METHANE EMISSION ESTIMATION FROM APPLE POMACE

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MAY-2021

DECLARATION

I certify that

- The work contained in this thesis is unique and has been completed by me under the direction of my guide.
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CERTIFICATE

This is to certify that the work which is being presented in the project report titled "Methane Emission Estimation from Apple Pomace" in partial fulfillment of the requirements for the award of the degree of Master of Science in Biotechnology and submitted to the Department of Biotechnology and Bio informatics, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by NATASHA PANCHAL (197813) during a period from January, 2021 to May, 2021 under the supervision of Dr. Sudhir Kumar, Department of Biotechnology and Bioinformatics, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of my knowledge.

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IPCC:	Intergovernmental Panel on Climate Change
GHG:	Greenhouse Gases
DM:	Default Method
FOD:	First Order Decay
TM:	Triangular Method
LandGEM:	Landfill Gas Emission Model
MSW:	Municipal Solid Waste
SW:	Solid Waste
SWDS:	Solid Waste Disposal Site
GSDP:	Gross State Domestic Product
GDP:	Gross Domestic Product
LFG:	Landfill Gas
SSF:	Solid State Fermentation
SmF:	Submerged Fermentation

ABSTRACT

India has around 500 apple processing industries which are responsible for production of variety of juices and 1.3 million tones of apple pomace annually. A rapid increase in the production of juices and ciders has generated a large amount of apple pomace but now its disposal is becoming a huge problem. Apple pomace is about 25% of its original mass and is a rich source of pectin, carbohydrates, crude fiber and also contains small fractions of minerals, proteins and vitamins. Therefore, it is often utilized as animal feed or as fertilizer. The production of apple pomace as a by-product offers a wide range of alternative substrates. Several attempts have shown its big potential in renewable energy i.e. in production of bio ethanol (by solid state fermentation), biogas (by process of anaerobic digestion) and other value added by- products such as organic acids (by solid state fermentation), biopolymers (by submerged and solid state fermentation), hetero polysaccharides, aroma compounds etc. The production of fungal chitosan which is a biopolymer can be done with apple pomace which has huge applications in tissue engineering, medical devices, pharmaceutical industries etc. But, it is used as animal feedstock or thrown away in waste dumps and landfills resulting in anaerobic degradation and production of methane and carbon dioxide which are greenhouse gases. Methane is 25 times more potent in trapping heat and increasing earth's temperature when compared to CO_2. Therefore, IPCC (Intergovernmental Panel on Climate Change) gives different methods for estimating CH_4 emissions and global warming potential. IPCC default method was used in estimating CH_4 emission from 5 different states of India and 20 different countries of the world and results were analyzed. Our main focus is finding the CH_4 emission and global warming potential from apple pomace which will further help to promote a more systematic and non- expendable conduction of this under- utilized and overgrowing waste. Usage of methane by recovery will help in reducing the effects of climate change and simultaneously increasing energy security, enhancing economy, growth and improving air quality. All of which will finally contribute to integrated apple pomace waste management, methane recovery and food economy.

Keywords: *Apple pomace, Greenhouse gases, CH_4 emission, Global warming potential, Energy recovery*

CHAPTER 1

INTRODUCTION

Apple fruit which is mostly grown in temperate regions is one of the most preferred fruit all over the world (Agrahari *et al*., 2003). India secured 9th position in producing apples and is responsible for contributing 1/3rd of it total produce (Anon. 2004). Currently, India has 5th position is production of apples. Apples are grown in hilly North Indian states which have appropriate physiographic and climatic conditions which support the production of apples. Generally, around 70% of apple from apple crop is directly consumed. 30% of apples are used for juice extraction out of which 76% is utilized by apple juice industries and the remaining 24% which is left as a byproduct is known as wet apple pomace. The water content in this wet apple pomace is 76.3% whereas 24% is dry material (Kennedy *et al*., 1999). Basically, apple pomace is the result of pressing apples for production of juice. Its composition depends on morphology of original feed stock and technique of its extraction (Hang and Walter.1989).

Apple juice industries are responsible for producing pomace which is a heterogeneous combination containing peel, core, seed, calyx, stem and soft tissues. This heterogeneous mix is rich in carbohydrates (9.5-22%), proteins (4.0%), sugars (3.6%), cellulose (6.8%). It is also composed of hemicelluloses, lignin, fibers, polyphenols (Shafiee. 2017). More than 12 million tones of apple pomace are produced in India from which only 10,000 tones is utilized (Shafiee. 2017). That's why its utilization becomes a necessity. Moreover, apple is directly related to rural economy of states like Himachal Pradesh, Jammu & Kashmir and N. eastern states (Shafiee.2017). HPMC (Himachal Pradesh Horticulture Produce Marketing and Processing Corporation) which is one of the major apple juice producing industries in India generates thousand tones of apple pomace, which remains dumped outside its industries. Due to its high moisture content it results in its rapid destruction thereby causing nuisance (Hang and Walter. 1989).

The uses of apple pomace is divided into two parts, one is waste reduction strategy which includes animal feeding, fuel use and composting and the other use is obtaining high value product which includes aroma production and pectin production (Kennedy *et al*., 1999).

Different microbial strains of bacteria, yeast and fungi have the ability to grow on apple pomace which helps in increasing its utilization (Vendruscolo *et al*., 2008). Therefore, different uses related with apple pomace are production of enzymes, ethanol, organic acids, biopolymers, pectin, aroma compounds, nutrient enrichment etc. Till now most popular use of apple pomace is feeding it to livestock, usage as a fertilizer, composting and landfill.

Dumping of apple pomace in landfills is widely used method for disposal (Ghosh *et al*., 2018). As it is organic material, it undergoes either aerobic or anaerobic bio-degradation resulting in production of carbon dioxide, water or heat for aerobic process and carbon dioxide and methane for anaerobic process (Jensen *et al*., 2010). The production of CH_4 causes entrapment of heat, results in increased earth's temperature and global warming. Methane is a greenhouse gas and has 28-34 times more global warming potential than carbon dioxide (Allen. 2016). 30-70 million tons of CH_4 gas is emitted from landfills all over the world per year (Johari *et al*., 2012). In India, methane contributes 29% of total GHG emission which is way more than global average of 15% (Sharma *et al*., 2014). There is no proper management of apple pomace hence it is disposed off in open dumps. Due to increasing problem of climate change, the estimation of methane emission becomes more important. This will ultimately lead to making proper arrangement for methane recovery for generation of electricity or other usage, thereby reducing emission of methane in atmosphere.

There are different models available for estimation of methane emissions like IPCC Default method (DM), First order decay (FOD) method, Triangular method (TM) and Landfill Gas Emission Model (LandGEM) version 3.02 method etc. In our work, we have used IPCC Default method for estimation of methane emission from apple pomace. The apple pomace data is in accordance with the percentage formula considering around 70% of apple from apple crop are directly consumed, 30% of apples are used for juice extraction out of which 76% is utilized by apple juice industries and the remaining 24% which is left as a byproduct is known as wet apple pomace. The water content in this wet apple pomace is 76.3% whereas 24% is dry material (Kennedy *et al*., 1999). 5 different states which are major producer of apples are taken into accounts which are, Jammu& Kashmir, Himachal Pradesh, Uttarakhand, Arunachal Pradesh and Nagaland. The data was taken from National Horticulture Board from 2003-2019 (http://nhb.gov.in/). Using the above stated method, 20 different countries of the world were also considered for finding out the methane emission and comparing global warming potential and this data was taken from Knoema data workflow (https://knoema.com/).

Not much study is done in relation to methane emission estimation from apple pomace that's why not much literature is available. Hence, the present study is aimed at estimating methane emission so as to gain an insight into energy recovery. Also, this study gives an insight into the recovery potential if methane emitted into environment was captured. Along with it, there is mention of different uses of apple pomace and how utilisation of apple waste is better approach for recovering bio-energy products in an economical way. By treating the apple waste we can leave a lesser carbon footprint on the earth and thus promote the well being of the environment for future generations. Study has been going on usage of apple pomace as a single substrate or along with co-substrates to utilise its maximum energy. It is an economic approach because firstly it reduces its rapid destruction, secondly it reduces methane emission. In this study each parameter was taken appropriately and was verified through research papers. But since there is no available data regarding production of apple pomace data and it is considered using mass flow of components, there might be some uncertainties in apple pomace production and estimates. This is the limitation of our study. Along with it, other methods along with IPCC DM should be considered for comparison between methane estimation to get a complete view of methane emission estimation from apple pomace.

The main objective is critical assessment of methane estimation from apple pomace, effects on energy and finding out global warming potential, to observe the trends on utilization of apple pomace, current limitations and recommendations for future research. The motive of this study is to enhance waste reuse and improvement in order to promote renewable source of energy and zero waste initiative.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Apple fruit which is mostly grown in temperate regions is one of the most preferred fruit all over the world (Agrahari *et al*., 2003). Generally, around 70% of apple from apple crop is directly consumed. 30% of apples are used for juice extraction out of which 76% is utilized by apple juice industries and the remaining 24% which is left as a byproduct is known as wet apple pomace. The water content in this wet apple pomace is 76.3% whereas 24% is dry material (Kennedy *et al*., 1999). Basically, apple pomace is the result of pressing apples for production of juice. Different researches have been going on utilization apple pomace but dumping of apple pomace in landfills is widely used method for its disposal (Ghosh *et al*., 2018). Open dumping of apple pomace leads to bio-degradation and production of CH_4 due to anaerobic digestion. This causes entrapment of heat and results in increasing the earth's temperature. Methane is a greenhouse gas and has 28-34 times more global warming potential than carbon dioxide (Allen. 2016). That's why its estimation is important so as to gain insight in energy recovery and examine the global warming potential.

Our objective is critical assessment of methane estimation from apple pomace, effects on energy and finding out global warming potential. Not much research is done with respect to methane emission estimation from apple pomace that's why we have considered a vast literature to find out proper method for its estimation. There are different methods for estimation as per IPCC guidelines for estimation of methane emissions like IPCC Default method (DM), First order decay (FOD) method, Triangular method (TM) and Landfill Gas Emission Model (LandGEM) version 3.02 method etc. In our thesis, we have used IPCC Default method for estimation of methane emission from apple pomace. The idea of literature review is to analyze the available literature for apple pomace and methane estimation, gather the limitations of different studies and find out the most appropriate method for estimation of methane from apple pomace. This chapter discusses the researches done with respect to apple pomace, its production followed by analysis of different methods available for methane estimation. It then discusses the importance of methane estimation and different uses of apple pomace.

2.2 APPLE POMACE PRODUCTION

The production of apple in world is around 58 million tons from area of about 5.26 million ha. Apple is the 4th major crop of India. India secures 9th position with 1.4 million tons of annual production in apples. India is responsible for production of 1million tons per annum of apple pomace. But only 10,000 tons of apple pomace is utilized productively and rest of it is dumped outside without any proper management (Shalini *et al*., 2010).

According to Lyu *et al*., 2020 Apples are the 4th most consumed fruit crop in the world. Of the total apple production in the world, 65.4% apples are produced in Asia. China is the leading producer of apples in the world with India securing fourth position. In 2018-19, China produced 29, 52,000 metric tons of apple pomace which is the highest amount in the world. On the other hand, India was responsible for production of 1, 70,640 metric tons of apple pomace.

2.3 METHANE EMISSION ESTIMATION

IPCC guideline offers different methods for CH_4 estimation. So as to compare different parameters and results two or more methods are generally used for estimation of CH_4 emission. Kumar *et al*., 2004 found out National methane emission from solid waste landfills using IPCC default method (DM) and triangular model for biogas and compared the results. DM gave CH_4 emission as 263.02 Gg in 1980 and 502.46 Gg in 1999 whereas triangular model gave 119.01 Gg CH_4 in 1980 and 400.66 Gg CH_4 in 1999. This study was based on published documents because of the constraints in data collection. It is suggested that two or more methods can be used for comparison of data and the default values as stated by IPCC must be used if the municipalities do not maintain solid waste data.

Irving *et al*., 1999 states that IPCC DM is the simplest method and requires least data for estimation of CH_4 emission but it is also responsible for overestimation of CH_4 emissions. Therefore, a correction factor can be used for adjustment to non- steady state conditions in annual waste disposal. After the application of correction factor, results showed 20% decrease in CH_4 emissions. It suggests that since IPCC DM assumes constant disposal rates even though the disposal rates are increasing or are expected to increase, the correction factor may help in finding the appropriate CH_4 emission estimation.

A research on trends and estimates of GHG emissions from Indian livestock shows increase in enteric CH_4 emission when compared to the world i.e. 70.6 % v/s 54.3 % for years 1961 to 2010 but it is less when compared to other developing countries. This paper suggests that GHG emission tends to increase in future because of the increasing demand of meat and dairy hence proper measures must be adopted (Patra. 2014).

MSW generation is directly linked to population explosion, growth and urbanization and the most common method for its disposal is land filling in developing countries (Jigar *et al*., 2014). A study was carried out in Addis Ababa, Ethiopia using IPCC DM which showed a huge increase in SW generation from 731,738 m^3 in 2003 to 1,022,814 m^3 in 2012. Similar increase was seen in CH_4 emission from 7.11 Gg/y in 2003 to 9.98 Gg/y in 2012. It suggests that rapid increase in CH_4 emission shows constraints in the available system and proper landfill sites with methane capture facilities needs to be installed (Jigar *et al*., 2014).

MSW is generated in huge amount in metropolitan cities especially Delhi. Singh *et al*., 2016 studied three landfill sites; Bhalswa, Ghazipur and Okhla and found out the CH_4 emissions using IPCC default method and first order decay method. For the year 2011-2012, the CH_4 emissions were 61.97 Gg/y, 2611.99 Gg/y and 52.60 Gg/y by first order decay method and 91.23 Gg/y, 3845.20 Gg/y and 77.42 Gg/y by default method for Bhalswa, Ghazipur and Okhla landfills respectively. They concluded that default method gives higher GHG emissions when compared to FOD method. It suggests separation of organic matter for composting and building of planned landfill site for fuel recovery.

Kumar *et al*., 2018 did quantitative analysis of CH_4 emission from MSW in India for the years 1999- 2015. They used IPCC default method, modified triangular method and first order decay method. They observed increase in CH_4 emission from 404 Gg in 1999- 2000 to 1084 Gg in 2015 and found out default method gives higher GHG than other two methods. They also stated that CH_4 emissions are related with gross state domestic product (GSDP) of states and gross domestic product (GDP) of country where GSDP and GDP is indicator of social well being and higher human activity level and higher MSW generation rate respectively. It suggests review of MSW management of India and use of CH_4 as source of energy.

Change in standard of living, lifestyles, food habits are one of the causes for rapid increase in generation of MSW which can be seen in Delhi landfills where MSW increased from 34,552 tones in 1984 to 2,096,165 tones in 2015 (Ghosh *et al*., 2018). Default method, first order decay method, Land GEM method were used for CH_4 emission estimation and energy potential for the years 1984- 2015. FOD and Land GEM showed increased CH_4 emission from 1.06, 0, 0.05 Gg/y in 1984 to 6356, 27.99 and 56.45 Gg/y in 2015 respectively. On the other hand, default method showed 14.42 Gg/y CH_4 in 1994 to 23.50 Gg/y in 2015 for Bhalswa, 1.06 Gg/y CH_4 in 1984 to 28.31 Gg/y in 2015 for Ghazipur and 7.10 Gg/y CH_4 in 1996 to 11.75 Gg/y in 2015 for Okhla landfill. When the results were compared with previous studies of Kumar *et al*., 2004, Jha *et al*., 2008, Chakraborty *et al*., 2011 and Gollapalli and Kota. 2018 it showed that field values are lower than calculated values. The reason for the difference is uncertainty during sampling and collection of accurate data.

