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Authors(s)	Mc Carthy, Ultan, Uysal, Ismail, Badia-Melis, Ricardo, Mercier, Samuel, O'Donnell, C. P. (Colm P.), Ktenioudaki, Anastasia
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Global Food Security – Issues, Challenges and Technological Solutions

*Ultan Mc Carthy [a], Ismail Uysal [b], Ricardo Badia Melis [c], Samuel Mercier [b], Colm O Donnell [d], Anastasia Ktenioudaki [d]

[a] School of Science & Computing, Department of Science, Waterford Institute of Technology, Ireland

[b] Department of Electrical Engineering, University of South Florida, Tampa, USA

[c] Departamento de Ingeniería Agroforestal. ETSIAAB. Universidad Politécnica de Madrid (UPM), Edificio Motores, Avda. Complutense 3, 28040 Madrid, Spain

[d] School of Biosystems & Food Engineering, University College Dublin, Ireland

**Corresponding author email:* umccarthy@wit.ie

Highlights

222 millions of tons are annually wasted in developed countries.

Increasing pressure is being placed on shrinking finite resources produce our food.

The European commission has recently committed to decrease food waste 50% by 2025, as well as the US who have adopted a national waste reduction goal by the year 2030.

We must adopt a fully coordinated global effort to achieve sustainable food security.

Technology has a significant role to play in global food security.

Abstract:

Background

Food security is both a complex and challenging issue to resolve as it cannot be characterized or limited by geography nor defined by a single grouping, i.e., demography, education, geographic location or income. Currently, approximately one billion people (16% of global population) suffer from chronic hunger in a time when there is more than enough food to feed everyone on the planet. Therein lies the Food security challenge to implement an ability to deal with increasing food shortages, caused by a combination of waste and an ever expanding world population. At current levels prediction state that we must increase global food production by 70% on already over exploited finite infrastructures before 2050.

Scope and Approach:

This review paper firstly introduces the concept of Food Security with an overview of its scale and depth in the context of the global food industry. It then highlights the main sources. The readership is then introduced to the key factors affecting food security and highlights the many national and international measures adopted to tackle the problem at both policy and technological level.

Key Findings and Conclusions:

Food experts indicate that no one single solution will provide a sustainable food security solution into the future. Collective stakeholder engagement will prove essential in bringing about the policy changes and investment reforms required to achieve a solution. Achieving truly sustainable global food security will require a holistic systems-based approach, built on a combination of policy and technological reform, which will utilize existing systems combined with state-of-the-art technologies, techniques and best practices some of which are outlined herein.

Introduction

There is no shortage of definitions for food security available today. The FAO defines food security as when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food, which meets their dietary needs and food preferences for an active and healthy life. While there exist slight differences in the wording of its different definitions, the common underlying concept of food security is that *“all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life”*. This requirement for food security is set in a reality where unstable food prices triggered by global scale events such as political instability, climate change and fuel shortages have made the challenge of attaining and maintaining global food security even more complex. The FAO / UNICEF have described food security as a multi-layer concept focused on four key dimensions; (1) food availability (2) food access, which includes physical and economical access to food, (3) food utilization based on cultural and dietary requirements and (4) food stability, i.e., the stability of its provision. These pillars are represented in figure 1 and discussed in greater detail in later sections. It is also evident that the onus is now on policymakers, governments, industrial practitioners, environmental non-for-profit organizations and each individual to play their part in the food security challenge to ensure that a high quality standard of food will remain available in the foreseeable future.

The challenge of food security requires an ability to deal with increasing food shortages for an ever expanding world population. With a predicted increase of 1.7 billion in world population between now and 2050, mankind is placing more and more pressure on the shrinking finite resources used to produce our food. The current model of an ever-increasing population relying on finite resources is clearly un-sustainable and increases the importance of ensuring that we strive for “resource efficiency” within a “circular economy”. A number of recent investigations indicate that anywhere between 30 to 50 % of food produced is never consumed and inevitably goes to waste (Gunders, 2012). In the US, each citizen wastes upwards of 400 pounds (approx. 180 Kgs) of food per year, while in Europe this figure stands at 173 Kg of food wasted per year. The total cost associated with food waste for the EU-28 in 2012 was estimated at €143 billion. Similar statistics have revealed that the US spends up to $218 billion per year (1.3 % of GDP) on growing, processing and transporting food that is never eaten. In Canada, it is estimated that food wasted annually is worth more than $25 billion, nearly 2% of Canada’s gross domestic product (Young, 2012).
The devastating impact food security has on humankind *“the human effect”* cannot be ignored and presents significant societal challenges requiring immediate international attention. Latest estimates indicate that approximately 795 million people in the world – just over one in nine – were undernourished in the years 2014–16 (FAO, 2015c) and an estimated 805 million people were unable to access sufficient supplies of food between 2012 and 2014. The FAO recently reported that 60 % of hungry people on the globe are women and almost 5 million children under the age of five die of malnutrition-related causes every year (Worldfoodday, 2016). While being a startling figure it should be highlighted that it represents an improvement of 209 million people compared to 1990 and 1992 (FAO, 2015b). The stark and disturbing reality behind the food security challenge includes the fact that an estimated 1 in 7 Americans are food insecure today (2016). Recent figures in the EU report that in 2013**,** 55 million people (11%) reported themselves as being unable to "afford a meal with meat, chicken, fish (or vegetarian equivalent) every second day". Today in 2017, 31.7 % of SSA’s

(Sub-Saharan Africa) population are food insecure. Even more staggering is that this figure will remain above 20 % by 2027. Globally the Asia region has the largest number of food-insecure people in 2017, with 315.2 million individuals food insecure (ERS, 2017) . This Asia region is now the worlds fastest growing region whilst currently being home to 56 % of the global population (Asian Development Bank, 2013). The Asia region has the second largest food gap—10.8 million tons of grain in 2017, substantially below the 16.7 million tons for SSA. This “food gap” measures the amount of food necessary to allow all income groups to reach the caloric target.

With respect to the numerous publications, whitepapers, action groups and national strategies it is clearly evident that maintaining the “status-quo” in terms of simply increasing production to meet current needs is no longer viable. This strategy is not applicable because the global population is expanding rapidly while our food is being produced using shrinking natural resources. A total of 10 million ha of land is lost each year through soil erosion and a further 10 million ha due to irrigation related issues (Maggio et al., 2015). The U.N. has predicted a 0.96% annual increase in the global population between 2015 and 2030 followed by a yearly on year increase of 0.63% between 2030 and 2050, resulting in a global population increase from its current 7.3 billion to 9 billion by 2050. This population growth is expected to occur mostly in the lower income and less developed countries, which traditionally face more significant food security issues compared to developed countries. Therein lies a requirement to adopt a more collaborative vision towards food security encompassing all stakeholders both nationally and internationally. This will require, at the very least, a clear and concise focus on areas such as infrastructure at all actor levels, communication (between all partners of the supply chain), collective efforts, and clearly defined goals just to name a few. There will also be a requirement to clearly focus on issues such as human trends, dietary requirements, urbanization, natural resources and climate change, all of which will be discussed with in more detail in later sections.

