*23rd Cambridge International Manufacturing Symposium*
*University of Cambridge, 26 – 27 September 2019*

# Environmental Impact Assessment and Supply Chain Mapping of Kinnow Fruit Production – A Case Study of Punjab, India

Vikrant Bhakar *, Harpreet Singh, Kiranjot Kaur

Indian Institute of Technology (Ropar), Rupnagar, India

*vikrant.bhakar@iitrpr.ac.in, harpreetsingh@iitrpr.ac.in, kiranjot.kaur@iitrpr.ac.in

## Abstract

The Indian agriculture sector consumes 80 % of the freshwater available in the country. India with more than 18 % of world population has only 4 % of the world's freshwater. The unsustainable agricultural practices have led to deplete the precious natural resource - water, which is an essential element for livelihoods. An effective decision making to save this natural resource, its assessment in the context of crops, vegetables, and fruits is dire need. This paper attempts to address a small part of assessment and support decision making with an aim to assess the environmental impact of kinnow fruit product in a comparison of irrigation methods. The study also attempted to make the initial map of the supply chain. To carry out the environmental impact assessment a simple Life Cycle Analysis (LCA) approach has been used. To map the supply chain a sector mapping method has been utilized. The LCA analysis helped in visualizing the major hotspots during the kinnow fruit farming, distribution and use. To map the supply chain of kinnow, information on various stakeholders are collected and mapped across the value addition phase. The study can help the policy makers and stakeholders involved in the kinnow supply chain process, to take preventive measures in policy formation. The study can serve as a basis for replication of the approach for other crops.

Keywords: Irrigation; Supply Chain Mapping; Water Use; Life Cycle Analysis; Technological Interventions

## 1. Introduction

India is the second highest in vegetables and fruits production globally, after China. A total of $6.5*10^6$ metric tonnes of fruits and $97.35*10^6$ metric tonne of vegetables was produced in the year 2017-18 (Government of India, 2018). With a continuous growth of population an increase in demand for fresh fruits and vegetables is necessitated. In this context, high pressure has been imposed on the supply actors of the green grocery. These actors involve both producers and processors. Huge differences persist between the quantity of food produced in 2010 and the quantitative requirement necessary to meet demand in 2050 estimates. In the year 2050, 56 % more crop calories will be required to cater the demand of population. We see that the difference between agronomic land area in 2010 and the area that will be essential in 2050, an estimated gap to be 593 million hectares, astonishingly an area almost twice the size of India (World Bank, 2019). According to the Paris agreement, environment impact analysis, 11 Gigatons of greenhouse (GHG) mitigation gap could be seen in 2050 (World Bank, 2019). Need for ensuring adequate food with high nutrition value to an exponentially growing population and the requisite for fresh fruits and vegetables is a serious issue. In this context, tremendous pressure has been imposed on the supply actors of the green grocery. With India having the potential of self-sufficiency and export potential, there are tremendous losses and low competitiveness. More than half of India's population is dependent upon agriculture for its livelihood and contributes only 18 % to India's GDP. To increase the shelf life of food products, maintaining the food nutrients, and to provide fortified products using forward and backward linkages through supply chain mapping and environmental impact of these activities are the need of the hour. 10 % of the total area under all fruit crops in India is occupied by citrus fruits and kinnow has a huge potential in it. Punjab is the leading producer in sub tropics containing total area under vegetable and fruits as 258500 hectare (ha) and the production from this area was estimated to be 5136000 tonnes. This contribution of Punjab is 34.1 % (i.e. one - third) to India's central pool contribution, out of which kinnow has a significant share of 29 %. Thus, the significant share contribution makes kinnow a potential candidate for our study. In Punjab top kinnow producing district is Fazilka, with a production of 734962.40 MT (Metric tonne) as per Punjab state 2018-2019 report (as shown in Figure 1).
The problems concerning the marketing of fruits and vegetables can be outlined to their perishability. Perishability is accountable for high marketing prices, market gluts, price fluctuations, and other analogous problems. Moreover, there is a necessity for substantial increase in the production of fruits and vegetables but production per hectare is appreciably low.