Estimation of CH_4 is directly related to energy and global warming potential. Out of 82% waste collected, only 20-25% is treated and 80% is dumped openly in India (CPCB 2015). In India, there are around 179 landfills and only 12 out of 179 are operational in which LFG is captured (CPCB 2015) because of lack of proper management and collection mechanisms. Choudhary *et al*., 2020 estimated CH_4 emission using IPCC First order decay methods, the Landfill gas emissions model (Land GEM) with state specific values, LandGEM with default inventory values and LandGEM with clean air act values. Land GEM with state specific values shows Haryana with 3,820 Gg CH_4 emission potential which is maximum, followed by 3,354 Gg CH_4 of Maharashtra and 2,377 Gg CH_4 of Uttar Pradesh. It also showed 1,084 Gg CH_4 in 2020 and 1,969 Gg CH_4 in 2030 if no suitable measures are taken. The 2030 prediction analysis showed Haryana with highest energy potential i.e. 288 MW followed by 198 MW of Maharashtra and 150.9 MW of Uttar Pradesh. From the study it was concluded that IPCC DM predict emission in the initial year of study as well when compared to other models because of its assumption that emissions are produced in the same year waste is disposed of. It also concludes a relation between Gross Domestic Product and CH_4 emission which states higher the GDP, higher is the human activity, higher is MSW generation and higher is the CH_4. Finally it suggests conversion of open dumps to sanitary landfills and collection system for development of renewable energy.

2.4 IMPORTANCE OF METHANE EMISSION ESTIMATION

Methane is primary component of natural gas which is emitted during production and transport of coal, natural gas and oil. It is produced during the anaerobic bio- degradation, decay of organic matter in waste dumps, landfills, and waste water treatment systems. The production of CH_4 causes entrapment of heat, results in increased earth's temperature and global warming. Methane is a green house gas and has 28-34 times more global warming potential than carbon dioxide (Allen. 2016). 30-70 million tons of CH_4 gas is emitted from landfills all over the world per year (Johari *et al*., 2012). In India, methane contributes 29% of total GHG emission which is way more than global average of 15% (Sharma *et al*., 2014). Half of methane emissions all over the world are produced by eight major countries named United States of America, Russia, India, Brazil, Indonesia, Nigeria, and Mexico. Different sources such as coal production, natural gas, MSW, livestock, enteric fermentation, landfills, agriculture, waste management activities are responsible for CH_4 emissions. The major source of methane emissions are as follows:

a) Agriculture- Cattle, swine, sheep and goats produce methane and since human raise these livestock these emissions come under human related. According to *Inventory of US Green House Gas Emissions and Sinks* agriculture is the largest source of methane emissions.

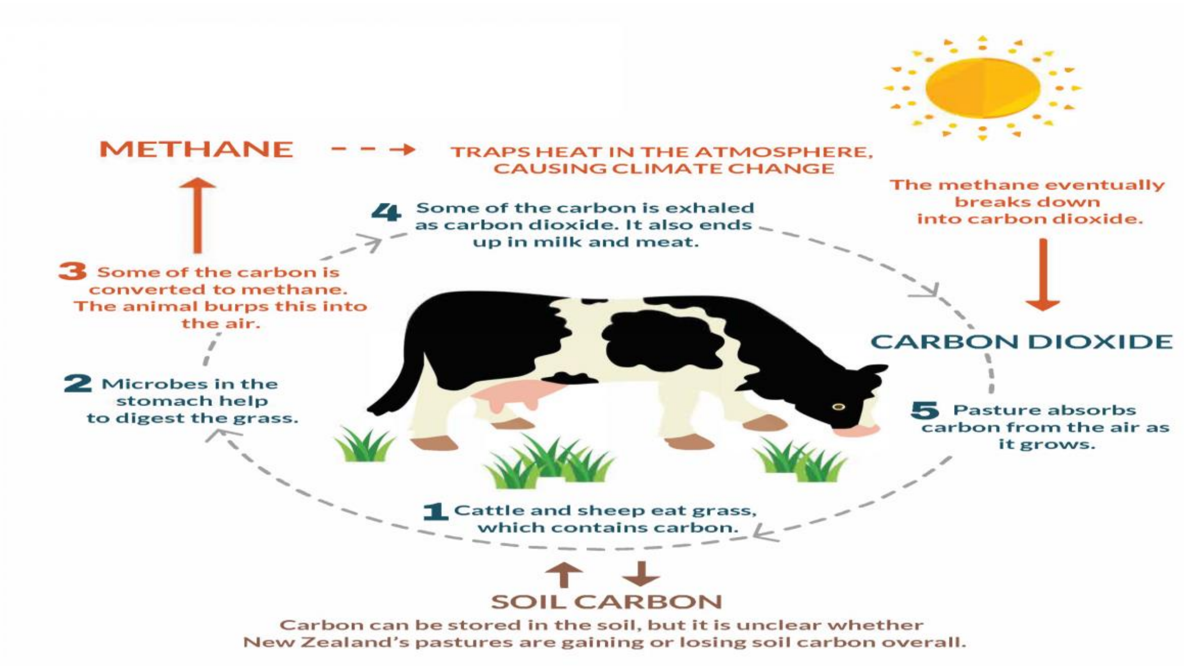

FIG.2.1: Presentation of methane emission from livestock (https://environment.govt.nz/)

b) Energy and Industry- Methane being the primary component of natural gas is considered to be the second largest source of methane emission and it is emitted during the production, refinement, transportation and storage of industrial waste.

FIG.2.2: Greenhouse gas emissions in the atmosphere from industries (https://www.livescience.com/)

c) Waste from homes- Generation of methane also occurs in waste dumps, landfills which is the third largest source of methane emissions. The waste from homes is generally organic material and comes under MSW. The major part of MSW is organic material. This organic material degrades naturally over short or longer period of time depending on the composition of matter and conditions of the landfills or waste dumps and results in methane emissions.

FIG.2.3 Food waste in waste dumps (https://www.bioenergyconsult.com/)

Dumping of food waste in landfills is widely used method for disposal (Ghosh *et al*., 2018). As it is organic material, it undergoes either aerobic or anaerobic bio-degradation resulting in production of carbon dioxide, water or heat for aerobic process and carbon dioxide and methane for anaerobic process (Jensen *et al*., 2010**).** The production of CH_4 causes entrapment of heat, results in increased earth's temperature and global warming. From industrialized countries, 20-40 million tones of methane are estimated as Global Annual Emission from SWDS (UNFCCC, 2000). Similarly, due to increase in population, per capita MSW generation, and improved economy there are chances of increase in methane emissions from developing countries (UNFCCC, 2000). As discussed above since it is a key point for increased global warming its emission estimation is required so as to take steps for its proper management and recovery.

Apple fruit which is mostly grown in temperate regions is one of the most preferred fruit all over the world (Agrahari *et al*., 2003). India secured 9th position in producing apples and is responsible for contributing 1/3rd of it total produce (Anon. 2004). Currently, India has 5th position is production of apples. Generally, around 70% of apple from apple crop is directly consumed. 30% of apples are used for juice extraction out of which 76% is utilized by apple juice industries and the remaining 24% which is left as a byproduct is known as wet apple pomace as shown in FIG.2.4. This apple pomace remains dumped outside for animal feeding, composting or landfill use.

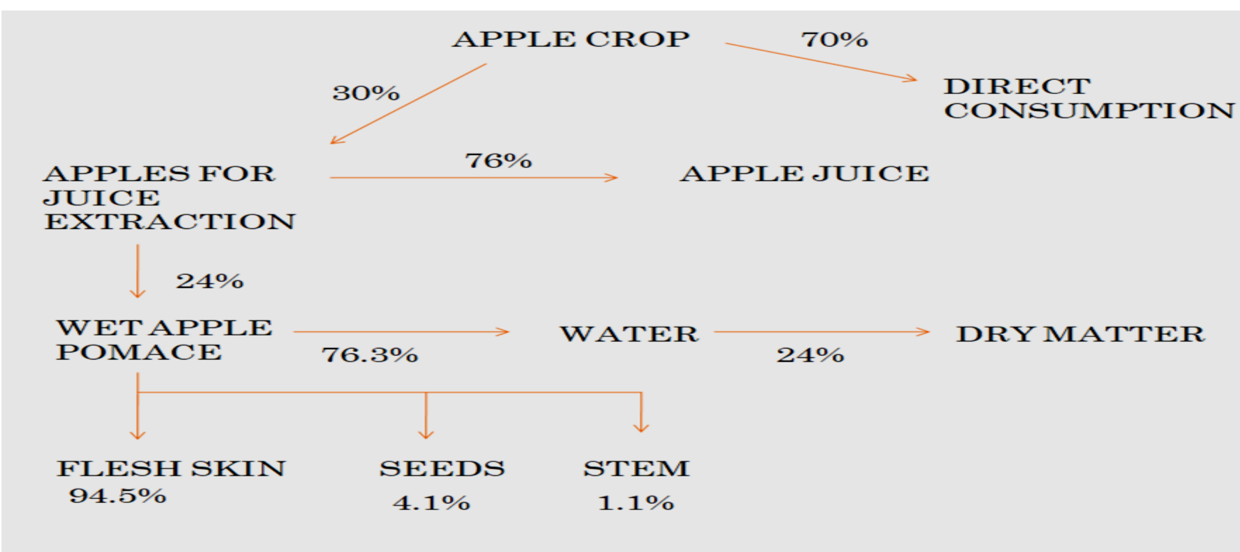

FIG.2.4: Flow chart of mass flow of components from apple crop.

Along with dumping of food waste outside industries, a huge amount of food waste is loss during quality attributes, inappropriate harvesting method, handling, inadequate storage facilities, over purchase, mechanical injuries which ultimately goes to open dumps and landfills (Omoleye., 2020). They stated that this open dumping is responsible for GHG emissions. Around 8% GHG is produced from agricultural production stage, 38% from processing, 18% from distribution and 36% from consumption. This can be reduced by application of resource and energy efficient systems that can minimize environmental impacts by waste. This may also include awareness, reduction in over purchase, reuse, proper handling etc.

Kumar *et al*., 2018 considers methane from landfills as a potential source of energy. India being one of the fastest growing economies is constantly working to improve its technological capacity so as to generate power sources and energy from MSW. Methane emitted from waste dumps can be used in the form of cleaner and greener energy i.e. biogas. There are many disadvantages of dumping waste in open which are reduction in nitrate, potassium, phosphorous, reduction in recycling and reuse capability, risk of pollution specifically groundwater pollution. It can also result in generation of air pollutants which increase risk of cancer, respiratory issue, unpleasant odors etc (Jigar *et al*., 2014). Estimation of methane emissions can lead to development of controlled landfills with proper management and collection systems which can be further used as source of energy (Kumar *et al*., 2018). Around 30- 60% of gases can be recovered if the landfills are properly controlled (Bishoi *et al*., 2009) which can be either used as direct energy source or upgraded for power generation or vehicle fuel (Kumar *et al*., 2014).

There are several clean development programs, zero waste initiative and renewable energy practices which states the capture of methane from landfills based on the rate of USD 13.20/t of CO_2 can produce revenue of 483 million USD in 2020, 673 million USD in 2025 and 877 million USD in 2030 via carbon reduction (Choudhary *et al*., 2020). Shin *et al*., 2005 states if 40% efficient gas engine is used it results in production of 305 MW of energy in 2020, 425 MW of energy in 2025 and 555 MW of energy in 2030. Therefore, we can say it has a huge potential in term of energy production. Collection via LFG system can curtail GHG emission and also act as revenue source which is profitable for environment as well as investors. Production of energy from landfill gas will directly help in reduction of GHG and also help in providing local energy source for neighboring area of landfill (Ghosh *et al*., 2018).

The whole idea of methane emission estimation, capture of methane, production of energy comes under integrated solid waste management which is need of the hour. Integrated solid waste management is important to prevent degradation of environment and promote sustainable development. Mitigation of climate change and promotion of national energy security requires stabilization of methane emissions. This can be done either by applying techniques for methane recovery or by production of energy via composting, digestion, biogas production etc (Jigar *et al*., 2014). Due to increasing population, food consumption is increasing which ultimately results in increased waste generation. Without proper landfill sites it is directly responsible for increased global warming potential. Hence, methane emission estimation becomes important as it can help in development of appropriate measures from construction of properly maintained landfill sites (Jigar *et al*., 2014) and reducing greenhouse gas emissions.

2.5 DIFFERENT USES OF APPLE POMACE

There are multiple uses of apple pomace because of its composition which is carbohydrates (9.5-22%), proteins (4.0%), sugars (3.6%), cellulose (6.8%). It is also composed of hemicelluloses, lignin, fibers, polyphenols (Shafiee. 2017). But it is still dumped outside industries as shown in FIG.2.5 without any treatment or utilization which lead to multiple problems. This open dumping leads to bio-degradation resulting in methane emission and increasing global warming potential.

FIG.2.5: Tones of apple pomace dumped outside industries (https://www.tribuneindia.com/)

Therefore, instead of throwing apple pomace without any treatment, its reuse capabilities must be explored. There are multiple uses of apple pomace which include production of enzymes, ethanol, organic acids, biopolymers, pectin, aroma compounds, nutrient enrichment etc. These utilization techniques of apple pomace must be explored as to reduce the waste and promote energy recovery. It is a sustainable way to prevent accumulation of waste and promote zero waste initiative. The different uses of apple pomace are as follows:

2.3.1 Animal Feed

Apple pomace is widely used either as source of food for animal or as a fertilizer. This method is part of waste reduction strategy. People are unaware about the different valuable use of apple pomace which results in its incomplete utilization. Leaving apple pomace outside industries can become a cause of nuisance. Therefore, in areas such as Himachal Pradesh, Jammu Kashmir etc. people use it for feeding their livestock. It is fed fresh either as silage or in the form of dried pomace. It is found to be suitable for cows and sheep etc. (Smock and Neubert., 1950) Feeding livestock is the traditional approach of utilizing apple pomace. On the other hand apple pomace has rich amount of nitrogen that’s why it can also be used an additional substrate for mushroom compost (Kennedy. 1994). But this method is not suitable completely because of its overall huge production example, in case of HPMC (H.P. Horticulture Produce Marketing & Processing Corporation) which is responsible for dumping thousand tones of pomace outside its industries.

2.3.2 Production of Enzymes

Apple pomace is used for the production of pectic enzymes. Degradation of pectic substances occurs with the help of hydrolytic depolymerases enzymes which are produced by bacteria, fungi or yeast (Torres- Favela *et al*., 2006). These are produced either by solid state fermentation (SSF) or submerged fermentation (SmF) which is further used in food, textile and waste water treatment industries. Different scientists over the years have produced different enzymes with the help of apple pomace, Hang and Woodams. 1994 (polygalactouronase with 5 strains of *Aspergillus niger*), Zheng and Shetty 2000 (polygalactouronase with *Lentinus edodes*), Berovic and Ostroversnik 1997 (pectolytic enzyme with *Aspergillus niger*), Hang and Woodams 1995 (β-fructofuranosidase with *Aspergillus foetidus*), Pericin 2001 (pectinase with *Polyporus squamosus*), Seyis and Aksoz 2005 (xylanase with *Trichoderma harzianum*), Villas *et al*., 2002 (hydrolytic and oxidative enzymes with *C. utilis*) and Joshi *et al*., 2006 (pectin methylesterase with *A. niger*). Generally, SSF has more advantage as compared to SmF because of it less water usage, low production of waste and low contamination problems. Therefore, production of enzymes is one of the valuable uses from apple pomace.

