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Global Food Security – Issues, Challenges and Technological Solutions

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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

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

188 With respect to the numerous publications, whitepapers, action groups and national
189 strategies it is clearly evident that maintaining the "status-quo" in terms of simply increasing
190 production to meet current needs is no longer viable. This strategy is not applicable because
191 the global population is expanding rapidly while our food is being produced using shrinking
192 natural resources. A total of 10 million ha of land is lost each year through soil erosion and a
193 further 10 million ha due to irrigation related issues (Maggio et al., 2015). The U.N. has
194 predicted a 0.96% annual increase in the global population between 2015 and 2030 followed
195 by a yearly on year increase of 0.63% between 2030 and 2050, resulting in a global population
196 increase from its current 7.3 billion to 9 billion by 2050. This population growth is expected
197 to occur mostly in the lower income and less developed countries, which traditionally face
198 more significant food security issues compared to developed countries. Therein lies a
199 requirement to adopt a more collaborative vision towards food security encompassing all
200 stakeholders both nationally and internationally. This will require, at the very least, a clear
201 and concise focus on areas such as infrastructure at all actor levels, communication (between
202 all partners of the supply chain), collective efforts, and clearly defined goals just to name a
203 few. There will also be a requirement to clearly focus on issues such as human trends, dietary
204 requirements, urbanization, natural resources and climate change, all of which will be
205 discussed with in more detail in later sections.
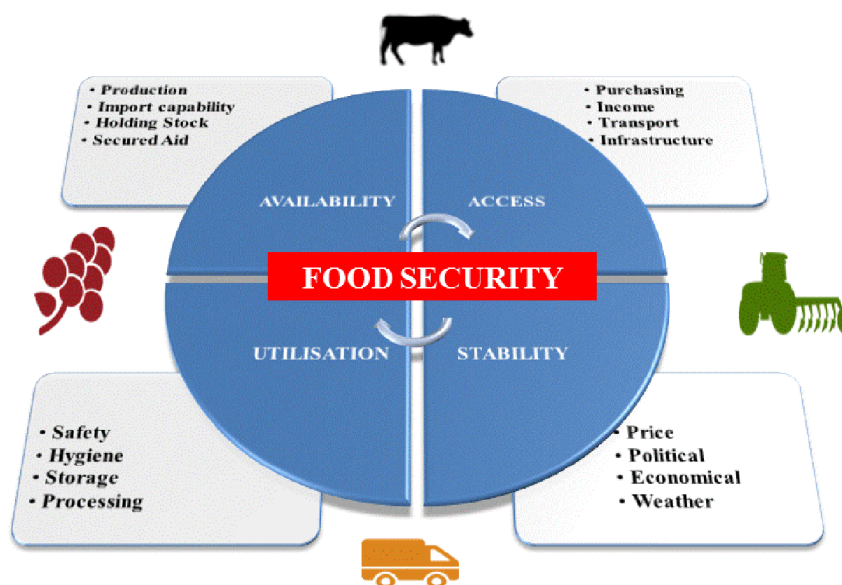
206
207
208 Figure 1 The four Pillars of Food Security>

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

254 have an intimate knowledge of their land: its history, needs and productive capacity and are
255 viewed by many as being custodians of the land as opposed to exploiters (FAO, 2014). The
256 figures discussed in this section serve to remind the readers of the importance of the Global
257 Food sector and security and the impact it has on major global economies.

Global food supply chains

260 There are a variety of definitions for "supply chain management", yet their common aim is to
261 coordinate and integrate all activities relating to a product during processing and transport.
262 Nowadays, food chains have evolved to become highly distributed, heterogeneous,
263 cooperative and globalized processes with extremely diverse requirements, which are in
264 many cases dictated by the product and its eventual destination (Badia-Melis et al., 2014).
265 Global food supply chains represent delicate balances between the transportation of
266 products across the globe while factoring internal considerations such as prevalence of food
267 spoilage, remaining shelf life and an array of external factors such as cost and distance-to-
268 market. The application of appropriate processing of food is of critical importance for
269 achieving sustainable supply. Nevertheless, food transport and distribution cannot be ignored
270 when considering food security and sustainability especially given that the vast majority of
271 food supply chains span globally. When considering the supply chain one must also consider
272 a number of linked activities including sourcing of raw materials and parts, manufacturing and
273 assembly, warehousing and inventory tracking, order entry and order management,
274 distribution across all channels and delivery to the customer (Mc Carthy et al., 2012). To
275 successfully reduce food waste and increase resource efficiency across the farm-to-fork
276 continuum one must adopt a strategic view through combination of local (national) and
277 international perspectives – and key to achieving a global solution lies in the ability to
278 successfully and holistically merge these local solutions.
279 Recent trends towards global trading and the formation of global scale supply networks make
280 the task of supply chain management more and more challenging and have significantly
281 increased competitive pressure. Not only do organizations have to continually evolve and
282 develop new strategies to meet the needs of their customers, they must also develop parallel
283 strategies to outperform their competitors to ensure sustainable corporate success. This
284 reinforces the need for the implementation of state of the art systems including a
285 combination of wireless technologies, operating models, networking protocols, hardware
286 (such as wireless sensor networks (WSN) and radio-frequency identification (RFID)) and
287 software to ensure food is distributed in a safe and secure manner (Badia-Melis et al., 2014).
288 Future developments must be built around sustainable food supply networks using innovative
289 technologies. This can only be achieved in an organizational learning environment, through
290 innovative value adding technologies that will improve the quality of our lives with a
291 negligible cost to the environment or to food security (McCarthy et al., 2013). As previously
292 mentioned current supply chain challenges must be addressed both nationally and
293 internationally given that in many countries, transport and logistics costs can be as high as
294 20%-60% of the food selling price (OECD, 2013a). From a trading and purchasing perspective
295 it is difficult for a manufacturer to export at a competitive price or import at a competitive
296 cost if the transport and logistics sector is volatile and/or dysfunctional (OECD, 2013a).
297 Internationally, recent reports have highlighted that, in some cases, a single day decrease in
298 time spent at sea can increase trade costs to the tune of 4.5% (OECD, 2013b). An investigation

