, production method, use of fertilizers, energy sources, land use change, food processing,

climate conditions, country's agricultural policies, packaging, storage, transportation to retailer or to public and transportation to other countries and mean of transportation and distance travelled.

It is not like just to grow a food product, but considering food security is the most important factor when a country is having its own food production. As it is said, when more food is produced by a country there will be less risk of shortage of food. For example, during the time of COVID-19, the boarders of many countries where closed, resulting in closure of import and export. Therefore, countries depending on the imported food suffered because of the closure of boarders.

Many countries have to rely on imports because climatic conditions are unfavorable and they cannot grow their own food. As an example, in Canada it is not possible to grow pineapple, mango and banana therefore, they import these from other countries as these are tropical fruits which grow in warm and humid climate which is not available in Canada.

Producing a food product is not an easy job, it requires time and money to plant the trees or vines and then wait for them to mature to produce the fruit. After producing the food product the next step is to store it or further process it if it is required and pack them for distribution, all this requires money and time and these processes also result in emission of carbon footprint.

According to the report by FAO 1997, the global trading of food is a varied and complex operation in which majority of countries aim to take part as it is consider as an important method of getting foreign exchange. There is increased number of countries that are becoming both importer and exporter of foods. It is normalizing that a country is self sufficient to meet their food requirements or have an excess of food and import food products also. Even countries that have sufficient production for their domestic use, also export to other countries. According to this report, in 1994 Europe was leading among the other continents in regards to food trading with almost 50 percent of all imports and 45 percent of all exports. International food trading started with minimal and it was decided that the producers will set their own rules and standards and will regulate the quality of food products offered to consumers. Many traders played good role in this while there were some fraudulent traders who took this opportunity to benefit themselves by doing unfair trading including pricing, misrepresentation of products and misleading labelling. Due to these fraudulent activities, government involved itself and took over to make food laws and regulations to avoid these corrupt activities. Now all food laws, regulations and guidelines are under the framework of World Trade Organization (WHO) to have fair food trading.

According to an article Feeding the World: Global Food Transportation, 2023, transporting chilled products are difficult therefore, greater care should be taken to maintain their freshness. Fruits like bananas, pineapple, citrus, grapes, apples, berries, kiwi and avocados usually travel long distances, so they

are required to be chilled during their transportation. The food products needed to travel short distances by road or rail across international borders, can travel in ambient state.

According to an article by Hannah Ritchie 2020, Consumers think that consuming locally produced foods will emit less carbon footprint but this case is true for food which are imported through air. To get the full picture of the emission it is important to know about the mean of transport, distance travelled (km) and also the quantity of food as ship can transport more quantity of food as compared to truck or plane.

According to the data taken from a science journal published in 2018 by Joseph Poore and Thomas Nemecek, Majority of the transportation of food is done through ship with the percentage of 58.97% while very less transportation is done by air with percentage of 0.16%.

Countries can either grow their own food products or import it from other countries but either way one of the thing that should be prioritize is to minimize environmental impact. In the case of coffee, it is better for European countries to import coffee from countries like Vietnam, Brazil rather than producing their own coffee. Many European countries import coffee in the form of green beans then they roast it according to their requirements and taste and even they re-export the coffee to other European countries. Brazil mainly exports unroasted coffee to Germany, Italy, Belgium, France and Spain as they are the biggest importers of coffee and they roast coffee according to their requirements and taste of consumers. Vietnam is the second largest exporter of coffee to Europe. According to the Vietnam chairman of Coffee and Cocoa Association, Vietnam is the largest Robusta coffee producing country and is highly demanded by the roaster around the world. Europe is the largest importer of coffee from Vietnam. The largest importers of coffee from Vietnam are Germany, Italy, Spain, Belgium, Netherland and France. It is difficult for many European countries to grow their own coffee because of the temperature, as growing coffee requires specific tropical climate that is not present in many European countries. The carbon footprint from growing coffee in Vietnam and Brazil is towards lower side and transporting green beans as compared to roasted beans is more carbon efficient as it will guarantee the freshness and better quality coffee. Conventional and sustainable coffee are produced in Vietnam and Brazil giving the values of 16.04 kg co2eq/kg-1 for production of conventional coffee in Vietnam and for sustainable coffee is 3.46 kg co2eq/kg-1. As compared to Brazil 14.61 kg co2eq/kg-1 for conventional coffee and 3.46 kg co2eq/kg-1 for sustainable coffee. Growing conventional coffee involves use of industrial agricultural practices which mainly aim to have high yields and low costs, while giving less importance to environmental sustainability. It involves using of synthetic fertilizers and pesticides to increase the yield but can be harmful to environment, farmers and to consumers as well. On the contrary, growing sustainable coffee involves