2.3.3 Production of Aroma Compounds

Kohl *et al*., 2001 states that any chemical compound portrays smell if it is in high concentration and volatile in nature. These chemical compounds are known as aroma compounds. Aroma compounds have various uses in cosmetic products example, in oils, shampoos, deodorants etc. Similarly, apple aroma is popularly used in shampoos and as food flavors. Nowadays fermentation and bioconversion methods are used for production of natural aroma compounds. McLellan and Acree 1989 state the presence of n-butanol, n- propanol, and 3 methyl butanol volatile compounds in apple juice which can be used. Different scientists have also explored the production of aroma compounds from apple pomace, Bramorski *et al*., 1998 (with the help of *Ceratocystis fimbricata*), Christen *et al*., 2000 (with the help of *Rhizopus* strains) etc. With the increasing interest of people in various kinds of aroma compounds, this has led to increased investment of industries in production of the same.

2.3.4 Production of Apple Seed Oil

Apple seed oil which is rich in fatty acids is widely used in cosmetic industry in innumerable products because of its ability to soften and hydrate the skin, ability to remove stretch marks and prevent aging. It has a good market among health conscious people. Various cosmetic brands are responsible for producing different qualities of apple seed oil, which is produced from the apple pomace itself. Since apple seeds are around 2-3 % out of the total weight of pomace, their production is less. The main step of extracting apple seed is removing the extra material from the pomace which is done by sieving or floating. Other than its use in cosmetic products it can also be used as health supplement and in cooking.

2.3.5 Production of Nutrient Enriched Pomace

Protein is an important nutrient in diet. The general intake of protein is through meat or milk which has high cost and is not accessible to all. That’s why; microorganisms such as algae, fungi, bacteria etc. are being explored because some of them are composed of 60% protein. Since they have the ability to multiply quickly on different industrial residues they can be utilized for producing nutrient enriched products. Therefore, protein produced from microorganisms can act as good alternative source. Enrichment of apple pomace is done with the help of various microorganisms which increases its protein content and improve its digestibility. Different microorganisms that scientists have worked upon are, *S.cerevisiae*, *C. utilis*, *Torula*. *utilis* via SSF done by Joshi and Sandhu 1996 which increased crude protein by three fold. Rahmat et al., 1995 increased crude protein by 7.5% with the help of *Kloeckera apiculara*. It is also seen that increase in microelements improves the nutritional quantity of apple pomace.

2.3.6 Production of Ethanol

One of the most important sustainable fuels is bioethanol whose feedstock is lignocellulosic biomass. Non-fermentable material produces energy gain from the biomass resulting in generation of heat and power. Agricultural residues, forestry wastes, food processing industries, industrial wastes are responsible for producing lignocellulosic biomass which is highly rich in carbohydrate generally found in sugarcane bagasse etc. Hang *et al*., 1981 used SSF with commercial yeast for production of ethanol whereas Khosravi and Shojaosadati. 2003 used *S. cerevisiae* for the production of ethanol. They were one of the early experiments but nowadays ethanol is widely produced with the help of apple pomace as shown in FIG.2.6.

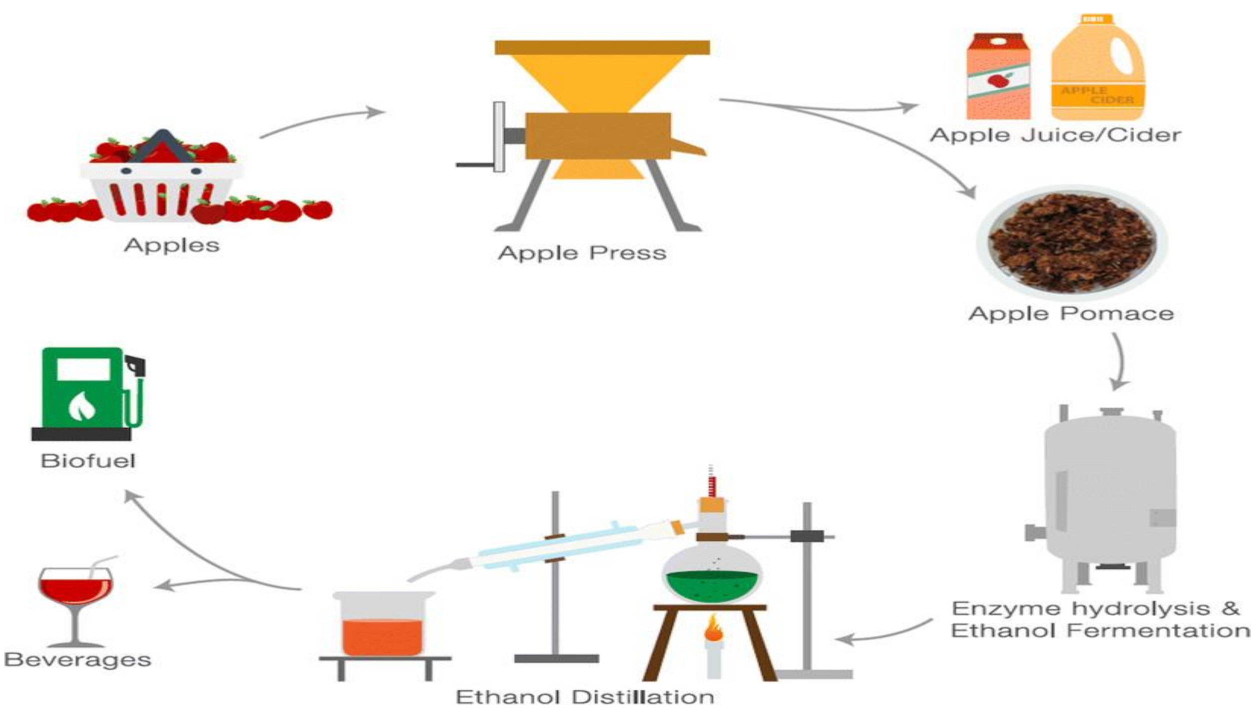

FIG.2.6: Overview of ethanol production (Magyar et al. 2021)

2.3.7 Production of Organic Acids

Diverse products are obtained via cultivating microorganisms on apple pomace. Carboxylic acids are generally manufactured in various products because of their wide applications. Citric acids have a huge potential in food and medical industry. Pandey *et al*., 2000 states that nowadays it is produced from agricultural industries via SSF. This usage of apple pomace is explored by many researchers example, Hang and Woodams. 1984 (produced citric acid from apple pomace), Stredansky *et al*., 2000 (produced fatty acid with *Thamnidium elegans* via SSF), Babaeipur and Shojaosadati. 2002 (produced citric acid with *A. niger* via SSF). Various researches also show direct effect of methanol production on citric acid production (Hang and Walter., 1989). Since the citric acid has a great potential in industries its demand is increasing day by day that's why its production becomes essential.

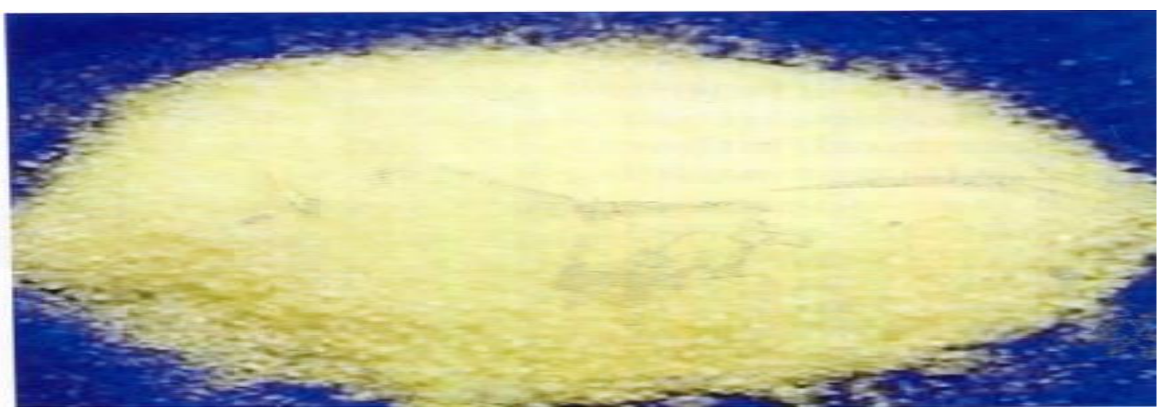

FIG.2.7: Citric acid extracted from apple pomace (Sharma *et al*.2016)

2.3.8 Production of Charcoal

Charcoal is residue of black carbon generally produced from coal or by heating wood to remove water and volatile components. There are different forms of charcoal like sugar charcoal, lump charcoal; Japanese charcoal, extruded charcoal and their uses vary according to the type of charcoal. Active form of charcoal can be used in the treatment of overdosing of drugs or in case of poison. It can also help in removal of unwanted substances. After heating of dried apple pomace at 160-200ºC, Walter and Sherman. 1976 were able to obtain charcoal briquette.

Similarly Jewell and Cumming 1984 determined the content of energy in wet apple pomace which can be used for getting information about the fuel value of dry matter. They suggested its usage in water purification. Therefore, it can be said that production of charcoal is one of the multiple use of apple pomace.

2.3.9 Production of Biopolymers

Biopoymers are also known as natural polymers or special class polymers which are produced from the cells of living organisms. They are made of monomeric units that bind together covalently to form larger molecules example, sugars form starch, amino acids form proteins and peptides, nucleic acids form DNA and RNA. Vuyst and Degeest 1999 described high molecular mass food polymers as long-chain molecules which have the ability to dissolve in water giving rise to different properties. Apple pomace with high amount of water content and pressed form of apple pomace was used by Streit *et al*., 2004 to produce fungal chitosan via SSF and SmF respectively. This experiment showed best productivity with *G. butleri.* On the similar grounds, Vendruscolo 2005 used *G. butleri* for production of chitosan and was successful. These researches indicate the varied use of apple pomace.

2.3.10 Production of Biogas

The mixture of gases produced after breakdown of organic matter by microorganisms (methanogens and sulfate reducing bacteria). Methane (60%), carbon dioxide (39%), hydrogen sulfides are present in larger amount. The biological process involved in biogas production is anaerobic digestion which works in the absence of oxygen (Zhang *et al*., 2016). It has been in usage for centuries, but it still acts as focus area for research (Zhang *et al*., 2016). It is a renewable source of energy which is naturally present in wetlands soil, oceans (Andrews. 2009). Biogas plants, also known as anaerobic digesters are generally used for treatment of wastes of farm. The biogas produced has multiple applications, like, production of electricity, heating of space, water and as cooking fuel. Biogas composition differs with change in factors such as composition of substrates, temperature, pH, concentration of substrates (Hafner *et al*., 2017). Similarly, the production of biogas from apple pomace varies according to substrate composition and concentration. In spite of vitality recovery, AD present other significant favorable circumstances, for example, high natural issue evacuation proficiency, low abundance slime creation and low space prerequisites (Van Lier *et al*., 2015). Different factors are responsible for production of biogas which is as follows:

a) Effect of single substrate digestion –

Jewell and Cummings 1984 performed anaerobic digestion and biological drying of apple pomace and concluded that it is responsive to low alkalinities and nutrient levels but successful, 45 days of HRT results in conversion of around 90% biodegradable organics into biogas whereas bio drying is able to produce 1.3 times more energy than it consumes. But the two methods needs more research. Some of the researchers used apple pulp with slaughterhouse waste and concluded that when pulp concentration is around 10% it gives high VFA (volatile fatty acids) and ammonia resulting in inhibition by bacteria, low amount of biogas and bad quality of biogas (Coalla *et al*., 2009). Molinuevo- Salces *et al*., 2020 also concluded that the fermentation has the ability to increase production of methane and the exhausted broth is able to produce 1.8 times more specific methane yield than that of the normal apple pomace. Single substrate digestion as a whole doesn't provide high biogas productivity; therefore, co-digestion of substrate is preferred.

b) Effect of co-digestion of substrates-

The benefit of co-digestion of substrates is that it helps in balancing the C/N ratio of feedstock. Knol *et al*., 1978 concluded that due to presence of apple pomace there is decrease in pH because of carbohydrate richness and unbalanced digestion and it can be improved via alkali addition, feed interruption and mixing. Whereas, Lane. 1984 concluded that manures rich in nitrogen taken from poultry or pigs as a form of supplement can be used with apple pomace along with constant concentration of weekly OLR, can ensure appropriate levels of phosphorous and alkalinity. Riggio *et al*., 2015 also concluded that when the substrates are used alone poor biogas and methane production is there as compared to co-digestion of substrates. Fruit wastes are potential substrates for the production of bio energy due to high biodegradability and high moisture content (75%-90%), co-digestion of the fruit wastes yield higher biogas because of increase in load of organic waste, dilution of potential toxic compounds, and improvement in balance of nutrients (Gargi. 2016). When apple pomace is considered independently or in comparison with substrates like maize silage it doesn't show high biogas productivity but it does show improvement in methane quality (Kuznia *et al*., 2019). Experiments have also been conducted to see if experimental results can be considered for full scale AD power plant it was concluded that daily estimate of methane production (290 Nm^3/d) leads to 42Kw power output and 300MW h/year of annual electric production (Scano *et al*., 2013). Higher methane yields are obtained if co-digestion is done. 15% of AP gives methane yields of up to 596 mL CH_4 g^{-1} VS added which is supposedly high biochemical methane potential. This results show apple pomace can act as appropriate co-substrate for existing agricultural biogas plants which are based on manure (Molinuevo- Salces *et al*., 2020). More research needs to be done to check the feasibility of co- digestion of substrates to get increased biogas productivity.

c) Effect of Pre-treatment-

These are the methods applied before applying anaerobic digestion to any feed. This is done to increase productivity of biogas so as to improve the energy gain. It can affect various parameters, like, hydrolysis rate, time etc. At temperature such as 55 - 120^{o} C, amount of methane production increases to a considerable amount. The pretreatment of the sludge by applying ultrasound increases biogas generation and methane percentage in the biogas. The ultrasound pretreatment also supports the growth of the methane-producing bacteria (Tulun *et al*., 2017). The basic idea of pretreatment is to improve biogas productivity. Various parameters can be tested to check the same.

These different uses state the varied utilization process of apple pomace and how it can help in its reduction. Our objective is to analyze the most popular method for apple pomace disposal which is open dumping which results in its biodegradation and methane emission. This ultimately results in increasing the global warming potential. After the review of literature we are able to determine the nuisance caused by open dumping of apple pomace, importance of methane emission and different uses of apple pomace. Since much of the literature is not available on methane emission estimation from apple pomace, we were able to find out due to increasing population; food consumption is increasing which ultimately results in increased waste generation. Without proper landfill sites it is directly responsible for increased global warming potential. Hence, development of appropriate measures for construction of properly maintained landfill sites is necessary (Jigar *et al*., 2014). After this different method from IPCC guidelines were analyzed as discussed in chapter 3 and appropriate method was found out after learning about the previous researches. This led us to our research objectives and questions.