299 within the U.S. reported that reducing shipping times by a single day can yield a 0.8% ad-
300 valorem for manufactured goods. Furthermore, this same single day reduction will also
301 increase the probability (by a factor of 1 to 1.5 %) that the U.S. will import the given product
302 from that country. Based on data from 133 countries' trade facilitation performance (i.e.
303 border streamlining) can be responsible for approximately 14% of the variance in bilateral
304 trade costs across trading partners (OECD, 2013a). Similarly, it has been shown that a single
305 extra day spent in customs causes a 2.8% decline in growth rates of exports for freight in
306 transit (Martincus and Graziano, 2012). These figures confirm the importance of efficient
307 supply chain management at the international level. At national level, it is expected that in
308 countries where there is poor internal connectivity (physical and virtual), the direct and
309 indirect costs associated with food transport are unnecessarily high when set against the
310 aforementioned 20-60% of food prices being governed by transport and logistics costs
311 (World-Bank, 2012). In countries with poor internal connectivity, where transport and
312 logistics services are under-developed, and supply chain governance is poor, both the direct
313 and indirect costs of transporting food from the farm to the consumer are significantly higher
314 when compared to countries with developed connectivity. This leads to inevitably higher
315 consumer prices (OECD, 2013a). Transport and logistics services also affect a country's ability
316 to respond to market price shocks. Lower transport costs can decrease the selling price of
317 imported goods and ensure that a greater share of the selling price of exported goods is given
318 to the producer (OECD, 2013a). Recent OECD research has reported that a 10% improvement
319 in transport and trade-related infrastructure quality can increase developing countries'
320 agricultural exports by as much as 30% (OECD, 2013a).
321 Irrespective of a national or international approach, it is also important to remain cognizant
322 of social movements and population shifts which have created challenges related to
323 consumer demand for specific food regardless of seasonality or geographical location. It is
324 also worth highlighting that efficient food supply chains have the potential to reduce food
325 waste as well as the cost to the consumer given that the cost of food waste is increasing
326 towards the consumer end of the supply chain. It is now clear that improvements in global
327 supply chain management may only be achieved through the implementation of chain wide
328 monitoring systems that facilitate the exchange of information in unison with the product.
329 Such systems will increase the transparency and security of the food supply resulting in more
330 flexible and responsive global supply chains and a reduction in global food waste.
331

Sources and Causes of Global Food Waste

333
334 There are variations in the reported amounts of food wasted globally. The U.N. FAO estimates
335 that each year, approximately one-third of all food produced for human consumption in the
336 world is lost or wasted. Similar reports have documented food waste figures as being as high
337 as 50%. The U.N. Environment Program says that 222 millions of tons are annually wasted in
338 developed countries, almost as much as the entire production of the sub-Saharan Africa (230
339 million tons). A study performed in U.S., Canada, Australia and New Zealand reveals that
340 during production, 20% of the fruit and vegetables are lost; consumers waste up to 28%, and
341 12% is wasted during distribution mainly because of the lack of refrigeration control (Gunders,
342 2012). Irrespective of the aforementioned reports being taken under consideration it is clearly
343 evident that global food waste is at unacceptable levels.