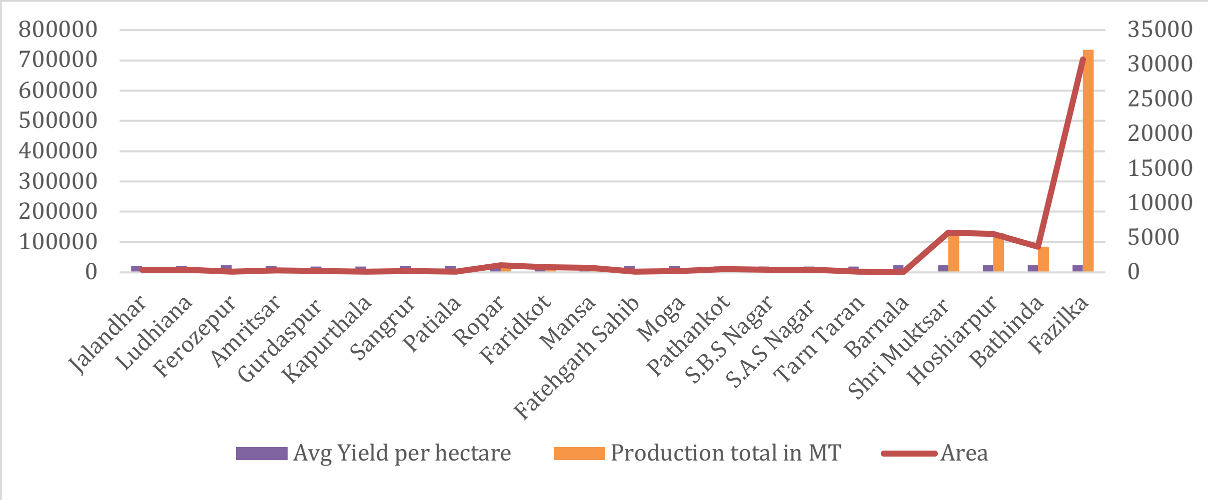


**Figure 1**. Graphical representation kinnow production in Punjab state district wise (2018-2019).

This phenomenon is triggered due to numerous factors, but solution lies only with economic and technological approaches contributing to lead the race. Making the producers aware of the latest technologies, assist them by providing support to obtain these technologies and proper supply chain management. This would help to prevent exploitation of farmers by increasing their income (Khandelwal et al., 2019). Considering the potential for profitability and export, organized export is yet to be established, although agro-ecological sub-tropical environment of India is conducive to the production of kinnows. It is learnt form the literature that, food losses contributing 30-40 % could be appreciably looked into for improving profitability (Khandelwal et al., 2019). Scarcities of Cold Storage facilities and transport with built in refrigeration system is hotspot in supply chain causing incompetency in handling perishables which manifest it into wastage.

## 2. Literature review

Kinnow Mandarin fruits containing kinnow, Sweet Orange, Lime and Lemon have a significant commercial value in Punjab. Production of kinnow was ranked first with respect to area as it is the prime fruits of the state and this production is followed up by sweet oranges, limes and lemons. The district of Hoshiarpur, Fazilka, Faridkot, and Ferozepur share over 50 % of the area under kinnow fruit in the state (as shown in Figure 1). The 'Kinnow' belongs to a high yielding Mandarin group composed of hybrid of two citrus species of Citrus nobilis Lour and C. deliciosa Tenora requiring for its productive maturing. Kinnow is commercially cultivated due to its good yield, high processing quality, fresh consumption, aromatic flavour, and better adaptation to agrarian environmental conditions existing in Punjab (Ahmed et al., 2006). However, kinnow production faces a number of problems during its production as the shelf life of kinnow is only a few days. Lack of storage facilities such as reefer trucks, precooling facilities and cold storage has become a major setback. Improved technological intervention for payment settlement mechanism and creating forward and backward linkages are the need of the hour. It was seen that kinnow pulp deteriorates due to high moisture and sugar content (Singla et al., 2006). Low yields are observed which are due to the fact that there is a decrement of fruit at various stages during its development, due to malnutrition, water stress, undue insect pest attack and most significant is the hormonal imbalance. Tree drops its fruit after the concentration of auxins declines and the concentration of abscisic acid rises (Azher et al., 2006). The waste from kinnow comprises of pulp residue, peel, and seed accounting almost 50 % of the whole fruit mass. Kinnow fruits are a rich source of vitamin C (ascorbic acid) and polyphenols (such as hesperidin naringin and Limonin), which have anti-inflammatory and anticancer activity. So Industrial processing of kinnow into juice has a huge potential providing multi dollar economical job and health output.