2.6 RESEARCH OBJECTIVES AND QUESTIONS

Based on the literature review, the following research objectives and questions were developed in order to determine methane emission estimation from Apple Pomace.

Objectives

1. A critical assessment of Methane Estimation from Apple Pomace and effects on energy and Global Warming Potential.

2. To observe the trends on utilization of Apple Pomace, current limitations and recommendations for future research.

3. To enhance waste reuse and improvement in order to promote renewable source of energy and zero waste initiative.

Questions

1. Are we ready to perceive waste from fruit juice industries as a valuable resource instead of throwing it away and letting it as it?

2. How the usage of methane by recovery can help reduce the effects of climate change?

3. How to leave a lesser carbon footprint on the earth and thus promote the well being of the environment for future generations?

CHAPTER- 3

METHODOLOGY

3.1 INTRODUCTION

Apple fruit which is mostly grown in temperate regions is one of the most preferred fruit all over the world (Agrahari *et al*., 2003). Generally, around 70% of apple from apple crop is directly consumed. 30% of apples are used for juice extraction out of which 76% is utilized by apple juice industries and the remaining 24% which is left as a byproduct is known as wet apple pomace. The water content in this wet apple pomace is 76.3% whereas 24% is dry material (Kennedy *et al*., 1999). Basically, apple pomace is the result of pressing apples for production of juice. Different researches have been going on utilization apple pomace but dumping of apple pomace in landfills is widely used method for its disposal (Ghosh *et al*., 2018). Open dumping of apple pomace leads to bio-degradation and production of CH_4 due to anaerobic digestion. This causes entrapment of heat and results in increasing the earth's temperature. Methane is a greenhouse gas and has 28-34 times more global warming potential than carbon dioxide (Allen. 2016). That's why its estimation is important so as to gain insight in energy recovery and examine the global warming potential.

Our objective is critical assessment of methane estimation from apple pomace, effects on energy and finding out global warming potential. Not much research is done with respect to methane emission estimation from apple pomace that's why we have considered a vast literature to find out proper method for its estimation. There are different methods for estimation as per IPCC guidelines for estimation of methane emissions like IPCC Default method (DM), First order decay (FOD) method, Triangular method (TM) and Landfill gas emission model (LandGEM) version 3.02 method etc. In our thesis, we have used IPCC Default method for estimation of methane emission from apple pomace. After the review of literature it was concluded that we can use the mass flow of components for finding out apple pomace since there is unavailability of proper apple poamce data. Also, after considering different methods IPCC DM is selected for methane estimation. This chapter discusses the method applied for data collection of apple pomace, followed by description of default method and global warming potential and energy potential.

3.2 DATA ACQUISTION

Around 70% of apple from apple crop is directly consumed. 30% of apples are used for juice extraction out of which 76% is utilized by apple juice industries and the remaining 24% which is left as a byproduct is known as wet apple pomace. The water content in this wet apple pomace is 76.3% whereas 24% is dry material (Kennedy *et al*., 1999). Basically, apple pomace is the result of pressing apples for production of juice. Apple fruit is grown in the hilly regions of India like Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Arunachal Pradesh and Nagaland (Sikka and Swarup. 1985) that's why only these states were considered for analysis. The production of apple in these 5 states from 2003- 2019 is shown in Table 3.1 and methane emission was estimated.

Table3.1: Production of apple in different states* (Gg/y)

S.No.	STATE YEARS	JAMMU & KASHMIR	HIMACHAL PRADESH	UTTARAKHAND	ARUNACHAL PRADESH	NAGALAND
1	2003-04	1041.5	459.5	11.3	9.3	NA
2	2004-05	1093.3	527.6	108.5	9.5	NA
3	2005-06	1151.71	540.36	112.3	9.6	0.02
4	2006-07	1222.18	268.4	123.33	9.79	0.02
5	2007-08	1268.5	592.6	130.5	9.8	0.05
6	2008-09	1332.81	510.16	132.31	9.8	0.05
7	2009-10	1372.97	280.11	113.99	10	0.04
8	2010-11	1852.41	892.11	135.89	10	0.05
9	2011-12	1775.04	275.04	122.65	30.5	0.12
10	2012-13	1348.15	412.39	123.23	30.95	0.6
11	2013-14	1647.69	738.72	77.45	31.87	1.89
12	2014-15	1368.63	625.2	106.1	32	1.89
13	2015-16	1672.72	777.13	61.94	7.28	2.01
14	2016-17	1725.75	468.13	62.06	7.18	2
15	2017-18	1808.33	446.57	58.66	7.35	1.99

16	2018-19	1882.319	468.603	60.09	NA	NA

*Source: Data from National Horticulture Board (http://nhb.gov.in/)

The data for apple pomace was acquired using the percentage formula. Firstly, the data of apples was collected and then using the mass flow of components from apple crop which is, around 70% of apple from apple crop is directly consumed. 30% of apples are used for juice extraction out of which 76% is utilized by apple juice industries and the remaining 24% which is left as a byproduct is known as wet apple pomace which remains dumped outside for animal feeding, composting or landfill use. Using this mass flow of components the data of apple pomace was produced in Gg/y (Gullon *et al.*, 2007; Shalini *et al.*, 2010; Zhang *et al.*, 2017) For example; if Himachal Pradesh produced 468.603 Gg of apples for the year 2016-2017 (National Horticulture Board), then 30% apples out of it will be used for apple juice extractions which are, 140.439 Gg. Now this production will be divided into two parts, 76% of 140.439 Gg will be used by apple juice industries and 24% of 14.439 Gg will be the wet apple pomace, therefore, the resultant wet apple pomace will be 33.73 Gg which is the required field. The production of apple pomace using the percentage formula for the 5 Indian states is shown in Table 3.2.

Table3.2: Production of apple pomace in different states (Gg/y)

S.No.	STATE YEARS	JAMMU & KASHMIR	HIMACHAL PRADESH	UTTARAKHAND	ARUNACHAL PRADESH	NAGALAND
1	2003-04	74.988	33.084	0.813	0.669	NA
2	2004-05	78.7176	37.9872	7.812	0.684	NA
3	2005-06	82.923	38.905	8.085	0.6912	0.0014
4	2006-07	87.996	19.324	8.879	0.704	0.0014
5	2007-08	91.332	42.667	9.396	0.705	0.0036
6	2008-09	95.962	36.731	9.526	0.705	0.0036
7	2009-10	98.853	20.167	8.207	0.72	0.0028
8	2010-11	133.373	64.231	9.784	0.72	0.0036
9	2011-12	127.802	19.802	8.83	2.196	0.0086
10	2012-13	97.0668	29.692	8.872	2.228	0.043
11	2013-14	118.633	53.1878	5.576	2.294	0.136
12	2014-15	98.541	45.0144	7.639	2.304	0.136

13	2015-16	120.435	55.953	4.459	0.524	0.144
14	2016-17	124.254	33.705	4.468	0.516	0.14
15	2017-18	130.19	32.15	4.22	0.52	0.14
16	2018-19	135.52	33.73	4.32	NA	NA

The data was taken from National Horticulture Board for the years 2003-2019 (http://nhb.gov.in/) for these states. The data from National Horticulture Board was then verified with respective State Horticulture Board and then taken into consideration.

The methane emission was estimated for countries other than India as well. The data for comparison between different countries was also considered on the basis of percentage formula and mass flow of components from apple crop (Kennedy *et al.*, 1999). 20 major apple producing countries were considered and apple production data was taken from Knoema data workflow for the years 2010-2020 (https://knoema.com/). Then, using percentage formula the production of apple pomace was found out for these countries as shown in Table 3.3.A and 3.3.B.

Table3.3.A: Production of Apple Pomace in different countries* (Gg/y)

COUNTRY	**2014**	**2013**	**2012**	**2011**	**2010**
CHINA	2689.2	2613.6	2578.32	2424.24	2278.8
UNITED STATES	368.06	340.685	291.527	304.666	300.623
TURKEY	178.592	225.248	208.0069	192.965	187.2
INDIA	179.834	179.834	137.88	158.6448	208.152
RUSSIA	101.419	101.988	91.008	80.928	65.52
UKRAINE	84.931	78.149	87.2208	81.13	68.6952
BRAZIL	91.058	99.259	88.668	96.538	96.408
CHILE	87.12	94.32	102.24	97.92	103.032
SOUTH AFRICA	66.269	57.06	65.39328	58.55	55.224
JAPAN	58.428	58.774	53.4024	57.154	47.1816
BELARUS	25.546	36.907	22.428	36.828	13.7376
MEXICO	51.657	61.819	27.072	45.36	42.12
MOLDOVA	22.154	26.64	22.1184	20.29	19.3536
NEW ZEALAND	39.816	34.957	38.2536	34.56	34.812

ARGENTINA	46.8	45.36	61.92	61.92	76.32
SERBIA	31.09	24.214	33.0048	17.568	19.1232
CANADA	28.97	27.842	19.728	28.423	26.7138
AZERBAIJAN	18.461	18.166	17.7624	16.906	16.0632
AUSTRALIA	21.254	19.21	20.8008	20.815	21.5856
KAZAKHSTAN	10.627	11.369	10.3608	9.338	8.2584

Table3.3.B: Production of apple pomace in different countries* (Gg/y)

COUNTRY	**2020**	**2019**	**2018**	**2017**	**2016**
CHINA	2916	3054.6	2376	2980.08	2908.296
UNITED STATES	336.312	347.09	322.465	366.1	360.734
TURKEY	309.6	260.64	259.2	218.316	210.66
INDIA	165.6	170.64	165.6	138.24	162.576
RUSSIA	110.88	128.059	115.991	97.89	108.659
UKRAINE	105.293	105.293	105.293	105.293	77.486
BRAZIL	86.04	86.04	86.04	86.04	94.147
CHILE	84.24	80.928	87.12	95.76	94.32
SOUTH AFRICA	69.12	67.839	64.357	60.183	64.953
JAPAN	54.439	54.439	54.439	54.439	52.934
BELARUS	50.414	50.414	50.414	50.414	22.831
MEXICO	48.996	54.827	39.425	51.419	51.619
MOLDOVA	47.894	47.894	47.894	47.894	35.078
NEW ZEALAND	41.976	42.264	40.536	41.436	37.656
ARGENTINA	41.04	41.04	39.6	40.32	40.32
SERBIA	33.149	33.149	33.149	33.149	27.259
CANADA	27.72	26.526	28.786	26.263	29.405
AZERBAIJAN	19.958	19.958	19.958	19.958	19.807
AUSTRALIA	19.325	19.325	19.325	19.325	22.586
KAZAKHSTAN	16.02	16.02	16.02	16.02	13.039

*Source: Knoema data workflow (https://www.knoema.com/)

Next step after collection of the apple pomace data was finding out the model for estimation of methane. After reviewing the literature, IPCC DM equation was found suitable for finding out methane emissions which are discussed in the next section (IPCC 2006).

3.3 ESTIMATION OF METHANE EMISSION

IPCC 2016 revised guidelines gives different estimation methods for finding out methane emission like IPCC Default method (DM), First order decay (FOD) method, Triangular method (TM) and Landfill gas emission model (LandGEM) version 3.02 method etc. It also discusses the uncertainty and quality management issues which are related to estimation of methane emission (IPCC 2006). The choice of method for emission estimation depends on national circumstances. According to the available and estimated data for apple pomace, IPCC default method is considered for methane estimation. IPCC default method is a simple method for emission estimation which is based on mass balance calculation. It helps in estimation of methane from the SWDS with an assumption that methane is released the year waste is disposed of. It requires annual SW disposal data of inventory years with proper information on composition of waste and conditions at the disposal site (IPCC 2006). The IPCC guidelines have default values for data which is required in the DM equation. The method is basic and requires input of only some parameters. It is an appropriate method if the yearly amount and composition of disposed of waste is nearly constant, doesn't change over time or slowly varies over a period of several decades. (IPCC 2006) The minimum national figures required are as follows:

1. National MSW quantities which end up at disposal sites.

2. If there is lack of solid waste statistics then we need to multiply number of urban inhabitants in country to specific national MSW disposal rate figure.

3. National quantities of landfill gas recovered. For developing countries there is no such gas extraction and recovery hence of only urban inhabitants is required.

Most developed or industrialized countries present a good SW disposal data because of proper sampling and collection of data whereas different uncertainties can be associated with the IPCC DM method while considering developing countries because of unavailability of data. (IPCC 2006) Other reason for this data discrepancy is frequent aerobic decomposition (IPCC 2006), fires or scavenging which may result in lower emissions when compared to industrialized countries. Many improvements are required in data collection as well as emission factors. Hence, proper data acquisition is required to find out emission estimation. The merit of IPCC default method is in studying different methods which can help in reduction of methane emissions by waste treatment methods (IPCC 2006)

The equation of default method is as follows:

$$\text{Methane emissions (Gg/y)} = MSW_T * MSW_F * MCF * DOC * DOC_F * F * 16/12 - R * (1-OX) \quad (1)$$

Where,

MSW_T: Total MSW generated (Gg/y)

MSW_F: Fraction of MSW disposed to solid waste disposal sites

MCF: Methane correction factor (fraction)

DOC: Degradable organic carbon (fraction) (kg C/ kg SW)

DOC_F: Fraction DOC dissimilated

F: Fraction of CH_4 in landfill gas

16/12: Conversion of C to CH_4

R: Recovered CH_4 (Gg/y)

OX: Oxidation factor

MSW_T and MSW_F is considered to be activity data since it changes depending on the country and composition of data (IPCC 2006) whereas MCF, DOC, DOC_F, F, R, OX are called emission factors which helps in estimation of methane emission. They have different values for developed and developing countries. IPCC guidelines also give certain default values for these emission factors where there is unavailability of data or associated uncertainties (IPCC 2006).

Choice of activity data:

MSW_T - Total MSW generated and MSW_F - Fraction of MSW disposed to solid waste disposal sites

It is generally defined as the total amount of MSW generated and the amount of MSW disposed at the landfill site (IPCC 2006) Different developed and industrialized countries have statistics on this which is based on sample surveys and collection of data. IPCC guidelines also give method for calculation of MSW_T and MSW_F for developing countries where there is unavailability of data due to certain uncertainties (IPCC 2006). These uncertainties may include lack of statistics, lack of updated figure of urban population, lack of information on collection and disposal conditions and lack of information on managing conditions of MSW. Also for calculation of methane emission from apple pomace we have considered 5 North Indian states which are responsible for production of apple (https://agriexchange.apeda.gov.in/) and 20 different countries of the world which majorly produce apple (Knoema data workflow https://knoema.com/). After collection of this activity data it was multiplied with the emission factors and using eq.2 methane emission was estimated.