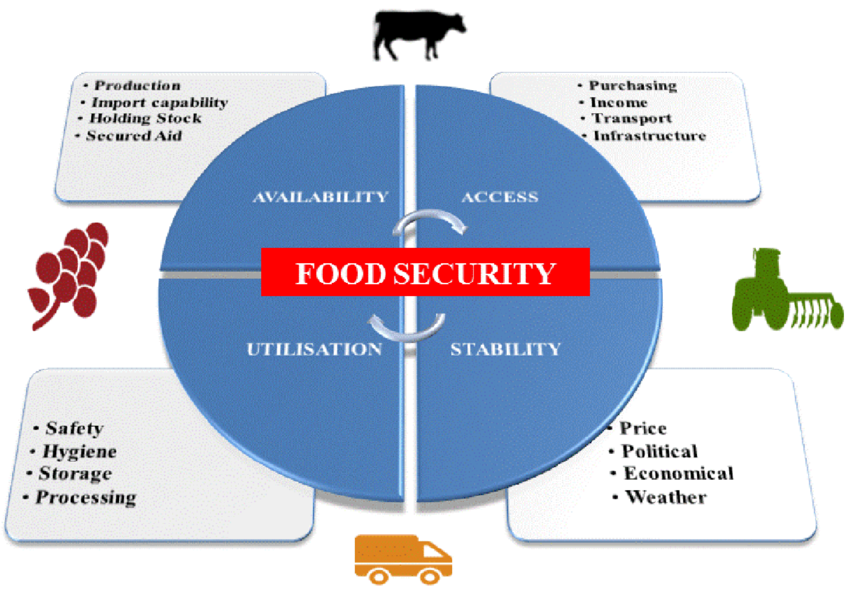


Figure 1 The four Pillars of Food Security>

Overview of current global food Industry

In an attempt to meet the ever changing nutritional requirements and preferences of consumers across the globe, the global agri-food sector is in a continual state of flux and restructuring. Key challenges within this industry include an attempt to strike a trade-off between product price versus safety, quality, variety and demand. To effectively meet these challenges and achieve cost efficiencies, industrial practitioners are required to address each of the major key areas in which a product is produced, processed, stored, distributed and accessed around the globe. Similarly, in an attempt to achieve market success, recent studies have reported that global food producing industries are now adopting strategies aiming to gain a competitive advantage through "category-focus " as opposed to other industries where the key players focus on portfolio management (in this $4 trillion per year industry) (USDA, 2016). The adoption of a product focused strategy helps companies becoming true leaders in their field for particular products and achieving global economies of scale.

In the U.S., agriculture and agriculture-related industries contributed $835 billion to U.S. gross domestic product (GDP) in 2014. The output of America's farms contributed $177.2 billion of this sum—about 1 percent of GDP. In 2014 agriculture was responsible for the employment of 17.3 million full- and part-time workers, about 9.3 percent of total U.S. employment. Direct on-farm employment provided over 2.6 million of these jobs whereas inter-related industries supported an additional 14.7 million jobs. Food services and accounted for the largest share—11.4 million jobs—and food/beverage manufacturing supported 1.8 million jobs. In 2013, the U.S. food and beverage manufacturing sector employed about 1.5 million people, or just over 1 percent of all U.S. nonfarm employment (USDA, 2016).

Similar trends can be observed for other countries. For example, in 2013, the agricultural and agri-food system generated $106.9 billion, equaling 6.7% of Canada's overall GDP - a trend which has increased annually since 2007, the exception being the economic recession of 2009. Employment in the majority of industries in this sector continued on an upward trend and accounted for one in eight jobs in Canada, employing over 2.2 million people. The food service industry was the largest employer in the AAFS, accounting for 5.3% of all Canadian jobs.

On the other side of the Atlantic, between 2008 and 2010 the European Union imported close to €60 billion worth of agricultural products from developing countries annually. The food value chain in Europe generates added value of €800 billion and a turnover of €4 trillion. Employment stands at 46 million people in more than 15 million holdings or enterprises in agriculture, the food industry, and food trade and services. The food and beverages industry is EU's largest manufacturing sector, in terms of turnover (€1.2 billion, or 1.8% of EU Gross Value Added - GVA), employment (4.22 million jobs), value added (€ 206 billion, or 12.8 % of EU manufacturing) and exports (€ 92 billion, or 18 % of EU exports). Small and Medium Enterprise (SME) companies account for 99.1 % of the sector.

Irrespective of the geographic location, much emphasis has been placed in the role of the family farmer in solving world food hunger. There are up to 500 million family farms globally which accounts for 98% of farming holdings worldwide. Typical family farms include fruit and vegetable farms, grain farms, orchards, livestock ranches, and even fisheries and those that harvest non-wood forest products. In Brazil family farms provide up to 40% of the major crops and in the U.S. these farms are responsible for producing 84% of all produce. Such farmers have an intimate knowledge of their land: its history, needs and productive capacity and are viewed by many as being custodians of the land as opposed to exploiters (FAO, 2014). The figures discussed in this section serve to remind the readers of the importance of the Global Food sector and security and the impact it has on major global economies.

Global food supply chains

There are a variety of definitions for “supply chain management”, yet their common aim is to coordinate and integrate all activities relating to a product during processing and transport. Nowadays, food chains have evolved to become highly distributed, heterogeneous, cooperative and globalized processes with extremely diverse requirements, which are in many cases dictated by the product and its eventual destination (Badia-Melis et al., 2014). Global food supply chains represent delicate balances between the transportation of products across the globe while factoring internal considerations such as prevalence of food spoilage, remaining shelf life and an array of external factors such as cost and distance-to-market. The application of appropriate processing of food is of critical importance for achieving sustainable supply. Nevertheless, food transport and distribution cannot be ignored when considering food security and sustainability especially given that the vast majority of food supply chains span globally. When considering the supply chain one must also consider a number of linked activities including sourcing of raw materials and parts, manufacturing and assembly, warehousing and inventory tracking, order entry and order management, distribution across all channels and delivery to the customer (Mc Carthy et al., 2012). To successfully reduce food waste and increase resource efficiency across the farm-to-fork continuum one must adopt a strategic view through combination of local (national) and international perspectives – and key to achieving a global solution lies in the ability to successfully and holistically merge these local solutions.

Recent trends towards global trading and the formation of global scale supply networks make the task of supply chain management more and more challenging and have significantly increased competitive pressure. Not only do organizations have to continually evolve and develop new strategies to meet the needs of their customers, they must also develop parallel strategies to outperform their competitors to ensure sustainable corporate success. This reinforces the need for the implementation of state of the art systems including a combination of wireless technologies, operating models, networking protocols, hardware (such as wireless sensor networks (WSN) and radio-frequency identification (RFID)) and software to ensure food is distributed in a safe and secure manner (Badia-Melis et al., 2014).

Future developments must be built around sustainable food supply networks using innovative technologies. This can only be achieved in an organizational learning environment, through innovative value adding technologies that will improve the quality of our lives with a negligible cost to the environment or to food security (McCarthy et al., 2013). As previously mentioned current supply chain challenges must be addressed both nationally and internationally given that in many countries, transport and logistics costs can be as high as 20%-60% of the food selling price (OECD, 2013a). From a trading and purchasing perspective it is difficult for a manufacturer to export at a competitive price or import at a competitive cost if the transport and logistics sector is volatile and/or dysfunctional (OECD, 2013a).

Internationally, recent reports have highlighted that, in some cases, a single day decrease in time spent at sea can increase trade costs to the tune of 4.5% (OECD, 2013b). An investigation within the U.S. reported that reducing shipping times by a single day can yield a 0.8% ad-valorem for manufactured goods. Furthermore, this same single day reduction will also increase the probability (by a factor of 1 to 1.5 %) that the U.S. will import the given product from that country. Based on data from 133 countries' trade facilitation performance (i.e. border streamlining) can be responsible for approximately 14% of the variance in bilateral trade costs across trading partners (OECD, 2013a). Similarly, it has been shown that a single extra day spent in customs causes a 2.8% decline in growth rates of exports for freight in transit (Martincus and Graziano, 2012). These figures confirm the importance of efficient supply chain management at the international level. At national level, it is expected that in countries where there is poor internal connectivity (physical and virtual), the direct and indirect costs associated with food transport are unnecessarily high when set against the aforementioned 20-60% of food prices being governed by transport and logistics costs (World-Bank, 2012). In countries with poor internal connectivity, where transport and logistics services are under-developed, and supply chain governance is poor, both the direct and indirect costs of transporting food from the farm to the consumer are significantly higher when compared to countries with developed connectivity. This leads to inevitably higher consumer prices (OECD, 2013a). Transport and logistics services also affect a country's ability to respond to market price shocks. Lower transport costs can decrease the selling price of imported goods and ensure that a greater share of the selling price of exported goods is given to the producer (OECD, 2013a). Recent OECD research has reported that a 10% improvement in transport and trade-related infrastructure quality can increase developing countries' agricultural exports by as much as 30% (OECD, 2013a).

Irrespective of a national or international approach, it is also important to remain cognizant of social movements and population shifts which have created challenges related to consumer demand for specific food regardless of seasonality or geographical location. It is also worth highlighting that efficient food supply chains have the potential to reduce food waste as well as the cost to the consumer given that the cost of food waste is increasing towards the consumer end of the supply chain. It is now clear that improvements in global supply chain management may only be achieved through the implementation of chain wide monitoring systems that facilitate the exchange of information in unison with the product. Such systems will increase the transparency and security of the food supply resulting in more flexible and responsive global supply chains and a reduction in global food waste.

