Role of Greenhouses in Sustainable Food Production – A Review

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Abstract— Due to the constant increase of population, globally, there is a severe shortage of food, despite it being produced on a large scale. Methods of food production have been discovered, and are being employed to meet the requirements of the growing population. One of the most popular methods, being used currently is crop production in greenhouses. The fact that crops can be produced apart from their season, owing to an optimum amount of temperature provided for their growth, overcomes the obstacle of growing seasonal plants during just a few months in the year. This increases the annual food production to a significant extent. However, this is beneficial, only if, the greenhouse structure is designed sustainably, overcoming the barrier of high maintenance costs on account of temperature control systems installed for providing a suitable environment. This paper aims to review the study of the role of greenhouses in sustainable food production.

Keywords – environment, food production, greenhouse, population, sustainable.

1. Introduction

World population had reached to 7.3 billion by 2015, and it has been increasing by about 1 billion, since the past 5 years. Global population has increased by many folds in the previous century. Food is an important part of life and the large population, increasing continuously, will be demanding more food in the future. Though agricultural growth has been higher than the rate of population growth, concerns have been raised as to whether the amount produced being sufficient enough to meet the requirements of the current generation. It is also important to ensure that the crops are produced, in a manner that the production contributes to sustainability of the environment. This can be done by use of technology, that ensures provision of an optimum temperatature, and minimum requirement of water and fertilizers. Also ensuring that all the produce is utilized optimally, without any of it getting wasted due to temperature fluctuations, or other climatic conditions like excess humidity, dryness, or wind. Use of technologies, which contribute to this, will definitely ensure that the food is produced sustainably, for the betterment of both, the people as well as the environment, more over, humanity as a whole.

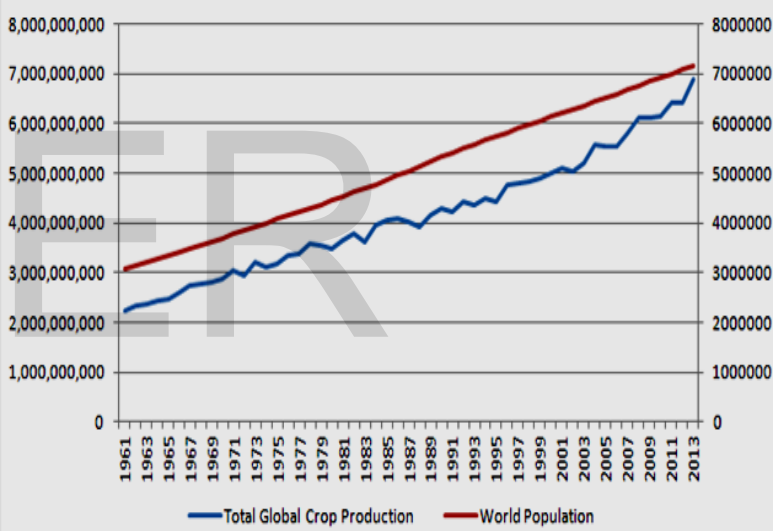

Fig1. Variation of Global Food Production with Population Growth

2. Food Production

2.1 Current Scenario

Growth of population and less food available have become a matter of concern, all over the world. Over the years, the world population has been increasing exponentially while food production has increased only arithmetically, as shown in Fig. 1 below [1]. This means that the amount of food available, per capita has reduced, significantly. This is more noticeable in the case of food like oils, milk, vegetables, fruits whereas it is minimum, in cereals. Apart from this, the population increase has also led to the use of more urban land area for habitation, less availability of land for cultivation and, hence, more requirement of food.

Food production results in change of climate, scarcity of water, degradation of soil and the destruction of biodiversity. It is estimated that 25% of total global greenhouse gas emissions are directly caused by crop and animal production and forestry. The crop and livestock sectors use 70% of freshwater resources and, together with forestry, occupy 60% of the Earth's land surface [2]. The level of environmental impact of food production depends on where and how the food is produced and the local availability of natural resources, like

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water and soil. Mostly, due to trade-offs in environmental factors, there is no simple set of principles to determine if one food product is more environmentally sustainable as compared to the other.

2.2 Sustainable Food Production

Sustainable food production is a method of food production using processes and systems that are non-polluting, conserve non-renewable energy and natural resources, are economically efficient, are safe for workers, communities and consumers, and do not compromise the needs of future generations.