Choice of emission factors:

a) MCF- Methane Correction Factor

The fact that poorly managed SWDS is responsible for producing less methane from waste when compared to managed SWDS is related to MCF (IPCC 2006). The reason being, some fraction of waste can decompose via aerobic degradation from the upper most layers of poorly managed SWDS. MCF is related to specific area and changes according to change in management of area. The SW is generally disposed of in different range of sites which are divided into managed, unmanaged, and unspecified. The sanitary landfills which are modern in range are characterized by their conditions for anaerobic biodegradation. These conditions where waste is disposed of and anaerobic digestion takes place must include proper depth minimum 10m, appropriate design, good site management, control of waste, protection from fires or unnecessary scavenging, control of operation and recovery of gas (IPCC 2006). The IPCC Guidelines offers some default data for different sites depending on their conditions. Managed sites has MCF = 1.0; Unmanaged, deep sites (>5m) has MCF = 0.8; Unmanaged, shallow sites (<5m) has MCF = 0.4 and Unspecified SWDS has MCF = 0.6 as their default data. Since there is no proper management of apple pomace by industries due to which it is usually thrown away without any usage we consider it under unspecified SW therefore for apple pomace MCF is 0.6.

b) DOC- Fraction of degradable organic carbon

It is defined as the organic carbon which is utilized for decomposition biochemically. It is expressed in the form of Gg C per Gg waste i.e. gigagram carbon per gigagram waste. It is linked with composition of waste and is calculated using weighted average of carbon content from different components of the waste (IPCC 2006). The default value for DOC is 0.5. In consideration of MSW with regard to developing countries DOC is generally high because of high content of paper, textile, wood etc. Since apple pomace is food waste and has high organic content for biochemical degradation, we have considered the default value of DOC for methane estimation (IPCC 2006).

c) DOC_F – Fraction of degradable organic carbon dissimilated

It is defined as the fraction of estimated carbon that is degraded and then released from the SWDS (IPCC 2006). But sometimes organic carbon doesn't degrade or takes time to degrade when deposited in the SWDS which is reflected by the DOC_F factor. Since we have considered apple pomace under unspecified site, the default value for DOC_F is taken into account which is 0.77.

d) F- Fraction of methane in landfill gas

Methane and Carbon dioxide are the main components of landfill gas (Rettenberger. 2018). The fraction of methane in the landfill gas is considered to be 0.5 which can vary between 0.4 and 0.6 (IPCC 2006). The variation in the fraction of methane in landfill gas depends on different factors like waste composition, site management etc. Generally, methane concentration in recovered landfill gas is lower than actual value. The reason for this uncertainty is dilution by air (IPCC 2006). We have considered the default value of F for methane estimation from apple pomace.

e) R- Recovered gas or Methane Recovery

It is defined as the amount of methane recovered and used from the total production of methane at SWDS. The default value for R is 0 because most of the developing countries don't adopt recovery of LFG (Singh *et al*., 2016). LFG plants are unmanaged and there are no equipments or methods for extraction and recovery of methane (Singh *et al*., 2016). The recovered methane is not subtracted from total methane emissions while considering the total emissions from SWDS. Recovery of methane is not adopted in India; therefore, we have considered the default value for methane emission estimation from apple pomace.

f) OX- Oxidation factor

It is defined as the amount of methane which gets oxidized in soil or other material from the SWDS (IPCC 2006). The default value for OX is 0 which means there is no oxidation taking place in waste site. If the value of OX is 1 it means 100% of methane is oxidized (IPCC 2006). The oxidation effect increases with increase in temperature. It also depends on the type and thickness of waste cover at SWDS (IPCC 2006). Managed landfills have high oxidation because of proper cover of waste when compared to unmanaged sites because of associated uncertainties (IPCC 2006). Developed countries with well managed SWDS use 0.1 values for OX and the developing with unmanaged landfills use the default value for OX. For apple pomace the default value of OX i.e. zero is considered while finding out the methane emission estimation.

The IPCC default method provides good annual estimates of methane emission (Ghosh *et al*., 2018). Since many developing countries lack activity data due to associated uncertainties, the IPCC guidelines helps in determination methane emission for those countries as well. Since it has default values for all the emission factors the estimation becomes easier (IPCC 2006). It is simple and basic method for estimation of methane emission which can help in providing reliable data through which we can analyze the energy and global warming potential (Choudhary *et al*., 2020). By comparing the methane emission of different states we can analyze the potential problems and take steps towards methane recovery via different available methods. Therefore using eq. 2 the apple pomace, data of 5 different hilly states of North India was used from 2003-2019 and methane estimation was done. Similarly, apple pomace data from 2010-2020 was used for 20 different countries and using eq. 2 methane estimation was done and compared.

3.4 ESTIMATION OF GLOBAL WARMING POTENTIAL AND ENERGY POTENTIAL

The temperature of earth is increasing day by day because of greenhouse gases. They are responsible for altering the global temperature and thereby affecting climatic conditions of the world (Singh *et al*., 2017). GHGs absorb energy and slow down the escaping ability of energy due to which they heat up the earth (*Inventory of U.S. Greenhouse Gas Emissions and Sinks. 2007)* Development of GWP was done to do comparison of global warming impacts between different gases. It is defined as the measure of absorption of energy by 1 ton of emitted gas in a given time in relation with 1 ton of carbon dioxide (*Inventory of U.S. Greenhouse Gas Emissions and Sinks. 2007)*. High GWP means high warming capability of the gas in comparison to carbon dioxide over a given time which is generally 100 years (*Inventory of U.S. Greenhouse Gas Emissions and Sinks. 2007)*. Carbon dioxide one of the prominent GHG has GWP of 1. This gas is used as reference hence its GWP is 1. This is done without consideration of time. Carbon dioxide doesn't escape fast and remain in the environment for longer time (*Inventory of U.S. Greenhouse Gas Emissions and Sinks. 2007)*. According to *EPA's Inventory of GHG Emissions and Sinks* GWP of methane is 28-36 over 100 years. On an average if it is emitted in environment today it can last up to 10 years. The escaping time of methane is less when compared to carbon dioxide but it is responsible for absorbing more energy than carbon dioxide (*Inventory of U.S. Greenhouse Gas Emissions and Sinks. 2007)*. Hence, methane emission estimation becomes a necessity. Other gases such as nitrous oxide have GWP of 265-298 for 10 years (*Inventory of U.S. Greenhouse Gas Emissions and Sinks. 2007)*. Therefore, finding out GWP becomes a necessity.

IPCC DM was used for evaluating GWP due to apple pomace in India. Biochemical degradation of apple pomace which is organic waste produces various gas emissions. But carbon dioxide and methane have significant fraction in the landfill gas (Choudhary *et al*., 2020). For apple pomace two assumptions were considered, first out of the total landfill gas emitted from SWDS 90% is methane and carbon dioxide. Second assumption was in this 90% concentration of landfill gas, 45% is considered to be methane and 55% is carbon dioxide. Carbon dioxide emissions using these 2 assumptions were found out. Therefore, to find GWP only carbon dioxide and methane were used for analysis. Carbon dioxide which is generally used as reference has GWP of 1. Methane has GWP of 31 (USA EPA 2016). Hence, it is used to convert methane in terms of carbon dioxide. GWP with regard to apple pomace was found out using the following equation (USA EPA 2016):

$$GWP\ Gg\ (CO_2\text{-}eq) = CO_2\ emissions\ in\ Gg * 1\ (CO_2\text{-}eq) + CH_4\ emissions\ in\ Gg * 31\ (CO_2\text{-}\ eq) \quad (2)$$

Where CO_2-eq is a metric measure used for comparing emission from GHG. It is used after conversion of gases to their equivalent amount of carbon dioxide as it is standard measure for finding out GWP (USA EPA 2016). Hence, 5 hilly North Indian states whose methane emissions were estimated were considered for finding out GWP using eq. 2. Total methane and carbon dioxide emissions of these 5 states from 2003-2019 was calculated and using eq.2 GWP was found out and comparison was plotted. Similarly, for finding out GWP of different countries, total methane emissions from 2010-2020 were considered and results were compared.

Energy potential computation is done using the calorific value of methane (Choudhary *et al*., 2020) Calorific value is defined as the total amount of energy released in the form of heat during combustion process under aerobic conditions (Kumar *et al*., 2019). It is directly proportional to methane content of LFG (Kumar *et al*., 2019). The calorific value of methane is 55.4 MJ/kg (Rohr *et al*., 2015). For determination of energy potential of states of India with apple production, total methane emission from 2003-2019 were considered and results were compared.

These methods were followed for finding out production of apple pomace, methane emission, global warming potential and energy potential. Since not much literature is available for methane estimation from apple pomace it was difficult to consider each method. That's why we have considered mass flow of components from apple crop to find the data for apple pomace. IPCC DM for calculation of methane emission is considered because of its ability to predict methane emission in lack of accurate data. It predicts methane emission even for the initial years and is one of the most used methods for calculating methane emission. GWP is found out using eq. 3 to know about the contribution of apple pomace in increasing the earth's temperature. In similar way energy potential of apple pomace was found out for hilly North Indian states to know about the potential of apple pomace in energy recovery.

CHAPTER- 4

RESULTS

4.1 INTRODUCTION

Apple fruit which is mostly grown in temperate regions is one of the most preferred fruit all over the world (Agrahari *et al*., 2003). Generally, around 70% of apple from apple crop is directly consumed. 30% of apples are used for juice extraction out of which 76% is utilized by apple juice industries and the remaining 24% which is left as a byproduct is known as wet apple pomace. The water content in this wet apple pomace is 76.3% whereas 24% is dry material (Kennedy *et al*., 1999). Basically, apple pomace is the result of pressing apples for production of juice. Different researches have been going on utilization apple pomace but dumping of apple pomace in landfills is widely used method for its disposal (Ghosh *et al*., 2018). Open dumping of apple pomace leads to bio-degradation and production of CH_4 due to anaerobic digestion. This causes entrapment of heat and results in increasing the earth's temperature. Methane is a greenhouse gas and has 28-34 times more global warming potential than carbon dioxide (Allen. 2016). That's why its estimation is important so as to gain insight in energy recovery and examine the global warming potential.

Our objective is critical assessment of methane estimation from apple pomace, effects on energy and finding out global warming potential. Not much research is done with respect to methane emission estimation from apple pomace that's why we have considered a vast literature to find out proper method for its estimation. After reviewing the literature it was found out that mass flow of components from crop will be the criteria for finding out apple pomace production. Similarly, different methods from IPCC were analyzed for their suitability to find out methane estimation and finally IPCC DM was considered appropriate for methane estimation from apple pomace as discussed in the previous chapter. Although, unavailability of apple pomace data portrays a limitation to our study but several research papers were analyzed for the same and the percentage formula method was chosen and results were produced. The global warming potential and energy potential is also produced to know about the severity of methane emissions from apple pomace open disposal and energy recovery respectively. The results from all the parameters considered in this study are discussed in this chapter along with the analysis.

4.2 ANALYSIS OF APPLE PRODUCTION

Apple fruit which is mostly grown in temperate regions is one of the most preferred fruit all over the world (Agrahari *et al*., 2003). India secured 9th position in producing apples and is responsible for contributing 1/3rd of it total produce (Anon. 2004). Currently, India has 5th position in production of apples. Apples are the 4th most consumed fruit crop. 65.4% apples are produced in Asia. In 2018-19, India produced 1, 70, 640 metric tons of apple pomace (Lyu *et al*. 2020). Apple fruit is grown in the hilly regions of India like Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Arunachal Pradesh and Nagaland (Sikka and Swarup. 1985) so only these states were considered for analysis. The production of apple has increased from 2003-2019 as seen in FIG.4.1. There are different factors responsible for production of apple crop which include climatic conditions, pollination ability, irrigation, management and pesticide conditions (Singh *et al*., 2007) (Ajay. 2011). Maximum production can be seen in Jammu and Kashmir from 1041.5 Gg in 2003 to 1882.319 Gg in 2019 (Jammu and Kashmir Horticulture Statistics. 2003-2019). It is important fruit for Jammu and Kashmir since major portion of its population is dependent on this industry (Shah. 2019). It can be due to special location, advantage of low temperature (Shah. 2019). The second largest producer of apples is Himachal Pradesh (Wani *et al*., 2018) with 459.5 Gg productions in 2003 to 468.603 Gg in 2019 (Himachal Pradesh Horticulture Statistics. 2003-2019). Apple production is the fastest growing activity in Himachal Pradesh due to its physiographic conditions which also plays an important role in promotion of conservation of environment (Wani *et al*., 2018). Some slight increase and decrease in production of apples as seen in the FIG.4.1 is due to variation in agro-climatic conditions (Wani *et al*., 2018). Uttarakhand shows an increased trend in production of apples from 11.3 Gg in 2003 to 60.9 Gg in 2019 (Uttarakhand Horticulture Statistics. 2003-2019), which might be due to increased production area for apple cultivation and changing climatic conditions. Other North eastern states are also responsible for production of apple which shows slight change in apple production. In case of Arunachal Pradesh, apple production increased from 9.3 Gg in 2003 to 31.87 Gg in 2013 and Nagaland shows a similar pattern from 0.02 Gg in 2005 to 1.99 Gg in 2018 (Nagaland Horticulture Statistics. 2005-2018).

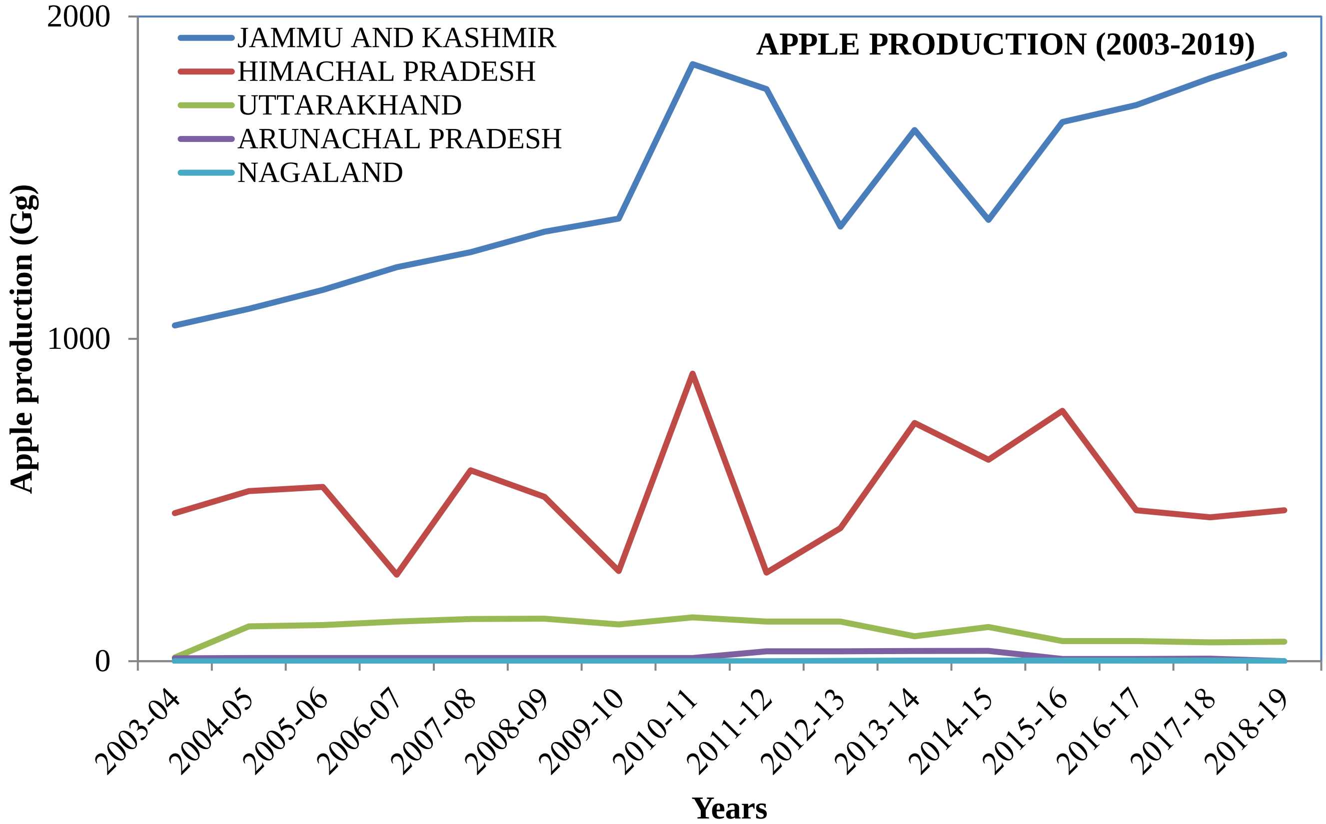

FIG. 4.1: Apple production curve in different states (Gg)

4.3 APPLE POMACE PRODUCTION ANALYSIS AND ESTIMATION OF METHANE EMISSIONS

Around 70% of apple from apple crop is directly consumed. 30% of apples are used for juice extraction out of which 76% is utilized by apple juice industries and the remaining 24% which is left as a byproduct is known as wet apple pomace. The water content in this wet apple pomace is 76.3% whereas 24% is dry material (Kennedy *et al*., 1999). Basically, apple pomace is the result of pressing apples for production of juice. Its composition depends on morphology of original feed stock and technique of its extraction (Hang and Walter.1989). More than 12 million tones of apple pomace are produced in India from which only 10,000 tones is utilized (Shafiee. 2017). Moreover, apple is directly related to rural economy of states like Himachal Pradesh, Jammu & Kashmir and N. eastern states (Shafiee.2017). HPMC (Himachal Pradesh Horticulture Produce Marketing and Processing Corporation) which is one of the major apple juice producing industries in India generates thousand tones of apple pomace, which at times remain dumped outside its industries. There is no proper management of apple pomace hence it is disposed off in open dumps resulting in production of LFG which causes entrapment of heat and result in climate change. That's why its methane estimation becomes a necessity. State wise methane emission was estimated using the IPCC DM eq. (2) from 2003-2019 as shown in Table 4.1.