methods like shade grown, organic farming, and water protection, maintain soil health and promote fair trade as well as promoting environmental sustainability. In comparison, conventional coffee gives high yield with low cost while sustainable coffee give lower yield at least initially and is more costly so by looking at the co2eq values for both type of coffee produced in Vietnam and Brazil, the best choice will be the sustainable coffee as it is emitting less co2eq values.

Transporting coffee from Vietnam and Brazil to Europe is usually done through ship in containers. It is accounted that the transportation of coffee can contribute to around 6-11% of co2eq so sustainable coffee can be a good option for European countries to import from Brazil and Vietnam although it will be towards higher price but will have less negative environmental impact. Costa Rica is among the countries that produce significant quantity of coffee although it is not among the largest producers but still export coffee to European countries. Emission from the production, exportation and roasting of coffee from Costa Rica was 4.98 kg co2eq/kg, towards lower side so it can be an option for European countries to import coffee as emission for the exportation of coffee from Costa Rica to Europe is 0.27 kg co2eq/kg for the unroasted green beans. The main importers of coffee from Costa Rica are Belgium, Luxemburg, Germany, Italy, Netherlands and Portugal in the form of green coffee beans and after reaching Europe, green beans are roasted emitting 3.05 kg co2eq/kg of carbon footprint.

Indonesia is the 9th largest exporter of coffee according to 2021 statistics. Germany is the main importer of coffee from Indonesia although the carbon footprint values from Indonesia are towards higher side like even on smaller level farm. The carbon footprint was 98.7 kg co2eq/kg-1 for Arabica coffee and for Robusta coffee is 119.6 kg co2eq/kg-1. So these are higher values and negatively effecting the environment. Indonesia should opt for more environmental friendly and sustainable practices.

Mango is among the fruit that is loved my many people. Growing mangos have low carbon footprint because the tree sequester a lot of carbon, irrigation and use of many pesticides is minimal and the land use is dense. It is said that the carbon footprint for growing mangos is 0.21 kg co2eq/lb regardless of any specific country or area. The main components that are involved in emitting carbon footprint during mango production includes harvesting, processing, packaging and transportation.

Mangos are perishable fruit so they have to be transported by air for longer distances and by refrigerated trucks or ships for shorter and as well as longer distances. So transporting through air or in refrigerated containers or refrigerated trucks emits higher carbon footprint. India is the biggest producer of mangoes and giving the GWP value of 2.86 kg co2eq/kg but this value is considered relatively high because of difference in agricultural practices like high energy consumption for irrigation and transportation, use of fertilizers and pesticides and intensive farming practices. India mostly use mangos for their domestic

consumption and a certain percentage of mango is transported to countries like UAE, USA, UK and Nepal. India export their mangos to European countries like Germany, France, Netherland, Belgium, Spain, Italy, Switzerland, Austria and Denmark but in lower quantity due to European Union's strict phytosanitary regulations as well as high costs of transportation as it is long distance so it will emit more carbon footprint due to transportation through air or refrigerated containers.

Europe usually export mangos mainly from Brazil and Peru but also Ivory Coast. Mexico is among the biggest producer and exporter of mango and USA is the biggest importer of mangos from Mexico emitting carbon footprint of 0.4556 kg co2eq/kg while export of mangoes to USA (Mexican border to USA distributers) emits carbon footprint of 0.008751 kg co2eq/kg. The value for the transportation is quite low due to short distance but mango being perishable fruit need to be transported in refrigeration even for shorter distance also.