Sources and Causes of Global Food Waste

There are variations in the reported amounts of food wasted globally. The U.N. FAO estimates that each year, approximately one-third of all food produced for human consumption in the world is lost or wasted. Similar reports have documented food waste figures as being as high as 50%. The U.N. Environment Program says that 222 millions of tons are annually wasted in developed countries, almost as much as the entire production of the sub-Saharan Africa (230 million tons). A study performed in U.S., Canada, Australia and New Zealand reveals that during production, 20% of the fruit and vegetables are lost; consumers waste up to 28%, and 12% is wasted during distribution mainly because of the lack of refrigeration control (Gunders, 2012). Irrespective of the aforementioned reports being taken under consideration it is clearly evident that global food waste is at unacceptable levels.

Recent publications have identified that up to 70 to 80% of food waste occurs at customer facing businesses and households in the EU and U.S., respectively. The total cost associated with food waste for the EU-28 in 2012 was estimated at €143 billion. Similar statistics have revealed that the U.S. spends up to $218 billion per year (1.3 % of GDP) on growing, processing and transporting food that is never eaten. This equates to approximately 400 pounds (180 kg) of food wasted per year for every American citizen. In Europe this figure stands at 173 kg of food wasted per year (compared to a total of 865 kg produced). In addition to this critical statistic it is worth highlighting that up to 10 million tons of products are unsold and eventually wasted each year at farms and packing facilities due to aesthetic rejection (consumer will reject based on the appearance). Similarly, in terms of waste recovery it has been reported that less than 10% of waste is recycled at consumer facing businesses, whereas for manufacturers approximately 95% of industrial food waste is recycled, primarily for animal feeding purposes. These statistics lead the authors to assert the point that the introduction of financial implications for volume of wasted food could possibly reduce the overall food waste levels (Vared Sarah, 2016). Even though the cost of food waste is higher at the consumer end of the supply chain, the irony is that this is where the majority of waste occurs (Gunders, 2012) (Maggio et al., 2015). When considering food waste it is important to consider the many factors which also have an impact on this issue. Factors include the different stages of the food product life cycle, which include primary production, processing, wholesale and logistics, retail and markets, food services and household consumption. Figure 2 presents a breakdown of the sources of food waste across the value chain from both a European and US perspective.

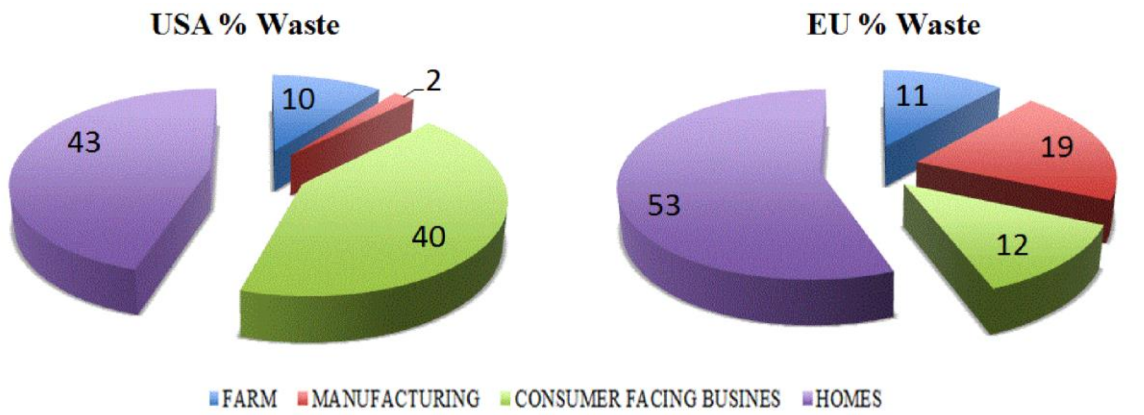


Fig 2 Main sources of Food Waste in the EU and US

It is clear that food waste in the world is at unacceptable levels, however, as can be seen from Figure 2 it is also important to note that the volume and stage of supply at which the food is wasted also varies according to the food type and geographical location. To facilitate the adoption of a systematic global approach towards a solution, one should be open to the idea that the issues of waste in one geographical region or sector may already be solved in another geographical area. Nevertheless, each demographical factor would present its own challenges as well. For instance, the causes of food losses and waste in low-income countries are mainly connected to financial, managerial and technical limitations in harvesting techniques, storage and cooling facilities in challenging climates, infrastructure, packaging and marketing systems (FAO, 2011). This may not necessarily be the case in developed countries where the main causes of waste can all too often be linked to purchasing patterns and education therefore supporting that both local and international perspectives are required for a solution. The net result is that full stakeholder engagement is critically important in delivering a sustainable solution.

Factors affecting Food Security

The EU has revealed that the food and drink industry is facing a decrease in competitiveness which may be linked to a lack of transparency in the food supply chain, sub-optimal business-to-business relationships, a lack of attractiveness for skilled workers, and a lack of market integration across EU countries (EU, 2016). These issues are not exclusive to the EU and can be directly attributed to food security challenges being experienced across other geographical regions. While it has been presented thus far that there is no single solution for solving global food security, it can also be deduced that there is no single root cause for the issue. This section outlines some of the major causes of global food insecurity which should be taken into consideration to identify the critical factors towards achieving a solution. To address these issues correctly the authors focus on the definition of food security according to the FAO as a time *"when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life"*. The concept of food security is built on 4 key pillars, each with its own core focus (figure 1). Each pillar is of equal importance and must be treated with equal levels of consideration. These four key pillars are (Aborisade and Bach, 2014)

i. Food Availability. This pillar entails having an adequate quantity of food available at minimal notice. This pillar considers food that is either produced locally by Food Business Operators or imported via the importing capacity of the region. It may also consider existing food stocks within a particular region and also the provision for food aid that have been assigned from other countries. It is also important to note that high food availability is not in itself sufficient to ensure food security (FAO, 2015a).

ii. Food Access. This pillar considers both the physical and/or economic access to food. Factors of importance here include the purchasing power of a particular region and the levels of income (per population) relative to other regions. Other factors for consideration include local infrastructures, such as transport modalities and or financial means to support trade within/across a particular region.

iii. Food Utilization. This pillar focuses on the entire supply chain and deals with the way in which the food is handled from a safety perspective. It focuses on hygiene across primary production, secondary processing, distribution, retail and household. This requires the creation of efficient and safe usage of food and also the creation of nutritional awareness across stakeholders to ensure that they become more nutritionally aware of different foods and their respective benefits.

iv. Food Stability. This pillar focuses on stability mainly from a supply and access perspective. Common factors with the potential to impact food stability include price, political stability and the local economy. Other factors which cannot be ignored include weather patterns with a negative impact on crop yields. It is generally accepted that the poorer the nation, household or consumer, the more susceptible it is to external factors (FAO, 2015a).

As previously mentioned there is no single cause or solution to the issue of food security. The following section will outline some of the wider cross cutting causes and/or factors affecting global food insecurity.

Population Increase: As previously mentioned, the U.N. has predicted an 0.96% annual increase in the global population between now and 2030 and thereafter a yearly increase of 0.63% through 2050 resulting in an overall global population increase from its current 7.3 billion (UNFPA) to 9 billion in 2050. This population growth is expected to occur mostly in the lower income, developing countries, which traditionally have faced more significant food security issues than developed countries.

Urbanization: By 2050 it is expected that more than 65% of the population will be living in urban areas. This trend of urbanization will occur mainly in low-income countries and will be a key driving force behind the creation of dense demand pockets throughout the world placing increased demand on food supply chains.