Table 4.1Methane emissions from different states of India (Gg/y)

S.No.	STATE YEARS	JAMMU & KASHMIR	HIMACHAL PRADESH	UTTARAKHAND	ARUNACHAL PRADESH	NAGALAND
1	2003-04	11.548	5.09	0.125202	0.103026	NA
2	2004-05	12.122	5.85	1.203048	0.105336	NA
3	2005-06	12.77	5.991	1.24509	0.1064448	0.000216
4	2006-07	13.55	2.975	1.367366	0.108416	0.000216
5	2007-08	14.065	6.57	1.446984	0.10857	0.000554
6	2008-09	14.778	5.656	1.467004	0.10857	0.000554
7	2009-10	15.223	3.105	1.263878	0.11088	0.000431
8	2010-11	20.53	9.891	1.506736	0.11088	0.000554
9	2011-12	19.68	3.04	1.35982	0.338184	0.001324
10	2012-13	14.948	4.572	1.366288	0.343112	0.006622
11	2013-14	18.26	8.19	0.858704	0.353276	0.020944
12	2014-15	15.17	6.932	1.176406	0.354816	0.020944
13	2015-16	18.546	8.616	0.686686	0.080696	0.022176
14	2016-17	19.135	5.19	0.688072	0.079464	0.02156
15	2017-18	20.04	4.951	0.64988	0.08008	0.02156
16	2018-19	20.87	5.194	0.66528	NA	NA

State wise comparison of apple pomace and methane emission was done for 5 hilly North Indian states for the years 2003-2019 followed by a year wise comparison between different states as shown in FIG.4.7. Jammu and Kashmir which is located at 33.2778° N and 75.3412° E is highest producer of apples. It is responsible for production of highest amount of apple pomace with 74.98 Gg in 2003 which increased to 135.52 Gg in 2019. Similar trend in seen in methane emission from Jammu and Kashmir which is 11.54 Gg in 2003 to 20.87 Gg in 2019 as shown in FIG.4.2. As seen in the figure as the production of apple pomace increases, the methane emission increases.

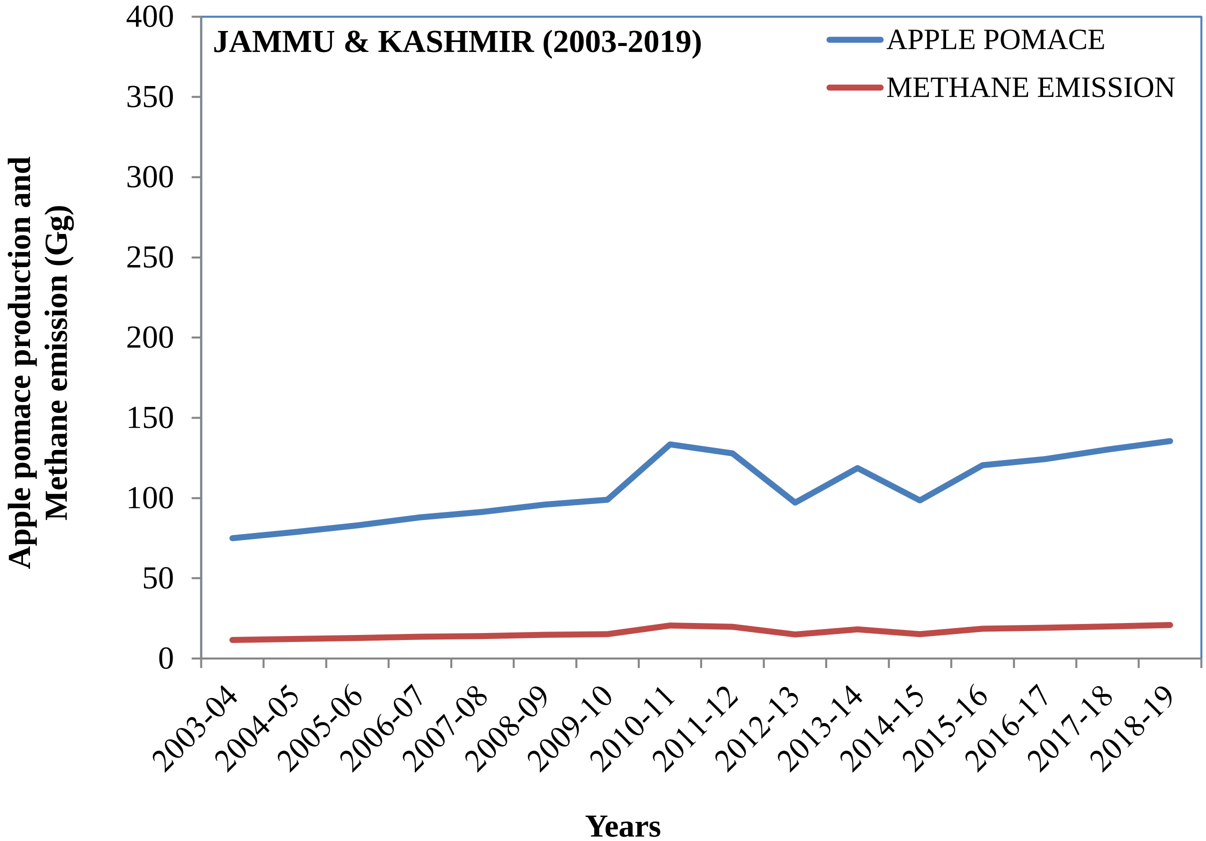

FIG.4.2: Apple pomace production and methane emission in Jammu and Kashmir (2003-2019)

Himachal Pradesh located at 31.1048° N and 77.1734° E being the second largest producer of apples is responsible for production of huge amount of apple pomace. The reason for it might be the HPMC which is one of the largest apple juice producing industries in India as it generates tones of apple pomace. Apple pomace production shows an increasing trend as shown in FIG.4.3. The production of apple pomace increased from 33.08 Gg in 2003 to 33.73 Gg in 2019. In comparison with different states the peak in the apple pomace production indicates increased production. This might be due to appropriate physiographic conditions and climatic conditions of the state (Wani *et al*., 2018). The methane emissions increased from 5.09 Gg in 2003 to 5.85 Gg in 2004, then going up from 6.57 Gg in 2007 to 9.89 Gg in 2010. A slight decrease can be seen in methane emission from 8.91 Gg in 2013 to 5.19 Gg in 2019 as seen in the FIG.4.3.

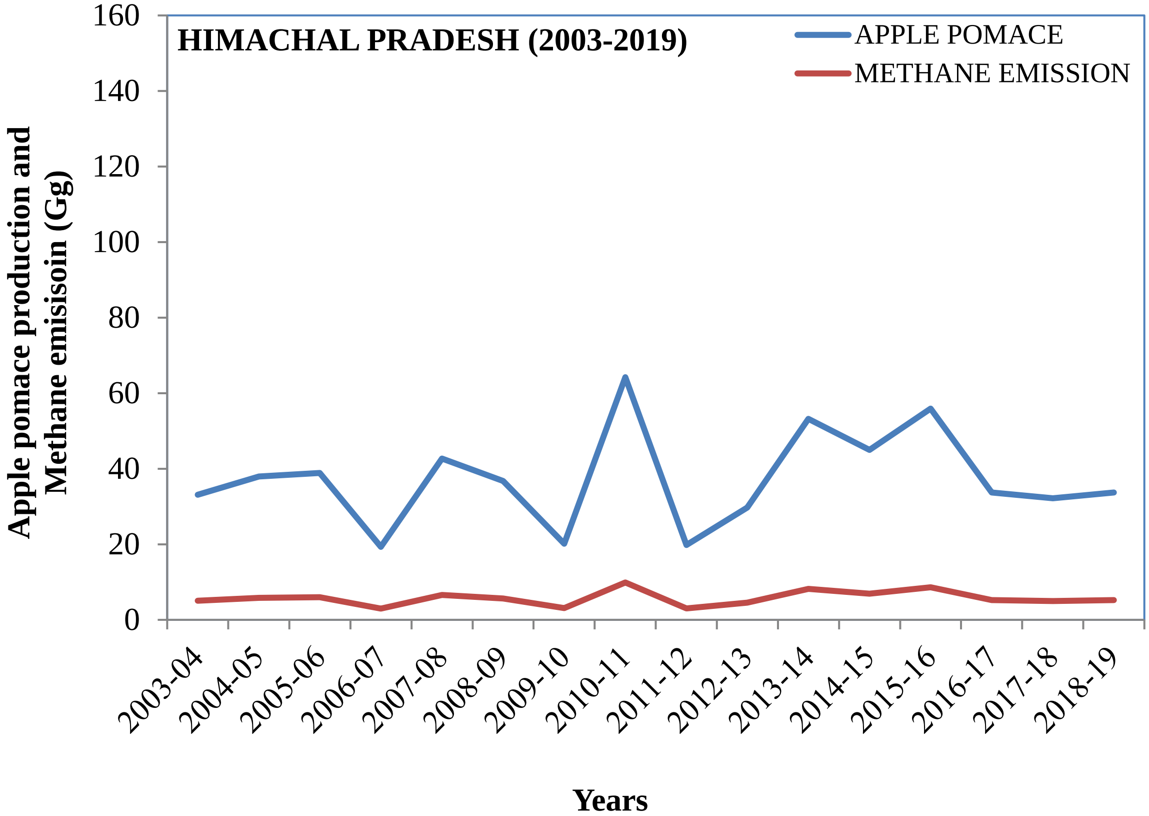

FIG.4.3: Apple pomace production and methane emission in Himachal Pradesh (2003-2019)

Uttarakhand is located at 30.0668° N and 79.0193° E and is the third largest producer of apples. Its apple pomace production has shown a linear trend as seen in the FIG.4.4 from 2003-2019. Apple pomace production has shown an increased trend from 0.81Gg in 2003 to 4.32 Gg in 2019 and this has resulted in increased methane emission form 0.12 Gg in 2003 to 0.66 Gg in 2019. Most of the production of apple pomace is from North western states of India like Jammu and Kashmir, Himachal Pradesh and Uttarakhand (Sikka and Swarup. 1985).

Arunachal Pradesh which is located at 28.2180° N and 94.7278° E is responsible for production of apple pomace in a slight amount when compared to Jammu and Kashmir. But the considerable increase in apple pomace production can be seen from 0.66 Gg in 2003 to 2.304 Gg in 2015 as seen in the FIG.4.5. This resulted in increased methane emission from 0.103 Gg in 2003 to 0.35 Gg in 2015.

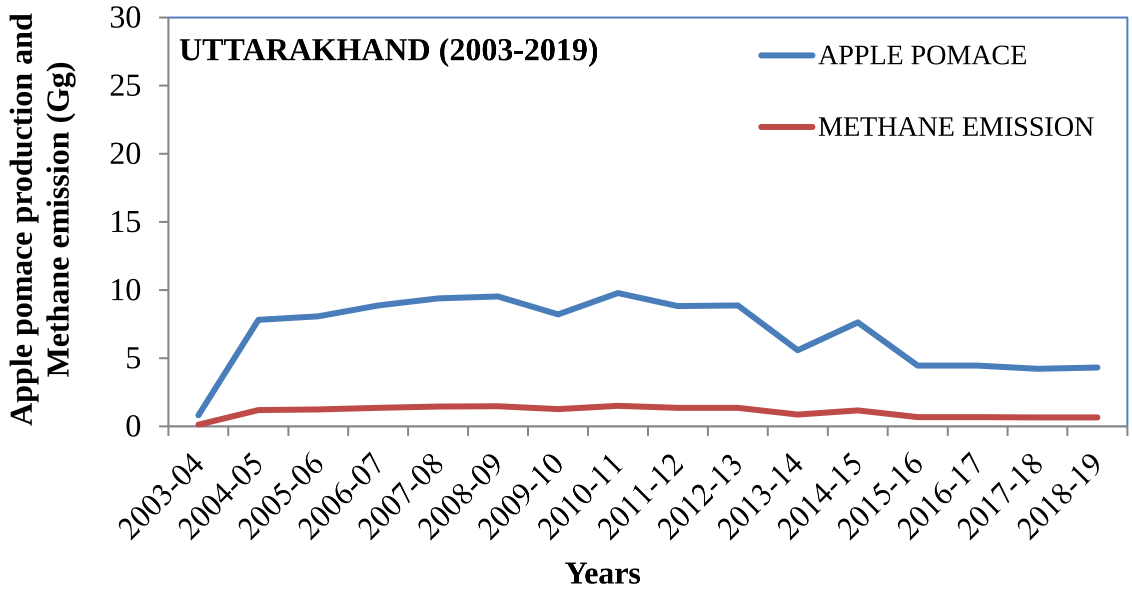

FIG.4.4: Apple pomace production and methane emission in Uttarakhand (2003-2019)