Brazil is the second biggest exporter of mango and the main region for producing and exporting mango is Vale do Sao Francisco giving the carbon footprint of 0.13 kg co2eq/kg-1 for packed mangos. Brazil is the largest supplier of mango to European countries. The carbon footprint from production till packaging of mangos from Brazil is towards lower side but to transport mangos from Brazil to Europe, the usual mean of transportation is through ship with specialized refrigerated containers. Due to long distance, transporting through ship can be a good option as it can transport larger quantities at a single time. Air transport can also be an option but lesser quantity would be transported in single time as compared to sea transport and air transport emits higher carbon footprint. Sea transport usually emits carbon footprint towards lower side so for European countries, importing mangos from Brazil can be a good option in regards to environmental impact. It is better for European countries to import mangos rather than growing their own. The reason is that growing mangos require tropical and warmer subtropical climate as this type of climate is not found in European countries so due to unsuitable temperature and climate it is better for European countries to import mangoes with usage of environmental friendly packaging and make sure to import mangos during their natural season to avoid artificial ripening and transportation. Although there are few European countries which grow mangos like Spain, Portugal, Greece, Italy and Cyprus but in smaller quantities and not even full filling the domestic consumption needs so they need to import mangoes from other countries.

Rice is one of the important staple food in many countries. The favorable weather to grow rice is hot and humid temperature. Many Asian countries have favorable temperature to grow rice. According to European commission rice fact sheet, Europe can produce small amount of rice around 60 % as it is not self-sufficient in rice so they need to import rice from other countries. Only 8 European countries can

produce rice including Italy which is the largest producer, Spain, Greece, Portugal, France, Bulgaria, Romania and Hungary. The biggest rice producing and exporting countries to Europe are India, Pakistan, Thailand and Vietnam. The main European countries importing rice include Germany, France, Spain, Czech Republic, Netherland and Austria. Rice emits carbon footprint towards higher side but depending on opting sustainable practices and technologies, carbon footprint can be reduced. Thailand is among the biggest exporter of rice to Europe emitting carbon footprint of 37.42 kg co2eq/kg for conventional jasmine rice and 38.36 kg co2eq/kg for organic jasmine rice. Yet different areas, different varieties and different agricultural practices of rice give different emissions like 2.39 kg co2eq/kg of organic KDML 105 paddy rice in Chiang Mai, 1.52 kg co2eq/kg of GAP KDML 105 paddy rice in NongKhai, 1.34 kg co2eq/kg of GAP sangyod paddy rice in Phatthalung, 3.57 kg co2eq/kg of organic KDML 105 brown rice with packaging in Chiang Mai, 2.58 kg co2eq/kg of GAP KDML 105 brown rice with packaging in NongKhai and 2.29 kg co2eq/kg of Gap sangyod coarse rice with packaging in Phatthalung, Thailand. Producing conventional rice in India emits 6720.46 kg co2eq/ha of GHG among which for cultivation the GHG was 4869 kg co2eq/ha while for harvest and post-harvest was 1851.46 kg co2eq/ha of GHG. Now a days, conventional practice and organic practice are becoming very common like in Thailand, the GHG for the post-harvest management for conventional rice is 1.4835 kg co2eq/kg while for organic rice is 2.6238. GHG for soil preparation is 0.1844 kg co2eq/kg for conventional rice while for organic rice is 0.0237 kg co2eq/kg. Cultivation contributed in 0.0473 kg co2eq/kg for conventional rice whereas for organic rice is 0.0126 kg co2eq/kg. During harvesting the emission is 0.0018 kg co2eq/kg for conventional rice and 0.0014 kg co2eq/kg for organic rice and lastly transporting rice to domestic retailers or distributors emits 1.3540 kg co2eq/kg for both conventional and organic rice. There are different means of transportation used to transport rice from Asia to Europe as Asia is the biggest producer of rice. To transport rice to Europe is a time taking process and the preferable mean of transport is through sea. After reaching European ports, rice is transported through trucks or trains for further transportation to other European countries. Rice are packed either in jute bags, polypropylene bags, woven bags, vacuum packaging or containers. Transporting rice through ship will take a lot of time as not all European countries import rice from Asia. The countries that import rice from Asia include Italy, France, Germany, Belgium and Netherlands, there ports are used for the import and after receiving the rice, they further export rice to other European countries. Although transporting rice through air can emits higher carbon footprint as compared to sea but it will take less time for the transportation, although ship can carry more amount of rice as compared to plane. So in order to minimize the emission of carbon footprint, it is best to use truck, rail or sea transport other than air and also they can carry bigger quantities of rice. For many European countries, it