Ensuring a sustainable supply of food for the world's fast growing population is a major challenge. According to forecasts from the United Nations, the world population is estimated to reach 9.7 billion by 2050. This will make the sustainable management of food, energy and water more critical than ever. To maintain current levels of nutrition with this population increase, the Food and Agriculture Organization of the United Nations (FAO), suggests that world food production must increase between 70% — 100% by 2050. The FAO estimates that 90% of this increase in food production must result from intensified cultivation. In particular, irrigated production must increase by 65% over the next 30 years while using only 14% more water. Global food production methods must change to minimize the impact on the environment and support the world's capacity to produce food in the future [3].

Therefore, the resultant need is to increase food productivity by cultivation, all year round. For maximizing production in order to meet the worldwide demand on vegetables, fruits and horticultural crops, it is a must to increase the effective production span of crops. It is evident that a shift to more sustainable and effective methods of food production is imperative to overcome the challenges associated with the increasing population while maintaining a sustainable food supply [4].

The above facts clearly indicate the need of a solution to meet the increase in demand for food. Greenhouse Farming can be an effective solution based on:

(i) its potential for high productivity with reduced water (up to 10 times less) and agrochemicals use per unit of production,

(ii) its production capacity is up to 10 times higher than open field-based agriculture per hectare and

(iii) its high potential for the recycling of water and nutrients.

3. Greenhouse

3.1 Definition

A greenhouse is a structure with walls and roofs made chiefly of transparent material, like glass, in which plants requiring regulated climatic conditions are grown. In order to provide light, greenhouses need to have some way for the light to come in. This is why greenhouses are made of mostly translucent materials, like glass or clear plastic, which gives the plants inside maximum access to sunlight.

3.2 Working Principle

When the light enters in through the glass walls of the greenhouse, it is absorbed by the plants, and ground in the greenhouse, converting it to infrared energy in the process. The darker the surface, the more energy it can absorb and turn into heat. This is why black pavement, present in the greenhouse gets really hot in the summer, as it absorbs heat.

The sun's radiation incident on the greenhouse is both, direct as well as indirect. Light in the form of direct radiation enters the greenhouse, part of which having short wavelength is trapped inside, and the part having longer wavelength is stored inside, as well, thereby creating a climate suitable for higher crop productivity. On the other hand, the indirect radiation in the form of associated diffuse sky-radiation, reaches the surface of the absorber, by passing through Fresnel lenses. The change in wavelength of these radiations, ensures that heat is prevented from escaping the glass walls of the green

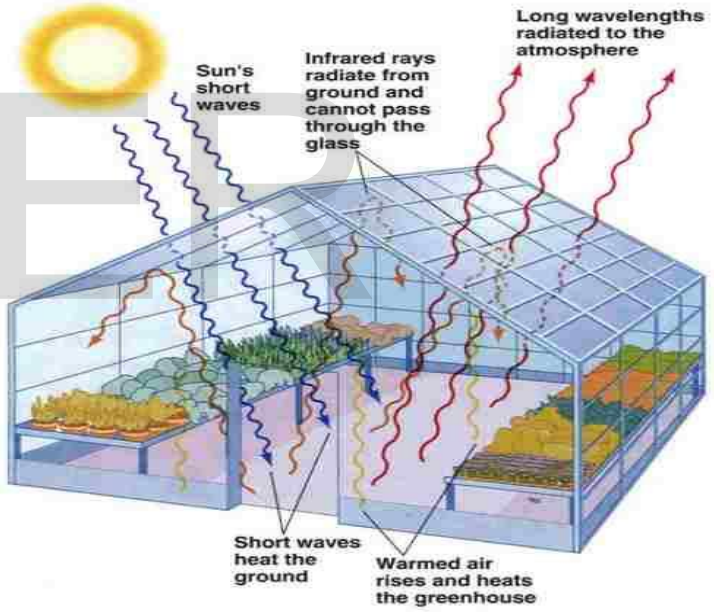

Fig. 2. Working Principle of a Greenhouse

house. The temperature inside the greenhouse increases because of the fact that, the heat trapped, warms the air present in it [5]. This provision of light and heat to the plants, serve as effective measures for photosynthesis to occur. The working principle of a greenhouse comprises of both these type of radiations, as shown in Fig. 2 below.