There are numerous possible methods of irrigation such as flood irrigation, drip irrigation, surface irrigation, centre pivot Irrigation, lateral move Irrigation system, sprinkler irrigation system, and manual irrigation. But Irrigation methods commonly used in kinnow farming are flood irrigation and drip irrigation. In Punjab region it is observed that almost 80 % is flood irrigation and 20 % is drip irrigation. This is due to the availability of both surface and groundwater in Punjab.

The environmental impact assessment of kinnow fruit production may lead to reduce the resource consumption and effective decision making. However, no such studies are found for Punjab region of India. The spoilage content at different levels of supply chain needs to be considered carefully, so studying it for stage-by-stage spoilage from the farmer to the retailer will be useful. Moreover, to improve the overall supply chain effectiveness, it is necessary to assess it. The next section of the study defines the research methodology used for the current study.

## 3. Materials and methods

The study utilizes a combined approach of literature research, empirical data collection, and life cycle analysis (LCA). Sustainability assessment canopy includes tools such as LCA that is applied to compute environmental impact values using GaBi and Eco-invent data dataset v3.0. This approach could be applied to a wider range of decisions throughout the globe empowering international as well as national policies, strategic plans, important trade treaties, at different levels from nano to macro level. There are identified synergies and trade-offs among the divergent sustainability scopes. Its subjective and ambiguous social, economic and ecological parameters are used in organizing the sustainability indicators. Although this approach is inclusive of organising sustainability assessment standards, unfortunately it does not integrate and deal with cross-pillar issues (Gibson et al., 2005). The supply chain analysis has been done using sector mapping approach and using software tool Microsoft Visio in three stages.

### *3.1. Kinnow supply chain mapping*

- The first stage comprised of institutional players and secondary stakeholders such as government agencies of India including Food Safety and Standards Authority of India (FSSAI), Agricultural and Processed Food Products Export Development Authority (APEDA), Ministry of Agriculture and farmer welfare (MOA), and National Bank for Agriculture and Rural Development (NABARD) These stakeholders are the key active actors in the supply chain contributing to high level of vertical integration in India (as shown in Figure 2 below).