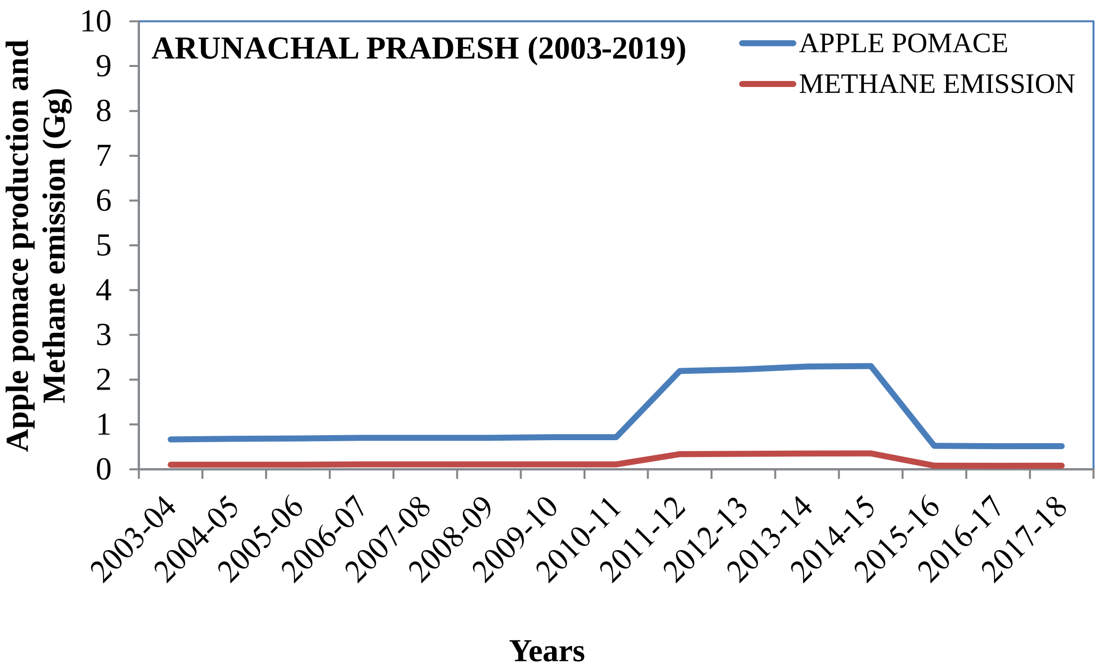

FIG.4.5: Apple pomace production and methane emission in Arunachal Pradesh (2003-2018)

Nagaland is located at 26.1584° N and 94.5624° E and is home to variety of tribes and is situated at far North eastern boundary of India adjoining Myanmar. It produces apple in considerable amount. The production of apple pomace showed a huge increase from 0.0014 Gg in 2003 to 0.136 Gg in 2013 and it further increased to 0.14 Gg in 2018 as seen in FIG.4.6. The methane emissions showed a similar trend with 0.00021 Gg in 2005 to 0.21 Gg in 2018.

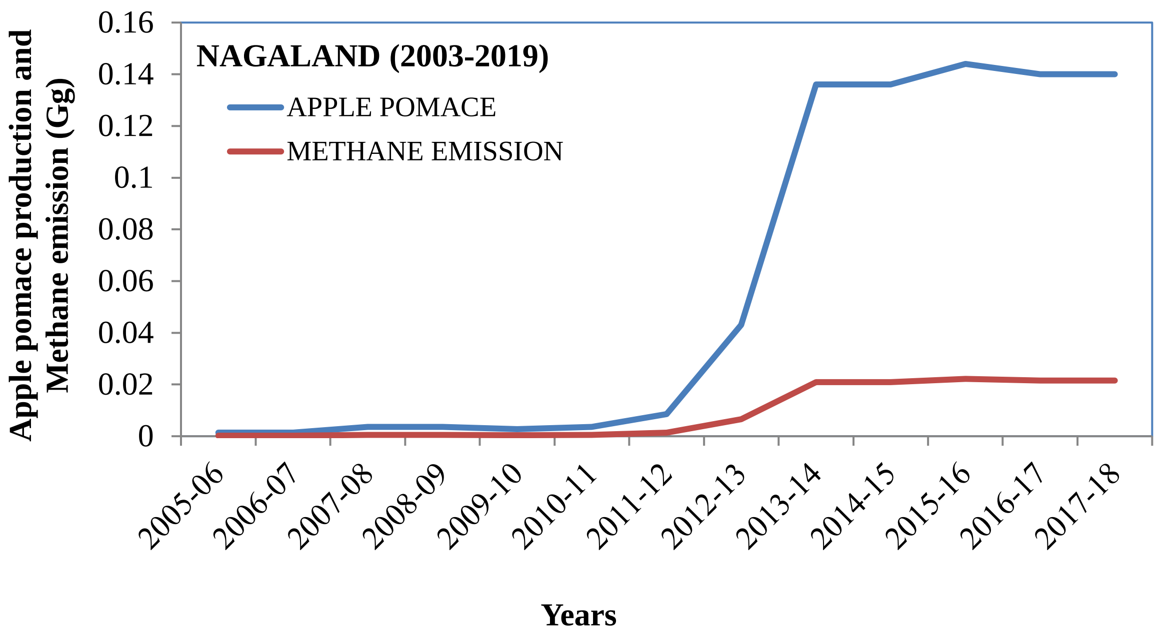

FIG.4.6: Apple pomace production and methane emission in Nagaland (2005-2018)

When year wise comparison of methane emission of all the five states was done it was seen that Jammu and Kashmir (261.235 Gg) has maximum methane potential, followed by Himachal Pradesh (91.813 Gg) and Uttarakhand (17.07 Gg). The variation of methane emissions for the period 2003- 2019 is shown in the FIG.4.7. Due to increasing food availability, the apple production has increased. This has resulted in increased apple pomace production and this increased apple pomace production has resulted in increased methane emissions. Since we have considered only apple pomace, the estimated methane emission should be taken into account as it is directly responsible for heat entrapment and climate change.

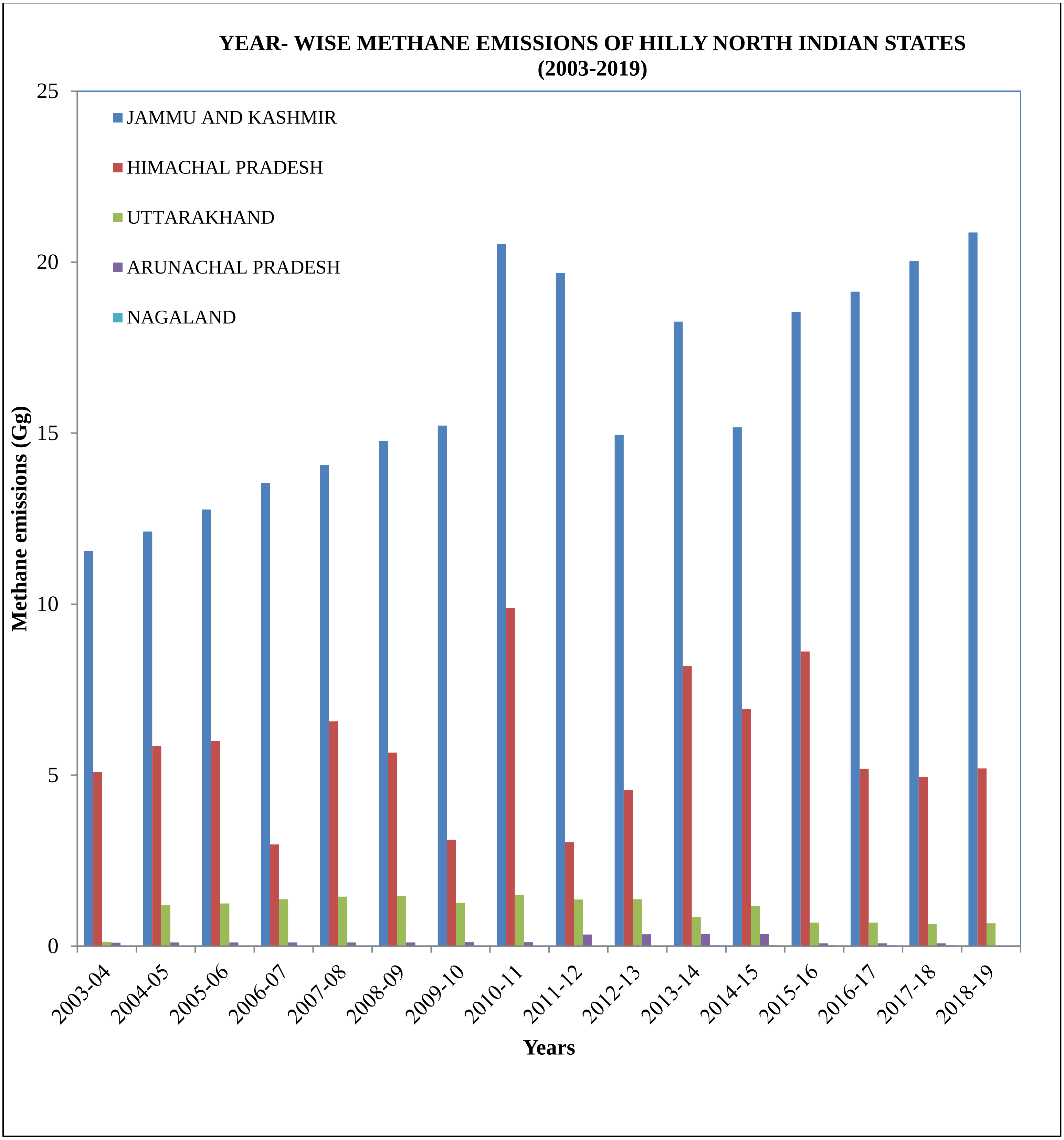

FIG.4.7: Year wise methane emission of hilly North Indian states from apple pomace (2003-2019)

In 2018-19, China produced 29, 52, 000 metric tons of apple pomace (Lyu *et al*., 2020). According to Lyu *et al*., 2020, 65.4% apples are produced in Asia. China is the leading producer of apples, followed by United States, Turkey, India, and Russia and so on. 20 different countries with leading producer of apple were considered from 2010-2020. The calculation of apple pomace of a decade shows China as the leading producer of apple pomace with 29619.936 Gg, followed by United States 3665.59 Gg, Turkey 2435.45 Gg, and India 1848.44 Gg as seen in Table 3.3.1 and 3.3.2. A comparison of cumulative methane emissions from all the 20 countries starting from 2010 to 2020 was done using eq. (2). It is seen the China has the maximum methane emission potential (4561.47 Gg), followed by United States (564.50 Gg), Turkey (375.059 Gg) and India (284.65 Gg) and so on as seen in Table 4.2. The comparison between the top 10 major apple producing countries shows China (4561.47 Gg) with highest methane emission potential, United States (564.50 Gg), Turkey (375.059 Gg), India (284.65 Gg), Russia (168.89 Gg), Ukraine (150.60 Gg), Brazil (151.87 Gg), Chile (157.56 Gg), South Africa (107.10 Gg) and Japan (92.50 Gg) as seen in FIG.4.8. Similarly, the other ten countries were compared for their methane emission potential as seen in FIG.4.9. It is seen that Argentina (82.82736 Gg) has highest methane potential followed by Mexico (81.363898 Gg), New Zealand (65.5723684 Gg), Belarus (61.0714104 Gg), Moldova (56.49644 Gg), Serbia (48.308414 Gg), Canada (45.3950112 Gg), Australia (34.7654076 Gg), Azerbaijan (31.6173704 Gg) and Kazakhstan (21.6547408 Gg).

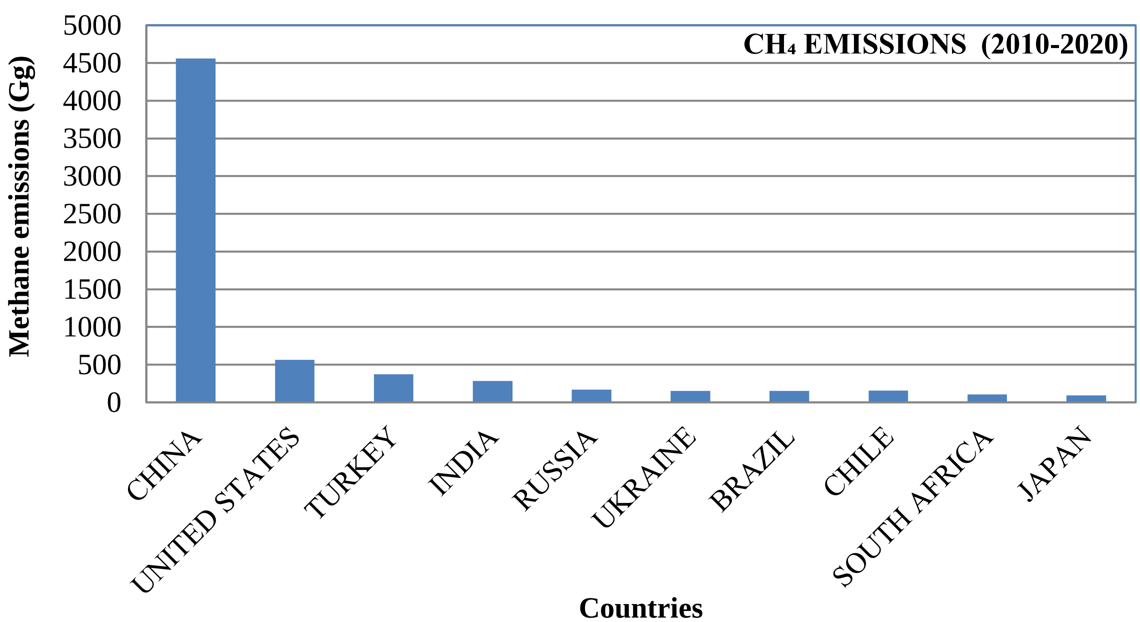

FIG.4.8: Methane emission of top 10 apple producing countries (2010-2020)

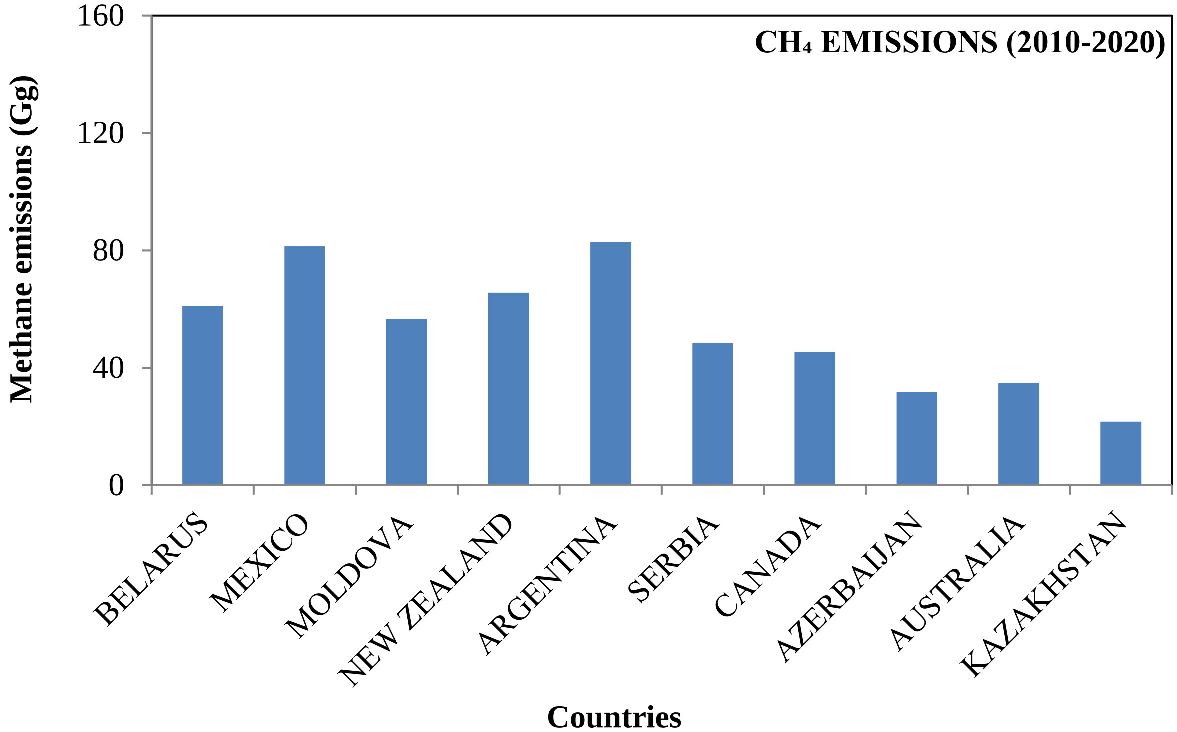

FIG.4.9: Methane emission of different countries (2010-2020)

4.4 ESTIMATION OF GLOBAL WARMING POTENTIAL AND ENERGY POTENTIAL

GWP of different hilly North Indian states shows a linear approach and increasing trend i.e. it increases with increase in production of apple pomace and passage of time. The GWP has increased from 541.206 Gg in 2003 to 1028.16 Gg in 2010. After some slight decrease in 2011, it again increased from 681.48 Gg in 2012 to 857.71 Gg in 2018-19 as shown in the FIG.4.10. In addition to this, GWP of different states was found out from 2003-2019. It showed Jammu and Kashmir has maximum global warming potential which is 8385.48 Gg. It was followed by Himachal Pradesh with 2947.1 Gg of GWP and Uttarakhand with 547.95 Gg of GWP. On the other hand, Arunachal Pradesh showed 79.93 Gg of GWP. Since, the production of apple pomace is increasing day by day it results in increasing open disposal resulting in emission of huge amount of methane and carbon dioxide which are greenhouse gases. All these emissions results in increase of global warming potential and cause climate change.