4. Contribution of Greenhouses to Sustainable Food Production

4.1 Plant Growth

The primary objective of greenhouses is to produce agricultural products outside the cultivation season. They offer a suitable microclimate for plants and make possible growth and fruiting, where it is not possible in open fields, in which crops are prone to damage due to extreme cold in the winter, extreme heat during the summers, or other factors like heavy rainfall, wind, or other harmful factors. Thus greenhouses protect plants from the effects of unseasonal temperature fluctuations, like exceptionally hot days in October or frosty mornings in May [7]. Under a translucent cover sunlight is diffused while sufficient ventilation flows throughout, and thus plants are protected. This increases food production, by preventing its loss, inspite of unfavorable climatic conditions.

Light that is needed for photosynthesis by plants comes from the diffuse radiation, which is free from substantial fluctuations throughout most of the time of the day. This process is generally completed at suitable atmospheric conditions, provided by nature in different seasons, but occurs artificially in a greenhouse. For instance, the air temperature inside the greenhouse is one of the factors that have an influence on the precocity of production. The selective collector acts in a more perceptible way on extreme air temperatures inside the greenhouse. Hence, the system makes it possible to avoid the excessive deviation of the temperature inside the greenhouse and provides a favorable microclimate for the precocity of the culture. This is the reason for which a greenhouse is also known as a 'controlled environment greenhouse' [8]. Due to the existence of a controlled environment, production in a greenhouse is much more advanced, it can be continued for longer duration, and finally, it can be increased to a great extent. The off-season production of vegetables, crops and fruits is one of the distinctive features of the controlled environment greenhouse.

Additionally, sediments and some amount of water from the sediment traps are used as organic fertilizers for enhancing cultivation of crops, in terms of both, quality and quantity. Greenhouses are extremely advantageous when it comes to protecting plants from animals, insects, pests and unfavourable weather.

Hence, greenhouse technology has evolved to create an optimum favorable environment to be able to contribute to cultivation of the desired crop, all year round. The use this technology is widespread. During the last 10 years, the number of greenhouses constructed, has increased considerably to cover up to several hundred hectares at present. Most of the produce from these structures, is commercialized locally or exported. In India, around 300 hectares of land are under greenhouse cultivation. On the other end, it is 98600 hectares in Netherlands, 48000 hectares in China and 40000 hectares in Japan [9]. This proves that there is a great scope to extend greenhouse technology varying climates of different parts of the world.

4.2 Fish Production

Some greenhouse owners believe in the practice of multi-tasking by keeping large fish tanks inside their greenhouses. Since water in the tank provides sufficient thermal mass to store heat, the fish grow faster due to the extra warmth, and the waste retrieved during cleaning out the fish tank serves as fertilizer for the greenhouse plants, thus improving crop quality.

By rearing fish in tanks, placed inside a greenhouse, the temperature of the water can be regulated to enhance growth. As a controlled environment, greenhouses also prevent predation and intrusion by other animals, enabling farmers to maintain higher levels of hygiene [10]. Rich in nutrients, wastewater from fish farming can also be used to irrigate vegetables, an added bonus for farmers. This maximizes for food production as a whole, as most of the countries in the world have fish as their staple food.

5. Greenhouse Technology

Greenhouse Technology is the technique of providing favourable environment condition to the plants. It is rather used to protect the plants from the adverse climatic conditions such as wind, cold, precepitation, excessive radiation, extreme temperature, insects and diseases. This can be achieved by making sure that the structural design is such that, these conditions are created easily and are maintained for requisite time periods, giving enough time for plants to be able to respond to them, and eventually adapt themselves to the environment thus created.

5.1 Need for Sustainable Greenhouse Technology

Planting in a greenhouse is the best way to produce crops through out the year by manipulating the seasons, especially in cooler climates, which are detrimental to plant growth. Growing plants in winter with equal efficiency allows one to garden outside seasonal limitations, but there are serious disadvantages of greenhouse technology. The controlled environment of a greenhouse increases maintainence cost and pest management cost [11]. Considering these challenges helps us determine whether a greenhouse is the perfect fit for our gardening needs, in a particular region. The site chosen for construction of a greenhouse should take care of the fact that it captures maximum sunlight, especially in the winter. If not, then production does not occur in the desired amount, and the construction cost is wasted. Designed to hold in warmth during cold seasons, a greenhouse also becomes a heat trap during warm weather. If temperatures exceed usual levels, plants will die due to extensive exposure to heat. In cold seasons, plants might freeze to death if temperatures

drop below usual levels. Although most greenhouse plants require night temperatures between 50 and 70 degrees Fahrenheit, ideal growing temperatures are plant-specific. This means that one may not be able to grow a variety of plants in the same greenhouse, which is one of the disadvantages of greenhouse farming. This delicate balance of temperature management requires heating and ventilating systems, which are the most expensive operating costs of a greenhouse [12].