is better to import rice form other countries as growing rice requires warm and humid climate which is not present in many European countries and they can try to grow their own rice using greenhouse with extra heating but it will emit higher carbon footprint, negatively impacting the environment. Growing rice requires large amount of water so if European countries try to grow rice, it will require extra water which will negatively affect the domestic water supply. Additionally, large area is required for rice farming which can lead to deforestation, becoming the source of heavy emission. But on the other hand, there are few European countries which have favorable conditions to grow their own rice like Spain, Italy, France and Portugal, called European Japonica rice. Although these countries can produce their own rice but the amount they are producing does not full fill the domestic need so they need to import rice.

Wheat is among an important staple food which is consumed by many countries. Wheat is highly adaptable crop which can be grown in many climates and different soil types. Wheat grow in warm temperature but not too hot temperature. India is among the top producer of wheat with the carbon footprint of 0.28 t co2eq/ton-1 while in Poland, if wheat is grown with different tillage system, giving carbon footprint for conventional tillage winter wheat is 309.9 kg co2eq/t and reduced tillage winter wheat is 393.5 kg co2eq/t of carbon footprint, and direct sowing winter wheat is 397.1 kg co2eq/t. Although there are European countries which produces their own wheat like France, Italy, Germany, Poland, Romania and Netherlands. According to a report, Canada is the biggest supplier of wheat to European countries.

European producers of wheat export their wheat to other countries. Health wise European wheat is more preferred as compared to wheat from USA as it is said that wheat from Europe contains less gluten and GMO's and glyphosate is banned so minimizing disturbance to digestive system. Europe produces enough wheat to full fill their domestic requirements as it is among the largest producer of wheat and even then production is increasing with years. With the amount of production, even after meeting the daily needs of wheat, Europe is also exporting wheat to countries like Morocco, Nigeria, Algeria, Egypt and South Africa. So as regards the carbon footprint, it is better for Europe to grow their own wheat as compared to importing as there will be no long distances transport, Europe is using better and sustainable agricultural practices which is giving health benefits as well as environmental benefits.

Chocolate is a food which is loved by many people but it also emits certain amount of carbon footprint as during processing from cocoa to chocolate, it goes through certain steps which also requires heavy use of electricity.

To convert cocoa into chocolate, the process involves roasting of the cocoa then removing the outer shell from the beans and grinding and addition of sugar and flavors, finally tempering and molding. All of these steps require electricity due to which there is certain emission of carbon footprint. In chocolate production emission also depends on whether chocolate is dark or milk or white chocolate. One of the main component that increase the emission is milk. Addition of milk in chocolate increases the carbon footprint value due to which dark chocolate emits less carbon footprint as compared to milk chocolate and white chocolate. Ivory Coast and Ghana are the largest producers of cocoa. It is said that more than 50% of world's cocoa is produced in Ivory Coast and Ghana and they further export to different countries for manufacturing of chocolate as they do not manufacture chocolate by themself. According to the statistics of 2018 and 2019, 65% of cocoa is produced by Ivory Coast while 54% of cocoa is produced by Ghana and mainly is exported to European countries but small quantities are also exported to US, Malaysia and Brazil.