Dietary demands: An increase in global agricultural and food products of 50% by 2030 and 110% by 2050 will be required to meet the demands of growing population and rising incomes. As an example, it has been predicted that there will be a 40% increase in demand (kg per person per year) for meat in higher income countries and a 69% increase in lower income countries between 2015 and 2050. Similarly, the demand for dairy products is expected to increase by up to 70% between 2000 and 2050 (Maggio et al., 2015). Globally, the average annual increase of total food production between 1961 and 2011 was 122 MMT (Million Metric Tonnes) (Dou et al., 2016)

Natural resources: This is collectively considered under a combination of urbanization, poor water management and poor soil conditions, all of which are major factors contributing to soil becoming unfit for agriculture. Similarly we cannot ignore other critical natural resources such as energy utilization and fuel dependence, which also directly have the potential to undermine global food security if not managed and monitored correctly. We should aim to exploit renewables where possible to reduce out carbon output. It has been reported today, humankind use roughly one-half of the planet's vegetated land to grow food (WRI, 2013). Similarly, it is estimated that approximately 10 Million ha of land is lost each year through soil erosion and a further 10 million ha due to irrigation related issues (Maggio et al., 2015). Water is currently over-exploited and not treated as a valuable resource in the agri-food industry which is responsible for 70% of global fresh water consumption. In practical terms, the NRDC has reported that the volume of water consumed by running a domestic shower for 104 minutes is equal to the water required to produce a pound of chicken. Similarly the production of 1 pound (0.45 Kgs) of tomatoes, bananas, white rice and beef requires 5, 42, 60 and 370 minutes, respectively, of running water from a domestic shower (NRDC, 2016).

Climate change: It is of common knowledge that local climate variations are exploited to promote cultivation of certain products. Climate shifts and changes in weather patterns have drastic effects on the productivity and economic prosperity at regional level and may in turn lead to population displacement and resource depletion. This in turn has a significantly negative effect on food security from a both a supply and demand perspective at global level as a result of inconsistent supply channels to market.

Food *versus* fuel debate: Stakeholders have major concerns that food supply chains which have been traditionally destined for food production may become redirected towards the production of biofuels due to economic pressure. Traditional crops which have been redirected for the production of biofuels include Maize, Oilseed and Sugar cane. This can significantly decrease access to locally produced foods and can result in local populations not being able to afford locally produced food (Tenenbaum, 2008).

Infrastructure: The issue of infrastructure spans the complete supply chain and is relevant to all stakeholders. At primary production in more developed countries certain products are grown in artificially created environments and require a high degree of control and monitoring while other foods are grown in the traditional farm setting and at the mercy of the weather during that season. At the secondary processing level the more developed countries have the ability to automate and modernize the process or the environment to increase production and in many cases achieve the required scale. Again, many regions do not have highly automated production systems and rely on human effort. At the consumer level the more developed countries can generally offer the consumer products in finely presented and specific packages containing marketing and nutritional information, which also help to extend the shelf life of the food. In less developed countries this is not always the case and products are very much at the mercy of the immediate surrounding in which they are transported and stored. It has been reported that is the same level of refrigeration used in developed countries were to be applied to developing growths this would result in those countries saving approximately 200 million tons (14 % of the countries consumption) (Mercier et al., 2017) . As previously mentioned 31.7 percent of SSA's (Sub-Saharan Africa) population, approximately 301 million people, are food insecure in 2017 which can be attributed, in part, to weak currencies and / or disruptions along the food supply chain (ERS, 2017).

Communication:

Communication across all supply chain stakeholders is critical. It is well-established that an ability to create information sharing channels across stakeholders can significantly increase profits and reduce food waste (McMurray et al., 2013) (Mc Carthy et al., 2012). These information sharing channels improve transparency across trading partners and increase the amount of information available on the arrival date of particular goods, such as information on its remaining shelf life and also significantly improve warehouse management and logistical efficiency (Hertog et al., 2014).

Future food Security - Global action plans and visions

As a general rule of thumb a simple, naive and all too often adopted solution to food security would involve increasing domestic production faster than the population growth for a particular area. Once these criteria are met at global level the world will become food secure. This however is a clear over-simplification of the issue and completely negates the reality of the situation. This section will outline in more detail the current and future action plans to tackle the issue of food security. There have been many action plans commissioned over the years both nationally and internationally attempting to tackle the issue of global food security and waste with varying levels of success. To successfully increase food security and reduce food waste it is important to combine a strategic multi-stakeholder approach with a deep comprehension of the scale, source and causes of food waste. Similarly this approach would have the flexibility to adapt to local issues while successfully integrating an international strategy.

The European commission has recently adopted a resolution to decrease food waste by 50% by 2025. Similarly, in 2015 the US had adopted a food waste reduction goal by the year 2030 under the ReFED initiative (Vared Sarah, 2016). All these targets are being put in place to promote what has been branded as a circular economy. With respect to food security a circular economy means "*an economy where the value of products, materials and resources are maintained for as long as possible with the aim of reducing waste and increasing a sustainable, low carbon, resource efficient and competitive economy"* (EU, 2015).

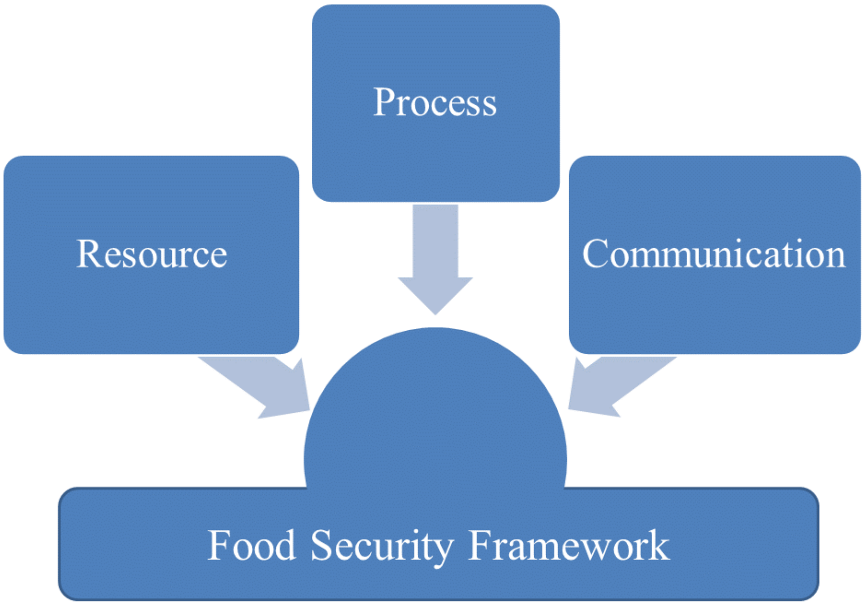
Regardless of the strategy or scale of the adoption plan many visions for global food security require a number of core fundamental pillars on which a wider and more comprehensive vision are actioned. Given that the solution is not a simple question of increasing production to meet demand, it is recommended that each of these strategies adopt a resource-based perspective prior to their implementation. This resource-based perspective should include a complete evaluation of existing processes with the aim of improvement prior to the step by step incremental introduction of new systems. It has been reported that if the US could reduce its waste by 20% - the net saving would be equal to two years of growth in productivity, where an average 7.7 MMT has been reported between the years 1961 and 2011 (Dou et al., 2016). With this in mind the criteria (perspectives) under which existing systems must be examined include:

Resource perspective: This requires a focus on the long-term preservation of the natural resources on which the food is cultivated. This will in turn promote the adequate preservation of the agricultural assets (land and housing) in the best way possible to ensure maximum profitability and sustainability.

Process perspective: The transformation of existing systems at each stage of primary production, secondary processing, distribution and retail. This will often require financial initiatives to encourage research, development and Innovation at regional and international level. An additional element included in this perspective is stakeholder training to promote resource efficiency at each stage.

Communication: This involves the implementation of a method/system of chain wide communication across product/process stakeholders. Ideally such a communication flow will span the complete farm-to-fork continuum. Information sharing across the product value chain will promote global demand-driven food trading systems and over time will facilitate a net balance between production and consumption.

The above criteria should help stakeholders to develop a framework on which strategies for improving food security can be implemented at both local and international levels. Figure 3 summarizes the requirements for the development of a Food Security Framework as outlined above.



<Insert Color Figure 3 here: 3 Food Security Framework>

Generic strategies and areas of development in recent times with respect to food security include, but are not limited to the following.