Globally, buildings account for approximately 40% of the total world annual energy consumption. Most of this energy is needed for the provision of lighting, heating, cooling, and air conditioning in buildings.The government agreed to ban the use of certain refrigerant chemicals, as a part of the 1997 Montreal Protocol, to prevent destruction of the stratospheric ozone layer [13]. Following this, there has been a significant increase in the awareness of CO_2 and NO_x emissions and the use of CFC's, has declined, to a great extent as well. Thus, decrease in the rate of depletion of energy reserves, started being considered as desirable, for reducing energy consumption.

These points definitely make designing of greenhouses challenging, but there are effective solutions for overcoming them. A greenhouse should be designed in a way keeping in mind the barriers to environment and cost. By optimizing the design, in a way, which maximizes food production, with minimum cost, effort, and harm to the environment, it would be nothing but a sustainable green house.

5.2 Sustainable Greenhouse

The ability of a greenhouse to be able to provide for good indoor environmental quality and achieving energy and cost efficient operation of the heating, ventilating and air-conditioning plants, at the same time, refers to its sustainability. The comfort of the crops and other species like fish, if being produced in the greenhouse depends on a lot of environmental parameters like wind speed, temperature, and relative humidity.

Sustainable buildings are the ones which help one reduce energy bills and does our bit for the protection of the environment. In fact, the construction of a greenhouse also includes energy efficient building materials and water. Greenhouses produce less waste and use less energy than conventional houses. Sustainable and recycled materials are used for their construction. A green house has a significant impact on the environment, if designed in a sustainable manner. It improves air quality around our house and makes sure we use renewable energy sources. The overall objective of a sustainable greenhouse should be to provide a high level of building performance (BP), which can be defined as indoor environmental quality (IEQ), energy efficiency (EE) and cost efficiency (CE), so as to resolve the problems created due to non-optimal values of these parameters [14].

5.2.1 Indoor Environmental Quality (IEQ)

Indoor Environmental Quality encompasses the conditions inside a building—air quality, lighting, thermal conditions, ergonomics—and their effects on occupants, which would be plants and crops grown inside the greenhouse [15]. Strategies for addressing IEQ include those that protect plant health, and reduce stress due to non optimal environmental conditions on them. The strategy of achieving this would be designing temperature control models and using efficient equipment for ventilation.

Crop production in greenhouses involves both physical and biological interacting systems. The major environmental factors affecting plants, are temperature, light intensity, relative humidity and carbon dioxide concentration. Thus, these need to be controlled and modulated [16].

Amongst all these, temperature control is of utmost importance, as it is the one that affects the physical aspects of the environment in a greenhouse. For instance, sudden changes occur in the heating and cooling loads due to rapidly varying solar intensity, which must be controlled. Controlling such environments, becomes difficult, due to slow response times of heating systems[17]. But, fortunately, mechanical cooling systems adjust easily and quickly to changing cooling loads, as their response times are very short and such systems need not be necessarily controlled [18].

5.2.2 Energy Efficiency

Energy efficient buildings are defined as structures that are designed to provide a significant reduction of the energy need for heating and cooling, independently of the energy and of the equipments that will be chosen to heat or cool the building [19].

The shape of a building, in order to for it to be energy efficient is compact, to reduce the surfaces in contact with the exterior. The openings in the building are given a specific orientation, and interior spaces are laid, to provide for the heating requirement [20].

Appropriate techniques are applied to the external envelope and its openings to protect the building from solar heat in both winter and summer. Passive solar systems collect solar radiation, and the building is protected from the summer sun, mainly by shading and use of appropriate reflective colours and surfaces.