Within EU, Netherland is the biggest importer of cocoa as around three quarter of cocoa beans are processed there. Switzerland is considered among the largest producer of chocolate but Switzerland does not directly import cocoa beans but it instead imports cocoa from Netherland, Germany and France. Germany, Italy, Belgium and Poland are the world's biggest chocolate producing countries. Chocolate produced with different practices emit different carbon footprint like Ecuadorian dark chocolate which was produced using three different techniques including conventional monoculture, conventional agroforestry and organic agroforestry. As a result, the carbon footprint according to cradle to retailer approach conventional agroforestry emitted 3.10-4.66 kg co2eq/kg-1, conventional agroforestry emitted 2.28-3.84 kg co2eq/kg-1 while organic agroforestry emitted 2.04-3.60 kg co2eq/kg-1. Conventional monoculture have the highest emission due to use of synthetic chemical fertilizer. The emission from different transportation scenarios with cradle to retailer approach and exportation include from Ecuador to Germany/Netherlands emits carbon footprint of 1.41-1.90 kg co2eq/kg-1 cocoa beans for supply chain and for exportation is 0.49-0.98 kg co2eq/kg-1. Then from Ecuador to Germany then to USA the carbon footprint was 1.61-2.76 kg co2eq/kg-1 of cocoa beans for supply chain and 0.69-1.84 kg co2eq/kg-1 for exportation of cocoa beans. While for carbon footprint from Ecuador processed into dark chocolate to Germany/Netherlands, the carbon footprint was 1.26-1.70 kg co2eq/kg-1 for supply chain and for the exportation was 0.34-0.79 kg co2eq/kg-1 of dark chocolate. In regards to these carbon footprint values, the exportation of chocolate to Europe emits less carbon footprint. Secondly, Ecuadorian chocolate from production to exportation emitted GHG of 2.49-2.82 kg co2eq/kg-1, while European countries to which chocolate is exported include Italy, Belgium, Netherland, Germany and Spain. From farm to wholesaler

then to port, the transportation is done through truck, while from port to port of importing countries in done by ship and from port to other destinations is done by truck. So Ecuador can be a good option for chocolate. If we see the comparison among Peru's chocolate and Ivory Coast's chocolate so in Peru, chocolate was produced using organic agriculture and fair trade practice and was transported to France giving the overall GWP of 3.37 kg co2eq/kg of chocolate while chocolate from Ivory Coast using conventional agricultural practice and exported to Spain giving GWP of 7.90 kg co2eq/ kg of chocolate as cocoa beans are exported and after reaching the destination, they are transformed into chocolate and then sent to retailers. The transportation from Peru to France and from Ivory Coast to Spain was done through ship while after reaching the destination and after processing and transported to retailer is done through truck.

Ghana is among the biggest producer and exporter of chocolate showing GWP100 1.65 kg co2eq/kg for packed extra dark chocolate bar, 4.21 kg co2eq/kg for packed flavored milk chocolate bar and 1.67 kg co2eq/kg for packed dark chocolate. All of this import of cocoa either directly or indirect emits great amount of carbon footprint. From Ivory Coast and Ghana, cocoa beans are transported to Netherlands in bags through ship in containers. Amsterdam port is considered as the entry point into Europe. After reaching Netherlands, for the further transportation to other European Countries, trucks are used for the countries like Germany, Belgium, France and while transportation is also done through trains to countries including Switzerland, Austria and Italy. Small quantities are also transported through plane and ship within Europe. To minimize the carbon footprint, the best option for Europe is to import cocoa beans from countries like Ghana, Ecuador, Peru or Ivory Coast and transform it into chocolate. Transporting cocoa beans emits less carbon footprint as compared to prepared chocolate and cocoa beans after reaching Europe can go throw sustainable and efficient processing which will help in reducing the emission. Cocoa beans require less packaging as compared to packed chocolate and cocoa beans are transported through ships in bulk form giving transportation to larger quantities with less emission.