Standardized Food traceability systems

Traceability is defined as "*the ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications*" (Olsen and Borit, 2013). It is important to note that traceability needs both "tracing" and "tracking" capabilities. According to (Petersen and Green, 2005), tracing is the backward process where the product's origin is identified by history and/or stored records in supply chain and tracking is the forward process where the end users and trading partners are identified by location in supply chain. Tracking requires the ability to monitor the location of an asset in real or near real-time (McCarthy et al., 2011). Collectively, both elements provide the basis of a successful traceability system (Van Dorp, 2002). To function correctly and efficiently, a traceability system must also be both scalable and standardized. The system must be scalable in order to meet the requirements of the modern day global consumer and also standardized to ensure that the items being tracked do not become hindered by challenges including language barriers and or counterfeit product.
The unfortunate reality is that current traceability systems are characterized by their inability to link food chains records, information inaccuracy and errors in records, which delays the transmission of essential information during time of food recalls (Badia-Melis et al., 2015). Effective traceability systems should have the ability to address the recall by firstly identifying potentially at risk products and then withdrawing the unsafe ones. Such systems therefore need to be flexible and responsive. While being essential in the battle to attain food security and for consumer safety, food traceability systems are not always off the shelf solutions and

all too often require a level of customization. This adopted customization ensures these systems meet the requirements of the individual customer or the specific requirements (legal and otherwise) of the supply chain and of the product (e.g., perishable, bulk, seasonal). To reinforce the business case for traceability systems, it is not only important to view these systems as a means of meeting safety regulations; these systems have many additional applications. Traceability systems can help overcome many issues such as food crisis management, quality concerns and identity preservation concerns, fraud prevention, anti-counterfeiting (Dabbene et al., 2014) and food adulteration (Spink et al., 2016).

Implementing monitoring technologies and techniques

A core requirement inherent to the food security challenge is the ability to secure a full product chain-of-custody. This requires the ability to monitor/query the state of the product during transit. These technologies are generally autonomous, of small dimensions and record a number of product's critical parameters including temperature and relative humidity. Recent developments have increased the monitoring capabilities of sensors, notably regarding the measurement of the concentration of gases, presence of pathogens, leaf freshness, mineral deficiency all of which combine to predict the remaining shelf-life of the product. Many of these sensor technologies are in their infancy however a significant number are currently being commercially deployed. Monitoring food temperature accurately to ensure the longest shelf life represents a difficult challenge due to the number of factors involved. Investigating the temperature gradient data inside refrigeration rooms, warehouses, containers and trucks is a primary concern for the industry. Any temperature disturbance can undermine the efforts of the whole supply chain (Mahajan et al., 2014). Inadequate temperature is the second prevalent factor causing foodborne illnesses, surpassed only by the presence of initial microflora in foods (Sánchez-López and Kim, 2008).

High temperatures trigger the growth of pathogens and accelerate natural processes causing food decay (Gwanpua et al., 2015, Giannakourou and Taoukis, 2003, Hertog et al., 2014). Low temperature can also be detrimental to the shelf life and the quality of perishable food because of cold injuries (Heap, 2006, Aghdam and Bodbodak, 2014). Time-temperature profiles measured along supply chains in Canada, France and Greece have showed that the temperature of perishable food frequently increases above the desired limit (Derens et al., 2006, Koutsoumanis et al., 2010, McKellar et al., 2014). Notable causes explaining the increases of temperature above the desired limit include the inappropriate precooling of the food, poor performance of temperature control systems, temperature oscillations caused by the on-off cycles of the refrigeration systems, local heat sources in trucks or warehouses, temperature abuses during truck loading and unloading, overloading of refrigerated display cabinets, temperature abuses during transportation by the consumer and high temperatures of domestic refrigerators (LeBlanc et al., 2015, Foster et al., 2003, Carullo et al., 2009, Jedermann et al., 2011).

Approximately 12% of food wasted in the USA occurs during distribution, mainly because of inappropriate storage temperatures (Gunders, 2012). The amount of food wasted because of inappropriate refrigeration is even more important in developing countries, because of the absence of proper refrigeration equipment, high energy cost of refrigeration and lack of knowledge on the impact of temperature on food safety. It is estimated that if developing countries could apply the same level of refrigeration that is used in developed countries, more than 200 million tons of perishable food waste would be avoided per year, approximately 14% of their yearly consumption (IIR, 2009). Ensuring the proper refrigeration of perishable food at a global scale and throughout the entire supply chain should represent a key objective in our endeavour to improve food security. Monitoring devices are used to ensure temperature integrity; however resource limitations and cost factors severely limit their use to one-per-pallet or even one-per-container scenarios (Badia-Melis et al., 2013).

Wireless technologies have been considered key technological enablers to promote supply chain transparency across all actors. The potential for monitoring technologies, WSN and RFID, has been suggested by several studies and extensive literature has been published to address the issue (Badia-Melis et al., 2014, Qi et al., 2014, Jedermann et al., 2014b, McCarthy et al., 2011). Their adoption, to monitor the temperature of food along the supply chain could significantly help improve food safety. The remaining shelf life of perishable food products can be estimated accurately from their time-temperature history using appropriate safety and quality models. From the knowledge of the remaining shelf life of perishable food, First Expired, First Out inventory management systems and dynamic expiry date management systems can be implemented, both of which have the potential to significantly reduce food waste (Tromp et al., 2012, do Nascimento Nunes et al., 2014).

Time-temperature data can also be combined with recently developed software such as the FRISBEE and CanGRASP tools. The FRISBEE tool includes extensive databases of time-temperature histories measured along the supply chain and quality models predicting the remaining shelf life of perishable food, as well as optimization modules to reduce food waste and energy consumption along the supply chain (Gwanpua et al., 2015). CanGRASP is a GIS-based simulation tool used for the traceability of contaminated food during foodborne outbreaks, the development of mitigation measures to prevent outbreaks and the training of stakeholders involved in public health risk assessment (Hashemi Beni et al., 2012, LeBlanc et al., 2015). The combination of efficient wireless temperature monitoring systems with recent software developments could open exciting new perspectives towards an improvement at a global scale of food safety and, by extension, food security.

In combination these monitoring techniques and technologies offer all stakeholders enhanced transparency across the complete food supply network and it is through the provision of this actionable data that more informed decisions can be made which will aid in addressing food losses and increasing food security.

Internet-of-Things/Big Data and Global Food Safety

Recent years have seen groundbreaking advances in wireless sensor and data processing technologies paving the way for a global scale cyber-physical infrastructure, which we now term the “Internet-of-Things” (IoT). Similarly, substantial amounts of data generated by IoT implementations and their subsequent analytics, such as advanced statistics and machine learning, to create actionable information are all included under the term “Big Data”. However, the wide-scale adoption of intelligent information systems still represents a particularly elusive problem specifically for the global food industry. In fact, as the world’s top economy, in the United States alone, up to 40% of all produced food is inconceivably wasted as 50 million Americans continue to live in food insecure households (Gunders, 2012) (DeNavas-Walt and Proctor, 2014).

IoT and data analytics or more specifically machine learning – when considered individually neither concept is brand new. Machine learning has been formally defined in the literature since 1980s, IoT is, at its core, a modern and holistic redescription of Internet connected devices and cyber-physical systems (Michalski, 1983, Weiser, 1999). In fact, considered as one of the “founding fathers” of machine learning, Michalski initially worked on computer algorithms to recognize handwriting as early as 1960s, and wrote the first volume of his landmark work “A Theory and Methodology of Inductive Learning” in 1983 which developed the framework for many more algorithms to follow (Michalski, 1983) (Vapnik, 1998). Building on Michalski’s research Vapnik introduced data centered supervised learning on statistical principles in his book titled “Statistical Learning Theory”. Since then, a myriad of machine learning algorithms and principles have followed mainly divided into four main categories: i) supervised learning which assumes completely labeled data in terms of input-output pairs to train an individual algorithm, ii) unsupervised learning which tries to find structures in unlabeled data, iii) semi-supervised learning operating on a mix of labeled and unlabeled data, and finally iv) reinforcement learning which is based upon the idea to maximize a reward function by optimizing specific actions in a given parametric setting (Mohri et al., 2013). Popular traditional algorithms include artificial neural networks (ANN), k-nearest neighbor classifiers (kNN), support vector machines (SVM), classifier ensembles, Bayesian networks, and hidden Markov models (HMM) among many others (McClelland and Rumelhart, 1988, Dudani, 1976, Cortes and Vapnik, 1995, Zhou et al., 2002, Friedman et al., 1997, Rabiner, 1989). In recent years, the concept of “deep learning” has gained significant traction, which attempts to find abstract structures in data without relying on explicit feature extraction common to many supervised learning schemes (Deng and Yu, 2014). As more, or “big” data has become available, it has become practically more feasible to successfully apply algorithms such as convolutional deep belief neural networks, deep Boltzmann machines and sparse auto-encoders for a wide range of applications (Hinton et al., 2006, Lee et al., 2009, Salakhutdinov and Hinton, 2009, Coates et al., 2011).