Well installed insulation ensures energy efficiency in every part of the building envelope, including wall and ground surfaces. It is also well suited for pipes and boilers to reduce the energy loss of a building's technical installations. Insulation is as relevant in cold regions as in hot ones. In cold regions, insulation keeps a building warm and limits the need for energy for heating whereas in hot regions the same insulation systems keep the heat out and reduces the need for air conditioning.

An exterior wall is said to be insulated perfectly, when its thermal resistance (R) value is high, which means that the heat losses through it are small, i.e. overall heat transfer coefficient (U) value is low [21]. Increased thermal resistance within the available space, can be brought about by using materials with low thermal conductivity, and high thicknesses [22].

5.2.3 Cost Efficiency

Cost efficiency is the financial expenditure on energy, relative to the level of environmental comfort and productivity that the building occupants (plants and/or fishes, in this case) attain. The overall cost efficiency can be improved by improving the indoor environmental quality and the energy efficiency of a building [23].

Out-of-season industrial production is vulnerable to competition from local growers**.** For instance, Florida's winter field-grown tomato market is collapsing continuously. Earlier, the winter tomato selection at a local grocery store in Florida, used to be dominated by green-harvested gas-ripened field tomatoes [24]. On the contrary, presently, over 70 percent of winter tomatoes for fresh eating are grown in greenhouses. And, since most greenhouse tomatoes harvested are partially ripe, they deserve being better in quality, than winter field tomatoes.Therefore, the only possible way for local growers to compete with off-season production from industrial agriculture, is by making use of protected culture. Since, locals always want to buy vegetables and fruits, out of the season, producing it at a price, off-season, is always challenging. Thus, a greenhouse, designed by investing certain amount of money, initially, to pay for the equipment required for providing a favorable environment, eventually leads to maximization of profits, from the sale of off-season crops in huge amounts, which are purchased by locals, quite easily.

The larger problem that needs an effective solution, is the fact that billions of dollars of farm subsidies go to commodity crops for being processed into junk food. This makes local vegetables out of reach for many households which have a low budget for food, and makes the worst types of junk food the most affordable option for them [25]. Since the 21st century has been prone to a lot of food borne diseases, wholesalers also appreciate the fact that food from protected agriculture is produced in a controlled environment, which should be clean and free of contamination [26]. Ultimately, local protected culture growers offer food that is of a better quality than anything industrial food. Produce wholesalers are against the current long industrial supply chain as it is cheap and efficient, but does not produce a high-quality product. Many would prefer to offer tastier and fresher local produce, but wholesalers' need for a reliable supply has long been a barrier for seasonal local growers. Greenhouse production is a way for local producers to remove this barrier, as production in a greenhouse becomes more dependable without the vagaries of weather.

6. Conclusion

From the study done in this review, it is quite evident, that a greenhouse, when designed in a sustainable manner, keeping in mind, the three main parameters of Indoor Environment Quality, energy and cost efficiency, contributes to an increased food production. The off-season production of crops, and fish production are two main factors, that contribute towards the maximization of food, since both of these are a major part of the diet of people in most countries across the globe. Development of temperature control models, with shorter response times, must be implemented in greenhouse design, to contribute to maximum production. Also, care must be taken regarding energy and cost efficiency while developing such models so that, the amount earned by sale of crops, out of the season, makes up for the cost of developing the models and maintaining the system.

7. REFERENCES

[1]. Butler, C. (2009). "Food security in the Asia-Pacific: Malthus, limits and environmental challenges". *Asia Pacific Journal of Clinical Nutrition*, *18*(4), 577-584.

[2]. Hassan, M.K. (2010). Postharvest handling of fruits and vegetables. Research Grant Report. National Food Policy Capacity Strengthening Programme.

[3]. Food and Agriculture Organization of the United Nations (FAO) (2014). Building a common vision for sustainable food and agriculture: principles and approaches. Rome, Italy: FAO.

[4]. Viktor D. Ventilation concepts for sustainable buildings. In: Proceedings of the World Renewable Energy Congress VII. Cologne: Germany; 2002. 551 p.

[5]. Erlich P. Forward Facing up to Climate Change, in Global Climate Change and Life on Earth. RC Wyman (Ed), London: Chapman and Hall; 1991.

[6]. Miller G. Resource conservation and management. California: USA: Wadsworth Publishers; 1990. p. 51–62.

[7]. ASHRAE, Energy efficient design of new building except new low–rise residential buildings. BSRIASHRAE proposed standards 90–2P–1993, alternative GA. American Society of Heating, USA: Refrigerating, and Air Conditioning Engineers Inc; 1993.