Palm oil is not only used as a vegetable oil but also used in manufacturing of many products like shampoo, lipstick, deodorant etc. one of the largest producers of palm oil are Indonesia and Malaysia. According to the 2022 statistics, Indonesia produces around 59% of world's palm oil and the main exporters are European Union, Pakistan, India and Africa. While as for Malaysia, it contributes 25% of world's palm oil production and its main exporters are European Union, Pakistan, China and USA. The third largest producer of palm oil is Thailand contributing only 4.4% of world's production but are working on development of palm oil plantation industry in next 10 years to increase their production. As Indonesia is

the main producer and exporter of palm oil, the GHG emissions are 1405.83 kg co2eq/kiloton/year for palm oil mill, 2509.93 kg co2eq/t of crude palm oil in 2014 while in 2015 it reduced to 2057.14 kg co2eq/t of crude palm oil. It included process from fresh fruit bunches cultivation to crude palm oil production and all of the by product and waste was utilized in the system. The reduced emission was due to decrease in the yield of fresh fruit bunches. As for Malaysia, the average GHG emission generated from crude palm oil is 1100 kg co2eq/t and for the exportation of palm oil emission was 328 kg co2eq/t of palm oil. This value was from traveling of 16750 km including port to mill transporting is 250 km while from port to overseas transport in 16500 km. Palm oil is transported through ships to European countries like Netherland, Germany, Italy, France, Belgium and Spain. These countries further transport palm oil to other countries through trucks or trains. The only option for Europe is to import palm oil from Indonesia and Malaysia because producing palm oil requires high and humid temperature and large area is required and certain type of soil is required like acidic pH, peat or loamy soil, have good water holding capacity.

Grapes are consumed not only in the form of fruit but also in the form of wine, jam, jelly, juice, vinegar and in dried form that is raisin. According to 2023 statistics, the biggest grapes producing countries are China, Italy, USA and Spain. Other countries that produce large quantities of grapes are Australia, South Africa, Chile, Turkey and Peru. The biggest exporter of Grapes include Peru, Italy, Chile and China while Netherland, Germany and France are the biggest importers of grapes. They import grapes from non-European countries like South Africa, Peru, Chile and Brazil, India and Egypt. Grapes are usually transported to European countries through ships to the ports and after reaching the port, further transportation is done through trucks or train. As grapes are perishable fruit, they are transported into refrigerated containers. In some cases, air transport in also used to minimize the travel time but air transport emits high amount of carbon footprint as compared to other means of transport. In the case of Italy, the large portion of grapes production is utilize for domestic use but a significant portion of grapes is imported to other countries like Germany, France, Austria, Switzerland and UK. Production of grapes in India emits GWP of 3.38 kg co2eq/kg and as for Italy, in many cases production of grapes are done with different techniques including integrated management and two type of organic management.

In integrated management, mineral fertilizers were used, in one type of organic management cattle manure fertilizers were used and in other type of organic management green manure fertilizers were used. So as a result, the carbon footprint emitted from integrated management was 0.213-0.227 kg co2eq/kg, the carbon footprint from organic management with cattle manure fertilizer was 0.144-0.168 kg co2eq/kg while in the case of organic management with green manure fertilizer was 0.134-0.147 kg

co2eq/kg. The difference in carbon footprint values are due to use of different fertilizers and different chemicals for pest control. Italy is famous for their wine so particular grapes are produced for the purpose of wine by using techniques like VCWNO is vine grapes cultivated for common wine production based on non-organic agricultural practice, VCWO is vine grapes cultivated for common wine production based on organic agricultural practices, VQWNO is vine grapes cultivated for quality wine production based on non-organic agricultural practices and lastly VQWO is vine grapes cultivated for quality wine production based on organic agricultural practices. As a result the GWP100 for VCWNO was 3383.4 kg co2eq/ha, for VCWO was 1282.81 kg co2eq/ha, for VQWNO was 2464.45 kg co2eq/ha while for VQWO was 1630.70 kg co2eq/ha, indicating that the use of organic practice showed lowered environmental impact as compared to non-organic practice as organic practice has lowered use of chemical fertilizer and pesticides. There are European countries that have suitable climate to grow grapes including France, Italy, Spain, Portugal and Germany and it is better for Europe to grow their own grapes as compared to import them from other countries while also increasing their yield can help them in full filling their requirement. Growing own grapes will eliminate transport emission, Europe can also grow grapes according to the sustainable or organic practices which will have low environmental impact. If European counties have low yield then they can opt for importing grapes from other European countries having enough yield to attain their domestic requirements as well as can export to other European countries or can import from non-European countries. Although producing grapes have lower carbon footprint and importing it within Europe will emit less carbon footprint but importing it from Non-European countries can emit higher carbon footprint.