Similarly, IoT concept, although gaining mainstream attention only recently, was introduced as far back as 1991 in Weiser’s article “The Computer for 21st Century” where he famously claimed “Specialized elements of hardware and software, connected by wires, radio waves and infrared, will be so ubiquitous that no one will notice their presence.” (Weiser, 1999). Considered by some as a mere redescription of computing devices connected to the Internet, IoT examples are widespread (Li et al., 2015). For instance, a wireless sensor network can easily be considered as an IoT framework as long as at least one sensor node has access to a remote server (Dargie and Poellabauer, 2010). Recent developments in radio frequency identification (RFID) domain and its wide-scale adoption in retail and supply chain can easily be considered as modern applications of IoT where Internet connected RFID readers communicate with RFID tags with unique identifiers attached to objects in the environment (Welbourne et al., 2009). Sometimes defined as Web 3.0, which signifies the next generation of ubiquitous computing web, IoT presents remarkable challenges and opportunities at the same time (Gubbi et al., 2013).

Many of these technologies are currently being adopted in the agriculture and food sectors globally. One of the key drivers of this is based on the aforementioned need to increase global food production on an ever shrinking finite resource. Initially this started with enhanced automation, robotics, vision systems and in / on line analytical technologies being incorporated to enhance production visibility and increase operational competitiveness. Such technologies and systems are now being deployed across all sectors of the Agri-food sector globally. It is now common place to deploy a suite of sensors across produce sites and place sensors on animals monitoring a vast array of event for analysis, forecasting, and planning (Adrian et al., 2005) (Stephens et al., 2017).

Similarly whereas advanced analytics and machine learning has been used in the past for general supply chain studies such as demand forecasting, or automatic setup of supply chain network, its applications specific to cold supply chains have unfortunately been very limited (Carbonneau et al., 2008) (Piramuthu, 2005). Again considering the fact that in the United States alone, more than 40% of all produced food is never even consumed; there is a significant margin for improving sustainability and food (Gunders, 2012). Majority of data analytics studies and wireless sensor applications surrounding food supply chain focus on transportation, storage and distribution of perishable food items – commonly called as the cold chain (Regattieri et al., 2007, do Nascimento Nunes et al., 2014, Jedermann et al., 2006, Abad et al., 2009, Hertog et al., 2014). Researchers have proven time and again the incredible potential of reducing food losses by intelligent logistics such as shelf-life prediction and using first-expired-first-out (FEFO) instead of industry standard first-in-first-out (FIFO) (Hertog et al., 2014, Jedermann et al., 2014a). This is made possible through a unique combination of IoT frameworks such as RFID wireless sensor networks and data analytics. The biggest challenge for wide-scale adoption of IoT and associated smart data analytics solutions for the global food cold chain is the cost of implementation (Kelepouris et al., 2007, Angeles, 2005, Jedermann et al., 2009). For example, the most important segment, albeit the weakest link of the food cold chain is transportation from field to the warehouses and stores. It is well-known that the temperature distribution inside a shipping container is anything but uniform, which means perishable products placed at different locations inside the container will ultimately have different qualities, nutritional values, and even bacterial concentrations (James et al., 2006). Hence, in order to truly benefit from an IoT/big data solution, higher-resolution monitoring of the shipping container is necessary which requires more sensors and a higher cost of implementation which is an insurmountable barrier for many packers/shippers/retailers. Recent advances in machine learning can help surpass this limitation by achieving reliable and complete temperature mapping inside, for instance, a refrigerated sea container using only a single container sensor (Badia-Melis et al., 2016). However, as future direction, more research needs to be conducted to i) generalize such findings to different types of containers and ii) more importantly study different types of produce to improve the robustness of the estimation models to a level which is acceptable by the industry as a whole.

Conclusion

To attain and sustain a truly global solution for food insecurity is no simple endeavor, which requires a deep consideration for the concerns of a broad spectrum of stakeholders with an ability to merge both experienced and predicted consequences. Stakeholders include farmers, processors, producers, distributers, wholesalers, retailers, consumers, governments, environmental groups and a plethora of companies supplying goods and services to all of them – all of whom will be responsible for bringing about the policy changes and investment reforms required to achieve a solution. Hence, therein lies a requirement to appreciate the scale of the issue prior to developing strategies. In essence it is important to note that national or even local efforts, although being technically sound, may not have enough potential to create significant impact globally. In developing sure strategic aspirations one must adopt a fully coordinated global effort to achieve sustainable food security.

Equally as important is to successfully merge state-of-the-art research with informed high-level policy across a diverse range of populations and food types. From the complex issues surrounding food security presented herein it is important to remain open to the fact that a sustainable solution to food security will facilitate the improvement and transformation of food supply systems and will provide a level of enhanced transparency (RFID, WSN, IoT), never before experienced in the sector. It will also provide a provision of actionable data (IoT, Big Data) on which more informed decision can be actioned to improve both business and planning decisions.

This must be set within an economic reality, capable of solving a global issue while also being designed to deliver changes locally. It is obvious that a mere increase in production to meet demand is no longer sufficient and a long-term perspective must be adopted and should consider both environmental and social perspectives as well as its financial implications.

For any large scale challenge, it is important to gain a complete understanding of the issue and underlying causes prior to attempting to implement a solution – and food security is no exception. One proposed and widely appraised solution for food insecurity is found in the ability to correctly address the four pillars, food availability, access, utilization and stability, and each of their specific issues. A diverse portfolio of challenges one might expect would be weather extremes including flooding and droughts, political instability leading to supply issues and both product and resource overuse.

Between now 2050 and beyond, global value chains are facing a number of major challenges which need to be addressed to ensure a sustainable and secure supply of food for the world population. As previously mentioned, to achieve global food security, it is most essential that one adopt a strategy of resource efficiency. Resource efficiency aims to ensure that production is sustainable across the entire value chain. It provides an ability to monitor, evaluate and correct any value loss streams while at the same time leveraging the value adding for all relevant stakeholders.

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References

ABAD, E., PALACIO, F., NUIN, M., ZÁRATE, A. G. D., JUARROS, A., GÓMEZ, J. M. & MARCO, S. 2009. RFID smart tag for traceability and cold chain monitoring of foods:

Demonstration in an intercontinental fresh fish logistic chain. *Journal of Food Engineering,* 93**,** 394-399.

ABORISADE, B. & BACH, C. 2014. Accessing the Pillars of Sustainable Food Security. *European International Journal of Science and Technology,* 3.

ADRIAN, A. M., NORWOOD, S. H. & MASK, P. L. 2005. Producers' perceptions and attitudes toward precision agriculture technologies. *Computers and Electronics in Agriculture,* 48**,** 256-271.

AGHDAM, M. S. & BODBODAK, S. 2014. Postharvest Heat Treatment for Mitigation of Chilling Injury in Fruits and Vegetables. *Food and Bioprocess Technology,* 7**,** 37-53.

ANGELES, R. 2005. Rfid Technologies: Supply-Chain Applications and Implementation Issues. *Information Systems Management,* 22**,** 51-65.

ASIANDEVELOPMENTBANK 2013. Food Security in Asia and the Pacific. Philippines: Asian Development Bank.

BADIA-MELIS, R., BRECHT, E., LOWE, A. & UYSAL, I. Pallet wide temperature estimation and mapping for perishable food. Proceedings of the Poster on Annual Conference ASABE, 2013.

BADIA-MELIS, R., J, G., L, R.-G., T, J.-A., VILLALBA, J. I. R. & BARREIRO, P. 2014. Assessing the dynamic behavior of WSN motes and RFID semi-passive tags for temperature monitoring. *Computers and Electronics in Agriculture,* 103**,** 11-16.

BADIA-MELIS, R., MC CARTHY, U. & UYSAL, I. 2016. Temperature prediction and mapping for fruit transportation in refrigerated containers. *Biosystems Engineering,* In Press.

BADIA-MELIS, R., RUIZ-GARCIA, L., GARCIA-HIERRO, J. & VILLALBA, J. I. R. 2015. Refrigerated fruit storage monitoring combining two different wireless sensing technologies: RFID and WSN. *Sensors,* 15**,** 4781-4795.

CARBONNEAU, R., LAFRAMBOISE, K. & VAHIDOV, R. 2008. Application of machine learning techniques for supply chain demand forecasting. *European Journal of Operational Research,* 184**,** 1140-1154.