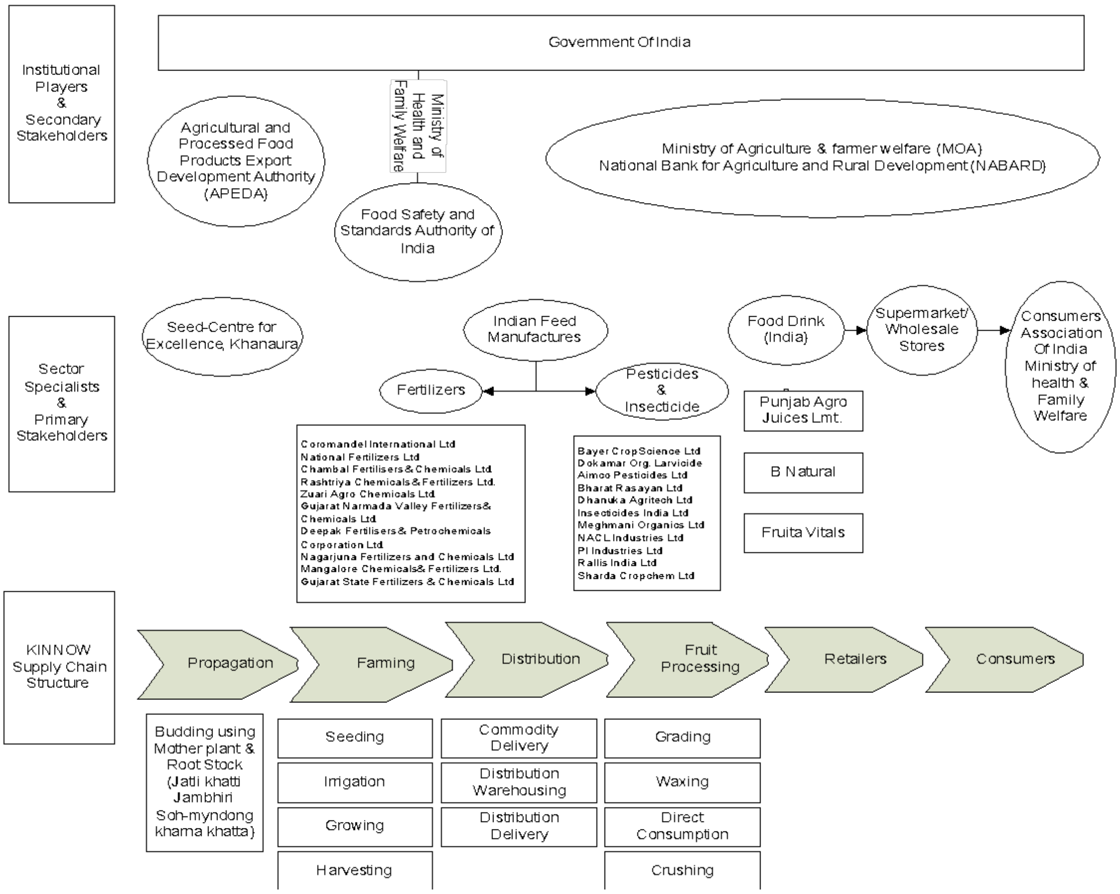


**Figure 2**. The current supply chain mapping of kinnow fruit production in India

- The second stage comprised sector specialists and primary stakeholders, which show the structural contribution from farm to shelf of the customer. To evaluate this a surveillance study was conducted at Centre of Excellence, Khanaura using hybrid of mother plant (Jatti Khatti) and wild plant root stock. Indian feed manufactures are contributing to fertilizers, pesticides and insecticides. Out of these few popular fertilizer manufacturers are Coromandel International Limited, National Fertilizers Limited, Chambal Fertilisers & Chemicals Limited, Rashtriya Chemicals & Fertilizers Limited, Zuari Agro Chemicals Limited, etc. or fertilizers. For fertilizers and chemicals associated names are Bayer Crop Science Limited, Aimco Pesticides Limited, Bharat Rasayan Limited, Insecticides India Limited, NACL Industries Limited etc.

- The supply chain (third stage) consists of key holders for kinnow supply chain structured by horizontal movement from propagation, farming, distribution, fruit processing and retail presenting high level of integration between the actors in the chain. Farming comprises of activities from seeding to procurement with inputs during seeding phase, followed by plucking the fruits from orchards manually or with the help of the plucker. It is then processed in pack houses which includes grading, sorting, and packing respectively. Grading is done according to the size (i.e. 45, 54, 60, 72, 84 in cm) as circular diameter. Generally smaller sizes are sent for juice making and bigger sizes are sent for retail purposes. Sometimes precooling and cold storage is done for increasing the shelf life of the fruits providing it more longevity.