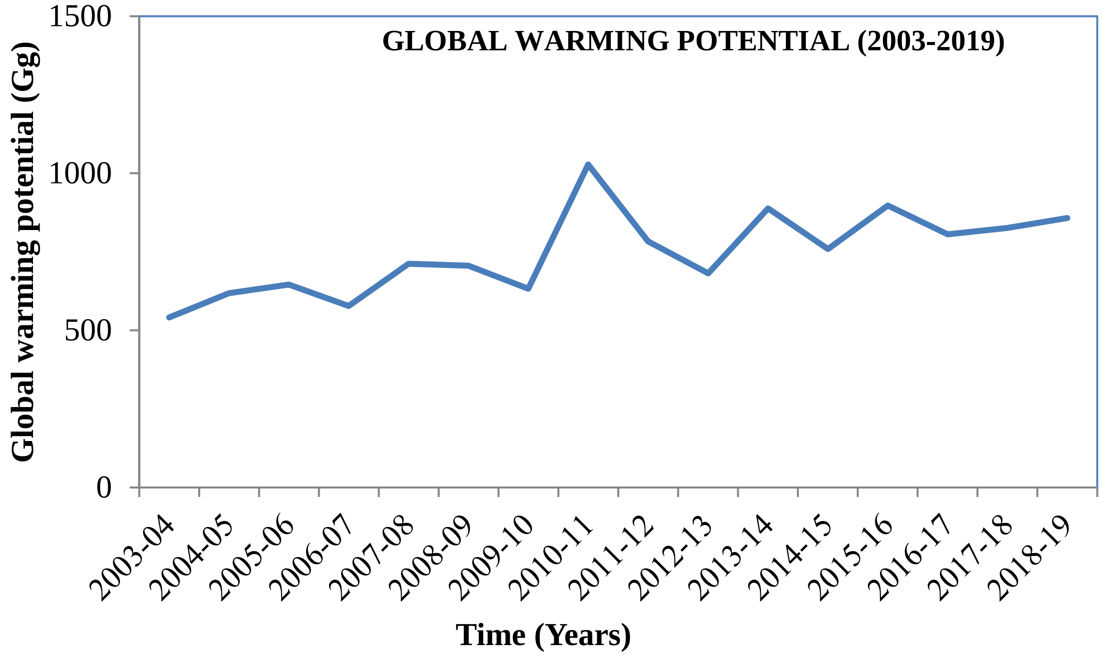

FIG.4.10: Global warming potential of India from apple pomace (2003-2019)

Methane emission is directly related to GWP. A country wise relation between methane emissions and GWP is shown in Table 4.2 which indicates direct relation between both the parameters.

Table4.2. Methane emission (Gg) and Global warming potential CO_2-eq (Gg) of different countries from 2010-2020

S.No.	COUNTRY	CH_4 emission (Gg)	GWP CO_2-eq (Gg)
1	CHINA	4561.470144	146423.1916
2	UNITED STATES	564.501784	18120.50727
3	TURKEY	375.0594417	12039.40808
4	INDIA	284.6598832	9137.582251
5	RUSSIA	168.897036	5421.594856
6	UKRAINE	150.600604	4834.279388
7	BRAZIL	151.878958	4875.314552
8	CHILE	157.56048	5057.691408

9	SOUTH AFRICA	107.1051951	3438.076763
10	JAPAN	92.50934	2969.549814
11	BELARUS	61.0714104	1960.392274
12	MEXICO	81.363898	2611.781126
13	MOLDOVA	56.49644	1813.535724
14	NEW ZEALAND	65.5723684	2104.873026
15	ARGENTINA	82.82736	2658.758256
16	SERBIA	48.308414	1550.700089
17	CANADA	45.3950112	1457.17986
18	AZERBAIJAN	31.6173704	1014.91759
19	AUSTRALIA	34.7654076	1115.969584
20	KAZAKHSTAN	21.6547408	695.1171797

GWP comparison between top 10 apple producing countries showed China with maximum GWP i.e. 146423.19 Gg, followed by United States (18120.50 Gg), and Turkey (12039.40 Gg) as shown in the FIG.4.11.

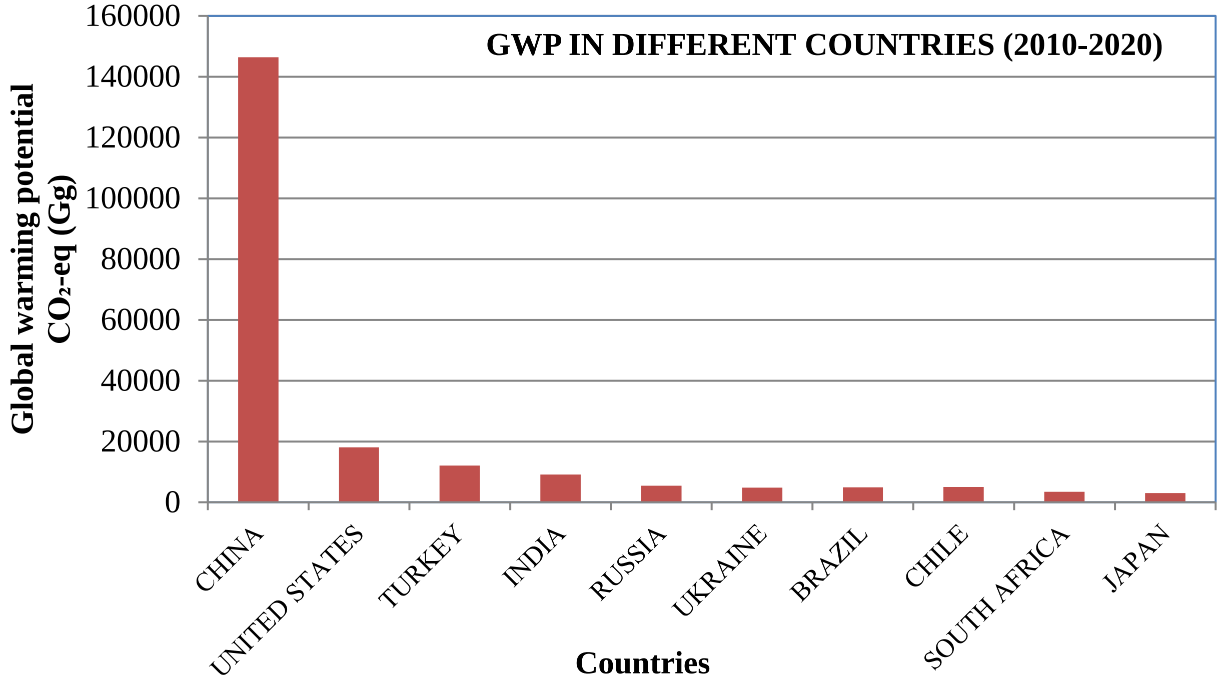

FIG.4.11: Global warming potential of top 10 apple producing countries (2010-2020)

Similarly, comparison between other 10 countries showed Argentina with maximum GWP i.e. 2658.75 Gg, followed by Mexico (2611.78 Gg), and New Zealand (2104.87 Gg) as shown in the FIG.4.12.

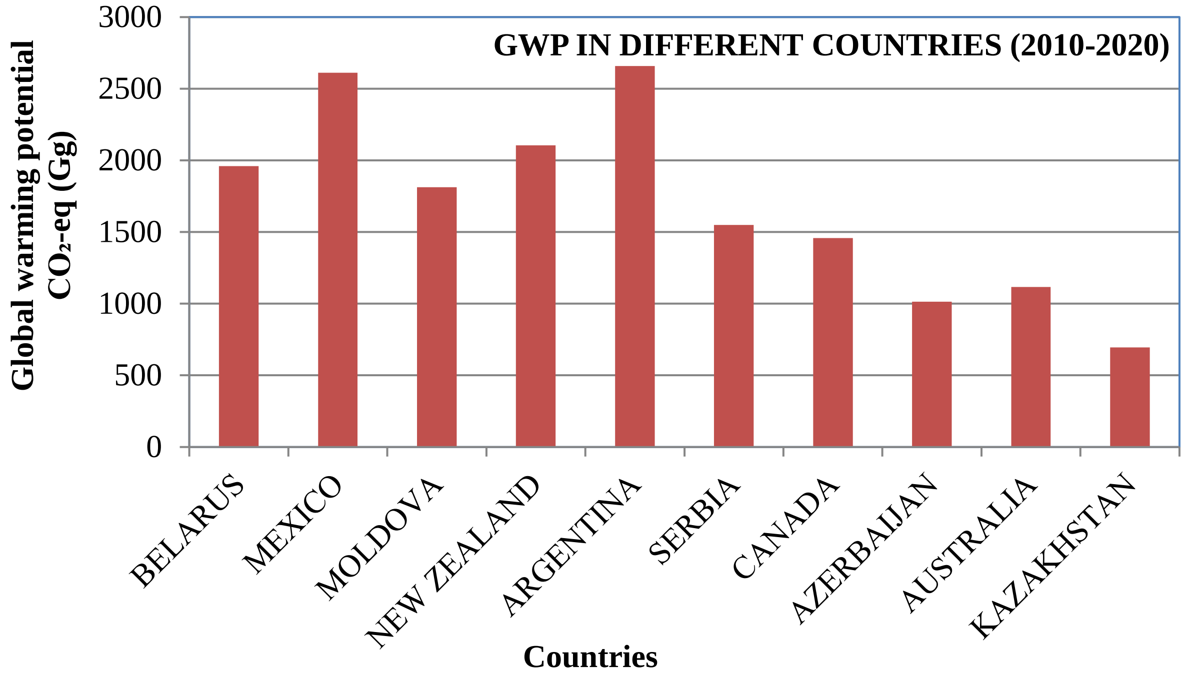

FIG.4.12: Global warming potential of different countries (2010-2020)

The calculation of energy potential with regard to Indian states is shown in Table 4.3. The gross calorific value of methane was taken to be 55.4 MJ/Kg. The total emission of states from 2003-2019 was taken and results indicated Jammu and Kashmir has the maximum energy potential i.e. 14472419000 MJ/Kg, followed by Himachal Pradesh 5086440200 MJ/Kg, and Uttarakhand 945678000 MJ/Kg.

Table4.3: Energy potential (MJ/Kg) of different North Indian states from 2003-2019

S.No.	STATES	ENERGY POTENTIAL (MJ/Kg)
1.	JAMMU AND KASHMIR	14472419000
2.	HIMACHAL PRADESH	5086440200
3.	UTTARAKHAND	945678000
4.	ARUNACHAL PRADESH	137946000

5.	NAGALAND	6094000

In this study each parameter was taken appropriately and was verified through research papers. But since there is no available data regarding production of apple pomace data and it is considered using mass flow of components, there might be some uncertainties in apple pomace production and estimates. This is the limitation of our study. A study by Du.*et al*., 2017 states that uncertainties associated with parameters can have an influence on outcomes i.e. 20% uncertainty in outcomes can be result of 10% uncertainty in parameters. Along with it, other methods along with IPCC DM should be considered for comparison between methane estimation to get a complete view of methane emission estimation from apple pomace.

The analysis of energy potential from apple pomace shows huge potential in energy production from apple pomace which is win–win situation for both environmentalists and investors. Therefore, we can say that the improper dumping of apple pomace outside industries can lead to its bio-degradation resulting in methane emissions as depicted in this chapter. These emissions are ultimately responsible for trapping the heat and increasing the global warming potential. While tabulating the energy potential of different states it was quite visible that apple pomace has got a huge potential in energy production and its proper recovery and use can act as a boon for renewable energy generation. The capturing of methane can applied to landfill sites and converted to energy which can be used as fuel for engines, turbines etc. It can be captured and refined for its usage in vehicles or gas pipelines. Other uses include production of biogas which is known as cleaner alternate for production of energy. On the other hand, it is important to note that open dumping is harmful in terms of methane emission, pollution of the land, air and groundwater. That’s why rather than dumping the apple waste outside it should be utilized.

CHAPTER- 5

CONCLUSION

This study reports the methane, global warming and energy potential of apple pomace in India for the period 2003- 2019 and 20 different countries for the period of 2010-2020. The result analysis showed dumping of apple pomace in waste dumps is responsible for GHG emissions in absence of proper LFG management system. Apple juice is widely consumed by people all over India but it's by product i.e. apple pomace comes under waste material. If is utilized to its full potential it can be converted to gold. Apple pomace has huge potential and can be used in the production of enzymes, aroma compounds, apple seed oil, ethanol, organic acids, hetero polysaccharides, mushroom, biopolymers, baker's yeast, pectins, fiber extracts, pigments and xyloglucan. Therefore, instead of throwing away a valuable resource with huge potential it should be recycled and reused.

If it is thrown away in waste dumps it must be utilized with proper LFG collection system. There is huge potential if energy recovery is done from landfill as it will help in reduction of GHG and help in increasing revenue which is beneficial for all of us. There are multiple benefits of LFG capture. LFG can be converted to energy and used as fuel for engines, turbines which can further produce electricity. It can also be used as an alternative in equipments like heaters, boilers etc or in the form of biogas. The biogas production application is thoughtful not only from the view that apple pomace is a low cost substrate, but also because it might help in decreasing problems related to the disposal of pomace which is responsible for producing a huge amount of pollution in states producing apples.

It is significant to inquire about endeavors going all over the world since collaborative innovation can be incredibly productive. Using the method of recycling and reusing of these wastes can help us in achieving quest for development of renewable energy.

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