CARULLO, A., CORBELLINI, S., PARVIS, M. & VALLAN, A. 2009. A Wireless Sensor Network for Cold-Chain Monitoring. *IEEE Transactions on Instrumentation and Measurement,* 58**,** 1405-1411.

COATES, A., LEE, H. & NG, A., Y. An Analysis of Single-Layer Networks in Unsupervised Feature Learning. 14 th International Conference on Artificial Intelligence and Statistics (AISTATS), 2011 Fort Lauderdale, FL, US.

CORTES, C. & VAPNIK, V. 1995. Support-vector networks. *Machine Learning,* 20**,** 273-297.

DABBENE, F., GAY, P. & TORTIA, C. 2014. Traceability issues in food supply chain management: A review. *Biosystems Engineering,* 120**,** 65-80.

DARGIE, W. & POELLABAUER, C. 2010. *Fundamentals of Wireless Sensor Networks: Theory and Practice*, John Wiley & Sons.

DENAVAS-WALT, C. & PROCTOR, B. D. 2014. Income and poverty in the United States: 2013 Current Population Reports,.

DENG, L. & YU, D. 2014. *Deep Learning: Methods and Applications*, Now Publishers.

DERENS, E., PALAGOS, B. & GUILPART, J. The cold chain of chilled products under supervision in France. IUFOST 13th World Congress of Food Science & Technology: Food is Life, 2006 Nantes, France. pp. 51-64.

DO NASCIMENTO NUNES, M. C., NICOMETO, M., EMOND, J. P., MELIS, R. B. & UYSAL, I. 2014. Improvement in fresh fruit and vegetable logistics quality: berry logistics field studies.

Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 372.

DOU, Z., FERGUSON, J. D., GALLIGAN, D. T., KELLY, A. M., FINN, S. M. & GIEGENGACK, R. 2016. Assessing U.S. food wastage and opportunities for reduction. *Global Food Security,* 8**,** 19-26.

DUDANI, S. A. 1976. The Distance-Weighted k-Nearest-Neighbor Rule. *IEEE Transactions on Systems, Man, and Cybernetics,* SMC-6**,** 325-327.

ERS, U. 2017. International Food Security Assessment, 2017-2027.

EU 2015. Closing the loop - An EU action plan for the Circular Economy. *In:* COMISSION, E. (ed.). Brussels: European Comission.

EU. 2016. *Food and drink industry* [Online]. Available: http://ec.europa.eu/growth/sectors/food/ [Accessed 28 August 2016 2016].

FAO 2011. Global food losses and food waste – Extent, causes and prevention.

FAO 2014. Family Farmers Feeding the world, caring for the earth.

FAO 2015a. FAO Statistical Pocketbook. *In:* NATIONS, F. A. A. O. O. T. U. (ed.) 2015 ed.

FAO 2015b. The State of Food and Agriculture. Social protection and agriculture: breaking the cycle of rural poverty. FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS.

FAO, I., WFP 2015c. The State of Food Insecurity in the World 2015. Meeting the 2015 international hunger targets: taking stock of uneven progress. Rome.

FOSTER, A. M., SWAIN, M. J., BARRETT, R. & JAMES, S. J. 2003. Experimental verification of analytical and CFD predictions of infiltration through cold store entrances. *International Journal of Refrigeration,* 26**,** 918-925.

FRIEDMAN, N., GEIGER, D. & GOLDSZMIDT, M. 1997. Bayesian Network Classifiers. *Machine Learning,* 29**,** 131-163.

GIANNAKOUROU, M. C. & TAOUKIS, P. S. 2003. Application of a TTI-based Distribution Management System for Quality Optimization of Frozen Vegetables at the Consumer End. *Journal of Food Science,* 68.

GUBBI, J., BUYYA, R., MARUSIC, S. & PALANISWAMI, M. 2013. Internet of Things (IoT): A vision, architectural elements, and future directions. *Future Generation Computer Systems,* 29**,** 1645-1660.

GUNDERS, D. 2012. Wasted: How America is losing up to 40 percent of its food from farm to fork to landfill. *Natural Resources Defense Council*.

GWANPUA, S. G., VERBOVEN, P., LEDUCQ, D., BROWN, T., VERLINDEN, B. E., BEKELE, E., AREGAWI, W., EVANS, J., FOSTER, A., DURET, S., HOANG, H. M., VAN DER SLUIS, S., WISSINK, E., HENDRIKSEN, L. J. A. M., TAOUKIS, P., GOGOU, E., STAHL, V., EL JABRI, M., LE PAGE, J. F., CLAUSSEN, I., INDERGÅRD, E., NICOLAI, B. M., ALVAREZ, G. & GEERAERD, A. H. 2015. The FRISBEE tool, a software for optimising the trade-off between food quality, energy use, and global warming impact of cold chains. *Journal of Food Engineering,* 148**,** 2-12.

HASHEMI BENI, L., VILLENEUVE, S., LEBLANC, D. I., CÔTÉ, K., FAZIL, A., OTTEN, A., MCKELLAR, R. & DELAQUIS, P. 2012. Spatio-temporal assessment of food safety risks in Canadian food distribution systems using GIS. *Spatial and Spatio-temporal Epidemiology,* 3**,** 215-223.

HEAP, R. D. 2006. Cold Chain Performance Issues Now and in the Future. *Innovative Equipment and Systems for Comfort and Food Preservation.* Auckland, New-Zealand.

HERTOG, M. L. A. T. M., UYSAL, I., MC CARTHY, U., VERLINDEN, B. M. & NICOLAI BART, M. 2014. Shelf life modelling for first-expired-first-out warehouse management. *The Royal Society,* 372.

HINTON, G. E., OSINDERO, S. & TEH, Y.-W. 2006. A fast learning algorithm for deep belief nets. *Neural Comput.,* 18**,** 1527-1554.

IIR. 2009. The role of refrigeration in worldwide nutrition. 5th Informatory Note on Refrigeration and Food. Available: http://www.iifiir.org/userfiles/file/publications/notes/NoteFood_05_EN.pdf [Accessed 26 aUGUST 2016].

JAMES, S. J., JAMES, C. & EVANS, J. A. 2006. Modelling of food transportation systems – a review. *International Journal of Refrigeration,* 29**,** 947-957.

JEDERMANN, R., BEHRENS, C., WESTPHAL, D. & LANG, W. 2006. Applying autonomous sensor systems in logistics—Combining sensor networks, RFIDs and software agents. *Sensors and Actuators A: Physical,* 132**,** 370-375.

JEDERMANN, R., NICOMETO, M., UYSAL, I. & LANG, W. 2014a. Reducing food losses by intelligent food logistics. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences,* 372**,** 20130302.

JEDERMANN, R., PALAFOX-ALBARRÁN, J., ROBLA, J. I., BARREIRO, P., RUIZ-GARCÍA, L. & LANG, W. Interpolation of spatial temperature profiles by sensor networks. Sensors, 2011 IEEE, 2011. IEEE, 778-781.

JEDERMANN, R., PÖTSCH, T. & LLOYD, C. 2014b. Communication techniques and challenges for wireless food quality monitoring. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences,* 372**,** 20130304.

JEDERMANN, R., RUIZ-GARCIA, L. & LANG, W. 2009. Spatial temperature profiling by semi-passive RFID loggers for perishable food transportation. *Computers and Electronics in Agriculture,* 65**,** 145-154.

KELEPOURIS, T., PRAMATARI, K. & DOUKIDIS, G. 2007. RFID-enabled traceability in the food supply chain. *Industrial Management & Data Systems,* 107**,** 183-200.

KOUTSOUMANIS, K., PAVLIS, A., NYCHAS, G. J. & XANTHIAKOS, K. 2010. Probabilistic model for Listeria monocytogenes growth during distribution, retail storage, and domestic storage of pasteurized milk. *Appl Environ Microbiol,* 76**,** 2181-91.

LEBLANC, D. I., VILLENEUVE, S., HASHEMI BENI, L., OTTEN, A., FAZIL, A., MCKELLAR, R. & DELAQUIS, P. 2015. A national produce supply chain database for food safety risk analysis. *Journal of Food Engineering,* 147**,** 24-38.