### *3.2. Life cycle analysis*

This analysis requires inputs such as water requirement and energy inputs to accomplish the journey of the fruits from farm to shelf including identification of the hotspots which is the primary objectives of our study. Life cycle analysis of kinnow fruit from farm to fork was done by considering both solar and solar with diesel-based irrigation. This assessment is to integrated both quantitative and qualitative data in a single structural unit by visualizing the major hotspots during the kinnow fruit sorting, grading, waxing, distribution to retail and customer use.
LCA is defined as the "compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle" (Kuppel et al., 2005). This scientific technique is commonly used for evaluating the environmental burdens of products, process, and systems (Bhakar, 2015). It is widely used for assessing environmental impacts of various products – HDPE pipes (Sangwan, 2017); packaging (Baruffaldi, 2019), training process (Bhakar, 2013), etc. According to the ISO 14040 (Finkheiner, 2016) series standards, LCA framework consists of four steps: goal and scope definition, life cycle inventory analysis, impact assessment, and results interpretation.

a) Goal and scope definition

The aim of the study is to assess the environmental impacts of one tonne kinnow production in the Punjab region. The functional unit of the study is one tonne kinnow production using solar powered irrigation combined with diesel for backup.

b) Inventory analysis

To carry out the inventory analysis offline survey has been carried out among the kinnow farmers. The data was collected from the farmers and secondary data obtained from eco-invent dataset and literature studies. Both primary and secondary data were then compiled to evaluate for inventory analysis. The outcome obtained of inventory analysis data of energy and material consumption was then used to model the LCA using GaBi software and eco-invent v3.0 dataset. Majorly it is observed that the average water requirement of kinnow fruit is about 55 litres/plant, but in peak summers it goes up to 85 litres/plant. The inventory analysis data are listed in Table 1.

**Table 1**. Life cycle inventory analysis for one tonne kinnow production.

| Experiment | Value | Per Tonne Kinnow |
|---|---|---|
| Fruit wastage | 13.88889 | Kg |
| Total plants | 9.722222 | Units |
| Water requirement | 2.314833 | M3 |
| Diesel with solar power | 0.886111 | Litre |
| Diesel without solar power | 1.825769 | Litre |
| Intercropping earning/hectare | 16666.67 | INR |
| Kinnow earning/hectare | 1111.111 | INR |
| Market distance | 10 | Km |
| Solar pumps | 0.041667 | kWh |
| Total productivity of kinnow | 40000 | per hectare |
| Total kinnow from 9 hectare | 360 | Tonne |
| Flood irrigation | 20 | % |
| Drip irrigation | 80 | % |
| **Pesticides** | | |
| Ameda confidor | 9.722222 | gm/tonne |
| Ektara | 9.722222 | gm/tonne |
| Ethion | 0.055556 | Litre/tonne |
| Trizofoss | 0.069444 | Litre/tonne |
| **Fungicide** | | |
| Blue copper | 0.055556 | Litre |

| Experiment | Value | Per Tonne Kinnow |
|---|---|---|
| **Fertilizers** | | |
| Urea | 388.8889 | gm/tonne |
| Zinc sulphate | 243.0556 | gm/tonne |
| Potassium sulphate | 534.7222 | gm/tonne |

### *3.3. Impact assessment*

The environmental impact assessment is carried out using the well-known ReCiPe method. Both midpoint as well as endpoint assessment have been carried out in different environmental impact and damage categories. The midpoint assessment for one tonne kinnow production is carried out in 11 categories. Table 2 shows the environmental impacts measured in midpoint assessment method. To maintain the brevity and page limitation only quantitative values of environmental impacts for midpoint assessment are given in the manuscript.

**Table 1**. Midpoint assessment results for one tonne kinnow production.

| Midpoint assessment category | Unit | Total | With Solar | Without Solar |
|---|---|---|---|---|
| Climate change | kg CO2 eq. | 29.6 | 14.7 | 14.7 |
| Fine particulate matter formation | kg PM2.5 eq. | 0.0508 | 0.0251 | 0.0251 |
| Fossil depletion | kg oil eq. | 79.2 | 39.2 | 39.2 |
| Freshwater consumption | $m^3$ | 4.71 | 2.36 | 2.36 |
| Freshwater eutrophication | kg P eq. | 4.37E-05 | 2.17E-05 | 2.17E-05 |
| Human toxicity, cancer | kg 1,4-DB eq. | 7.49 | 3.7 | 3.7 |
| Ionizing radiation | Bq C-60 eq. to air | 0.495 | 0.247 | 0.247 |
| Land use | Annual crop eq.·y | 1.62 | 0.81 | 0.81 |
| Marine eutrophication | kg N eq. | 0.000532 | 0.000265 | 0.000265 |
| Metal depletion | kg Cu eq. | 0.202 | 0.101 | 0.101 |
| Photochemical ozone formation, ecosystems | kg NOx eq. | 28.3 | 14 | 14 |