[8]. Raja J, Nichol F, McCartney K. Natural ventilated buildings use of controls for changing indoor climate. In: *Proceedings of the 5th World Renewable Energy Congress V*. Florence, Italy; 1998. p. 391–394

[9]. Viktor D. Ventilation concepts for sustainable buildings. In: Proceedings of the World Renewable Energy Congress VII. Cologne: Germany; 2002. p. 551

[10]. Somerville, C., Cohen, M., Pantanella, E., Stankus, A. & Lovatelli, A. 2014. Small-scale aquaponic food production.

Integrated fish and plant farming. FAO Fisheries and Aquaculture Technical Paper. No. 589. Rome, FAO. 262 pp.
[11]. Lam JC, Shading effects due to nearby buildings and energy implications. Energy Conservation and Management. 2000; 47(7):647–659.
[12]. Grange, R. I., and D. W. Hand. 1987. "A review of the effects of atmospheric humidity on the growth of horticultural crops." Journal of Horticultural Science 62(2): 125–134.
[13]. Goetzler, W.; Sutherland, T.; Rassi, M.; Burgos, J. "Research & Development Roadmap for Next-Generation Low Global Warming Potential Refrigerants." Washington, DC: EERE/DOE, 2014.
[14]. Jovicich, E., D. J. Cantliffe, S. A. Sargent, and L. S. Osborne. 2004. Production of Greenhouse-Grown Peppers in Florida. HS979. Gainesville: University of Florida Institute of Food and Agricultural Sciences.
[15]. Han, K.; Zhang, J.S.; Guo, B. A novel approach of integrating ventilation and air cleaning for sustainable and healthy office environments. Energy Build. 2014, 76, 32–42
[16]. Kang, J.; Hwang, K.-I. A Comprehensive Real-Time Indoor Air-Quality Level Indicator. Sustainability 2016, 8, 881.
[17]. Merema, B.; Delwati, M.; Sourbron, M.; Breesch, H. Demand controlled ventilation (DCV) in school and office buildings: Lessons learnt from case studies. Energy Build. 2018, 172, 349–360.
[18]. Daisey, J.M.; Angell, W.J.; Apte, M.G. Indoor air quality, ventilation and health symptoms in schools: An analysis of existing information. Indoor Air 2003, 13, 53–64
[19]. Mikuˇcioniene, R.; Martinaitis, V.; Keras, E. Evaluation of energy efficiency measures sustainability by decision tree method. Energy Build. 2014, 76, 64–71.
[20]. Chung, M.H.; Rhee, E.K. Potential opportunities for energy conservation in existing buildings on university campus: A field survey in Korea. Energy Build. 2014, 78, 176–182
[21]. Allab, Y.; Pellegrino, M.; Guo, X.; Nefzaoui, E.; Kindinis, A. Energy and comfort assessment in educational building: Case study in a French university campus. Energy Build. 2017, 143, 202–219.
[22]. Soares, N.; Bastos, J.; Pereira, L.D.; Soares, A.; Amaral, A.R.; Asadi, E.; Rodrigues, E.; Lamas, F.B.; Monteiro, H.; Lopes, M.A.R.; et al. A review on current advances in the energy and environmental performance of buildings towards a more sustainable built environment. Renew. Sustain. Energy Rev. 2017, 77, 845–860.
[23]. Congedo, P.; D'Agostino, D.; Baglivo, C.; Tornese, G.; Zacà, I. Efficient Solutions and Cost-Optimal Analysis for Existing School Buildings. Energies 2016, 9, 851.
[24]. Murthy D. S., Prabhakar B. S., Hebbar S. S., Srinivas V., and Prabhakar M. (2009). Economic feasibility of vegetable production under polyhouse : A case study of capsicum and tomato. J. of Hortic. Sci., 4(2): 148–152.
[25]. Yousefi M., Omid M., Rafiee S. H., and Khoshnevisan B. 2013. Modeling GHG emission and energy consumption in selected greenhouse in Iran. Int. J. of Energy and Environment (IJEE), 4(3): 511-518.
[26]. Pack M., & Mehta K. (2012). Design of affordable greenhouses for East Africa. Proceedings of IEEE Global Humanitarian Technology Conference, GHTC (October 2012),