LEE, H., GROSSE, R., RANGANATH, R. & NG, A. Y. 2009. Convolutional deep belief networks for scalable unsupervised learning of hierarchical representations. *Proceedings of the 26th Annual International Conference on Machine Learning.* Montreal, Quebec, Canada: ACM.

LI, S., XU, L. D. & ZHAO, S. 2015. The internet of things: a survey. *Information Systems Frontiers,* 17**,** 243-259.

MAGGIO, A., CRIEKINGE, T. V. & MALINGREAU, J. P. 2015. Global Food Security 2030 - Assessing trends with a view to guiding future EU policies. *In:* REPORTS, J. S. A. P. (ed.).

MAHAJAN, P. V., CALEB, O., SINGH, Z., WATKINS, C. & GEYER, M. 2014. Postharvest treatments of fresh produce. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences,* 372**,** 20130309.

MARTINCUS, C. V. & GRAZIANO, A. 2012. Customs as Doorkeepers: What Are Their Effects on International Trade? : Inter - American Development Bank.

MC CARTHY, U., AYALEW, G., CORKERY, G., LANIEL, M., UYSAL, I., BUTLER, F., MCDONNELL, K., WARD, S. & EMOND, J. P. 2012. RFID and the EPCGlobal network as a pivotal tool in the development of a sustainable organisational compeditive advantage *In:* NELSON, W. D. (ed.) *Advances in Business and Management. .* Nova Publishers.

MCCARTHY, U., AYALEW, G., BUTLER, F., MCDONNELL, K. & WARD, S. 2011. The case for UHF RFID application in the meat supply chain in the Irish context: a review perspective. *Agricultural Engineering International: the CIGR Ejournal,* 13.

MCCARTHY, U., UYSAL, I., LANIEL, M., CORKERY, G., BUTLER, F., MCDONNELL, K. & WARD, S. 2013. Sustainable Global Food Supply Networks. *In:* NORTON, T., TIWARI, B. & HOLDEN, N. (eds.) *Sustainable Food Processing.* Wiley-Blackwell.

MCCLELLAND, J. L. & RUMELHART, D. E. 1988. *Explorations in parallel distributed processing: A handbook of models, programs, and exercises*.

MCKELLAR, R. C., LEBLANC, D. I., RODRÍGUEZ, F. P. & DELAQUIS, P. 2014. Comparative simulation of Escherichia coli O157:H7 behaviour in packaged fresh-cut lettuce distributed in a typical Canadian supply chain in the summer and winter. *Food Control,* 35**,** 192-199.

MCMURRAY, G., ARRUDA, C., BRITTON, D., EIDENBERGER, T., EVANS, S., GIBNEY, M., MC CARTHY, U., MORAN, L., OPARA, L., SANER, S. & WEST, J. 2013. Food Security: A Systems Approach. EU Science: Global Challenges and Global Collaboration.

MERCIER, S., VILLENEUVE, S., MONDOR, M. & UYSAL, I. 2017. Time–Temperature Management Along the Food Cold Chain: A Review of Recent Developments. *Comprehensive Reviews in Food Science and Food Safety,* 16**,** 647-667.

MICHALSKI, R. S. 1983. A Theory of Methodology of Inductive Learning," Machine Learning: An Artificial Intelligence Approach. Springer-Verlag Berlin.

MOHRI, M., ROSTAMIZADEH, A. & TALWALKAR, A. 2013. *Foundations of Machine Learning*, The MIT Press.

NRDC. 2016. *http://www.savethefood.com/* [Online]. Natural Resources Defense Council. Available: http://www.savethefood.com/ [Accessed 28 August 2016 2016].

OECD 2013a. AID FOR TRADE AND VALUE CHAINS IN TRANSPORT AND LOGISTICS.

OECD 2013b. INTERCONNECTED ECONOMIES: BENEFITING FROM GLOBAL VALUE CHAINS – SYNTHESIS REPORT.

OLSEN, P. & BORIT, M. 2013. How to define traceability. *Trends in food science & technology,* 29**,** 142-150.

PETERSEN, A. & GREEN, D. 2005. Seafood Traceability: A practical guide for the US industry. North Carolina: National Fisheries Institute, Inc and North Carolina Sea Grant, nd.

PIRAMUTHU, S. 2005. Knowledge-based framework for automated dynamic supply chain configuration. *European Journal of Operational Research,* 165**,** 219-230.

QI, L., XU, M., FU, Z., MIRA, T. & ZHANG, X. 2014. C 2 SLDS: a WSN-based perishable food shelf-life prediction and LSFO strategy decision support system in cold chain logistics. *Food Control,* 38**,** 19-29.

RABINER, L. R. 1989. A tutorial on hidden Markov models and selected applications in speech recognition. *Proceedings of the IEEE,* 77**,** 257-286.

REGATTIERI, A., GAMBERI, M. & MANZINI, R. 2007. Traceability of food products: General framework and experimental evidence. *Journal of Food Engineering,* 81**,** 347-356.

SALAKHUTDINOV, R. & HINTON, G. Deep Boltzmann Machines. *In:* (AISTATS), T. I. C. O. A. I. A. S., ed., 2009 Clearwater Beach, Florida, USA.

SÁNCHEZ-LÓPEZ, T. & KIM, D. 2008. Wireless sensor networks and RFID integration for context aware services. *In White Paper Series 2008; AUTOIDLABS-WP-SWNET-026, Daejeon, Korea, 2008.*

SPINK, J., MOYER, D. C. & SPEIER-PERO, C. 2016. Introducing the Food Fraud Initial Screening model (FFIS). *Food Control,* 69**,** 306-314.

STEPHENS, E. C., JONES, A. D. & PARSONS, D. 2017. Agricultural systems research and global food security in the 21st century: An overview and roadmap for future opportunities. *Agricultural Systems*.

TENENBAUM, D. J. 2008. Food vs. Fuel: Diversion of Crops Could Cause More Hunger. *Environmental Health Perspectives* [Online], 116. Available: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2430252/ [Accessed 28 August 2016].

TROMP, S.-O., RIJGERSBERG, H., PEREIRA DA SILVA, F. & BARTELS, P. 2012. Retail benefits of dynamic expiry dates—Simulating opportunity losses due to product loss, discount policy and out of stock. *International Journal of Production Economics,* 139**,** 14-21.

USDA. 2016. *Ag and Food Sectors and the Economy* [Online]. Available: http://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/ag-and-food-sectors-and-the-economy.aspx [Accessed 22 August 2016.

VAN DORP, K.-J. 2002. Tracking and tracing: a structure for development and contemporary practices. *Logistics Information Management,* 15**,** 24-33.

VAPNIK, V. N. 1998. *Statistical Learning Theory*.

VARED SARAH, F. E. 2016. A ROADMAP TO REDUCE U.S. FOOD WASTE BY 20 PERCENT.

WEISER, M. 1999. The computer for the 21<supscrpt>st</supscrpt> century. *SIGMOBILE Mob. Comput. Commun. Rev.,* 3**,** 3-11.

WELBOURNE, E., BATTLE, L., COLE, G., GOULD, K., RECTOR, K., RAYMER, S., BALAZINSKA, M. & BORRIELLO, G. 2009. Building the Internet of Things Using RFID: The RFID Ecosystem Experience. *IEEE Internet Computing,* 13**,** 48-55.

WORLD-BANK 2012. Connecting to Compete 2012 - Trade Logistics in the Global Economy. *In:* JEAN-FRANCOIS, A., ALINA, M. M., LAURI, O., BEN, S. & DANIEL, S. (eds.). Washington, DC 20433: The International Bank for Reconstruction and Development/The World Bank.

WORLDFOODDAY. 2016. *Ending Hunger Starts with us* [Online]. Available: http://www.worldfooddayusa.org/what-is-wfd [Accessed 28 August 2016 2016].

WRI 2013. Creating a Sustainable Food Future - A menu of solutions to sustainably feed more than 9 billion people by 2050. *In:* INSTITUTE, W. R. (ed.). World Resource Institute.

YOUNG, L. 2012. Our biggest problem? We're wasting food. Canada tosses 40 per cent of the food we produce each year. It's bad for business and bad for the planet., November 2012. Available: http://www.canadiangrocer.com/top-stories/what-a-waste-19736 [Accessed 26 August 2016].

ZHOU, Z.-H., WU, J. & TANG, W. 2002. Ensembling neural networks: Many could be better than all. *Artificial Intelligence,* 137**,** 239-263.