Salmon is considered as a special consuming fish and Norway is the biggest producer of salmon. After Norway, Chile is among the largest salmon producing country. Poland does not produce salmon and take advantage from re exporting the imported salmon. One of the factor that contributes in the carbon footprint emission is the type of feed which was given during salmon farming. The importing European countries are Sweden, Denmark, France, Poland, Germany and Italy. As Norway is the largest salmon producing country it gives carbon footprint of 4 kg co2eq/kg in 2012. Although in 2010, the carbon footprint was 3.7 kg c02eq/kg. This increase was due to change in the feed of fishes. First the feed consisted of marine ingredients but was changed into vegetable ingredients so vegetable ingredients emitted higher carbon footprint as it consisted of soy whose production involves land use change. If we compare the salmon from Norway and UK, the GWP for Norway salmon was 1.8 kg co2eq/kg of fillet while UK salmon emitted 3.3 kg co2eq/kg of fillet and in regards to another comparison GHG emission value for Norway farmed whole weigh salmon that is 1.78 kg co2eq/kg as compared to UK farmed whole weight

Salmon that is 3.27 kg co2eq/kg due to difference in the feed ingredients and UK using higher quantity of marine by products in feed. In Norway the farming of salmon and long distance travelling in refrigeration emits GW of 6.6 kg co2eq/kg. It is said that refrigerant that was used emits higher GHG emission so it is recommended that the change in refrigerant can help in lowering the emission. The previously used refrigerant was HCFC R22 and it is being replaced by ammonia which is considered as environmentally harmless as refrigerant is involved in ozone depletion. So if European countries wants to import salmon, the best option is Norway. As for reducing environmental impact and lowering carbon footprint, farming own salmon will be better option even countries like Scotland, UK, Denmark and Sweden have already started salmon farming and as for other countries, they can also start their own salmon farming but will face some challenges in the early stages and with time progressing, the challenges can be overcome and will be able to produce their own salmon which will have low carbon footprint.

Chapter 5
CONCLUSIONS

Carbon footprint has become a hot topic in the past few years, People around the world are getting more and more aware and as well as concerned about the frequently increasing carbon footprint level in the atmosphere. Food in any form is a basic necessity of life. Every step of food production emits GHG that trap the sun's heat and can cause climate change. About a third of all human caused GHG emission is linked to food. The emission depends on the area where food product is grown, type of technique used, storage method, transportation and export. Similarly there are different values for carbon footprint for every country or region for same food because of the difference in production method, energy sources, transportation distance and transportation methods, handling food waste and the land use change, food processing and packaging, climate condition, agricultural policies and each country have their own way to calculate carbon footprint.

One of the important step towards safe and environmental friendly lifestyle is to minimize the carbon footprint emission not just in food production but every field of life. Whether a country chooses to grow their own food or import from other countries, it should be necessary to eliminate as much of carbon footprint as possible. If a country wants to grow their own food, it is important to promote urban faming as it will reduce carbon footprint emission. Urban farming helps in progressing food and nutritional security by providing fresh and healthy foods. Through urban farming, youth can participate in farming or gardening programs which will help them in increasing their knowledge about food. One of the main benefit for domestic food production is there will be no transport emission as in case of many food products transportation play an important role in emission of carbon footprint. It is important to opt for sustainable, organic and environmental appropriate agricultural practices. In the case of import and export, it is important for exporters to put labels which show the carbon footprint emission as it will help to create awareness among people. Means of transport that emit less carbon footprint should be encouraged. Promote circular economy principles to minimize food waste and eventually reducing the carbon footprint. Policies, standards, guidelines and agreements should be made on global level to encourage environmental friendly agricultural practices.

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