## 4. Government initiatives and practical implication

Formulation of policies by government influence kinnow fruit production. Punjab being the agrarian land has kinnow production of 1208423 metric tonne (MT) on the area of 53045 hectare, which yielded about 23505 Kgs/hectare. Obviously, such an important crop requires policies inclined to agricultural aspects such as agricultural farming, production, processing and retail distribution besides the financing until it reaches for the consumption of customers. There are several departments responsibly working at both State and Central Government level. In this era of globalization, the decisions taken and the choices made are mutually reinforcing which can be tremendously productive. For its profitability, Indian government has started initiatives to bridge this wide gap by inducting many National schemes such as Model Agriculture Produce Market Committee Act (APMC), which formulated liberalized market for the agriculturalists through commission agents at the local market (mandi) at wholesale rates (Khandelwal et al., 2019). Government has accorded high significance to promote cold chains by reassuring major initiatives such as foreign equal participation of 51 % granted for the cold chain project and there is no limit on establish cold storage or import of equipment for cold storages in India. (Viswanadham, 2006) The idea of Agri Export Zone [AEZ(s)], food parks, and human resources development have been introduced in Punjab and Andhra Pradesh in India (Dev and Rao, 2006). The main role of AEZ(s) is to focus on an agriculture produce in area under consideration with an aim to develop and source resources, the processing of product, its packaging, and in the end export (Viswanadham et al., 2005). Whereas the role of mega food parks is to provide infrastructural support for processing of food products across the supply chain starting from farm to market using transportation facilities, logistics, and central processing centres. The hub and spoke model among many of the government initiatives is commonly practiced by farmers, in this the farmer brings the vegetables and fruits to buying centres without involving any agent in the supply chain, whereas consumers purchase from supermarket or small retailers. The research community has provided supply chain/value chain models to directly connect farmer to consolidation centre, and then the produce (fruits, vegetables, crop, etc.) are transported to organized sector retailers and food processers. In the cold chain, preservation infrastructure, and value addition scheme attempt to connect the farmers with the end consumers. In this context, the study is an attempt to serve as a basis for initializing the supply chain mapping of Indian fruits and vegetables alongside providing value information on environmental impacts of their whole supply chain. These kinds of studies also lead to support the policy makers for developing the effective policy decision for improving the overall value of whole supply chain. These policies will also support in equal distribution of economic benefits among each stakeholders of the supply chain.

## 5. Conclusions

The kinnow fruit is a high value crop, which has a big market share in fruit production as well as in economy generation. The study carried out here is among the initial efforts to visualize the various stakeholders and environmental impact generated due to kinnow production. It is observed that from the beginning of seeding to consumer delivery, each part of kinnow supply chain is energy and water intensive. Particularly the harvesting and storage part are high impacting in almost all the categories. It is also observed that various stakeholders are involved in the kinnow supply chain. Particularly, if we talk about the pesticide and fertilizer manufacturers, the list is long and from the environment perspective – improvement possibilities are on lower side. However, studies like this can provide an initial basis for effective decision making and improving the supply chain effectiveness. The study will provide guidance to various stakeholders involved in the kinnow supply chain for reducing the environmental impact and maximize the profit of the supply chain.

## Acknowledgments

This research has received funding from the Biotechnology and Biological Sciences Research Council (BBSRC) under Reference No. BB/P027970/1, Project Title: "Transforming India's Green Revolution by Research and Empowerment for Sustainable food Supplies".

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