344
345   Recent publications have identified that up to 70 to 80% of food waste occurs at customer
346 facing businesses and households in the EU and U.S., respectively. The total cost associated
347 with food waste for the EU-28 in 2012 was estimated at €143 billion. Similar statistics have
348 revealed that the U.S. spends up to $218 billion per year (1.3 % of GDP) on growing, processing
349 and transporting food that is never eaten. This equates to approximately 400 pounds (180 kg)
350 of food wasted per year for every American citizen. In Europe this figure stands at 173 kg of
351 food wasted per year (compared to a total of 865 kg produced). In addition to this critical
352 statistic it is worth highlighting that up to 10 million tons of products are unsold and
353 eventually wasted each year at farms and packing facilities due to aesthetic rejection
354 (consumer will reject based on the appearance). Similarly, in terms of waste recovery it has
355 been reported that less than 10% of waste is recycled at consumer facing businesses, whereas
356 for manufacturers approximately 95% of industrial food waste is recycled, primarily for animal
357 feeding purposes. These statistics lead the authors to assert the point that the introduction
358 of financial implications for volume of wasted food could possibly reduce the overall food
359 waste levels (Vared Sarah, 2016). Even though the cost of food waste is higher at the
360 consumer end of the supply chain, the irony is that this is where the majority of waste occurs
361 (Gunders, 2012) (Maggio et al., 2015). When considering food waste it is important to
362 consider the many factors which also have an impact on this issue. Factors include the
363 different stages of the food product life cycle, which include primary production, processing,
364 wholesale and logistics, retail and markets, food services and household consumption. Figure
365 2 presents a breakdown of the sources of food waste across the value chain from both a
366 European and US perspective.
367
368
369
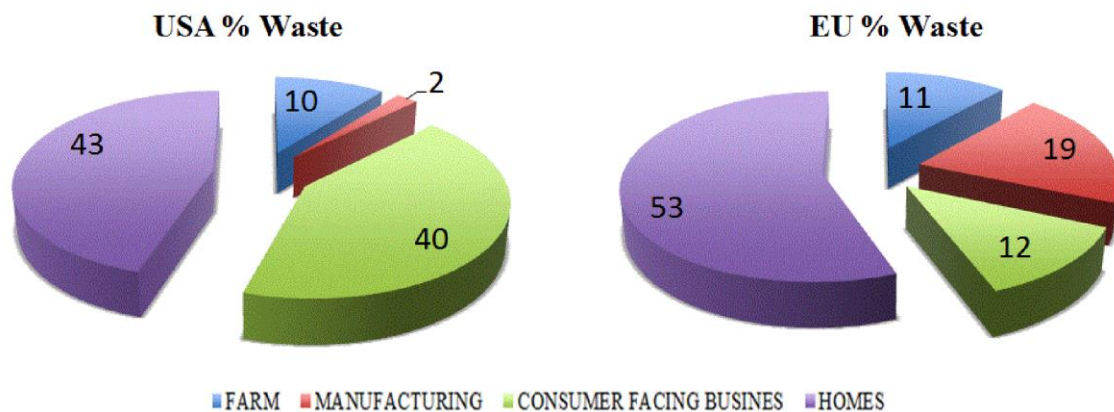
370
371 **Fig 2 Main sources of Food Waste in the EU and US**
372
373
374   It is clear that food waste in the world is at unacceptable levels, however, as can be seen from
375 Figure 2 it is also important to note that the volume and stage of supply at which the food is
376 wasted also varies according to the food type and geographical location. To facilitate the
377 adoption of a systematic global approach towards a solution, one should be open to the idea
378 that the issues of waste in one geographical region or sector may already be solved in another
379 geographical area. Nevertheless, each demographical factor would present its own challenges
380 as well. For instance, the causes of food losses and waste in low-income countries are mainly

381 connected to financial, managerial and technical limitations in harvesting techniques, storage
382 and cooling facilities in challenging climates, infrastructure, packaging and marketing systems
383 (FAO, 2011). This may not necessarily be the case in developed countries where the main
384 causes of waste can all too often be linked to purchasing patterns and education therefore
385 supporting that both local and international perspectives are required for a solution. The net
386 result is that full stakeholder engagement is critically important in delivering a sustainable
387 solution.
388

Factors affecting Food Security

390
391 The EU has revealed that the food and drink industry is facing a decrease in competitiveness
392 which may be linked to a lack of transparency in the food supply chain, sub-optimal business-
393 to-business relationships, a lack of attractiveness for skilled workers, and a lack of market
394 integration across EU countries (EU, 2016). These issues are not exclusive to the EU and can
395 be directly attributed to food security challenges being experienced across other geographical
396 regions. While it has been presented thus far that there is no single solution for solving global
397 food security, it can also be deduced that there is no single root cause for the issue. This
398 section outlines some of the major causes of global food insecurity which should be taken
399 into consideration to identify the critical factors towards achieving a solution. To address
400 these issues correctly the authors focus on the definition of food security according to the
401 FAO as a time *"when all people, at all times, have physical, social and economic access to*
402 *sufficient, safe and nutritious food which meets their dietary needs and food preferences for*
403 *an active and healthy life"*. The concept of food security is built on 4 key pillars, each with its
404 own core focus (figure 1). Each pillar is of equal importance and must be treated with equal
405 levels of consideration. These four key pillars are (Aborisade and Bach, 2014)
406 **i. Food Availability**. This pillar entails having an adequate quantity of food available at minimal
407 notice. This pillar considers food that is either produced locally by Food Business Operators
408 or imported via the importing capacity of the region. It may also consider existing food stocks
409 within a particular region and also the provision for food aid that have been assigned from
410 other countries. It is also important to note that high food availability is not in itself sufficient
411 to ensure food security (FAO, 2015a).
412 **ii. Food Access**. This pillar considers both the physical and/or economic access to food. Factors
413 of importance here include the purchasing power of a particular region and the levels of
414 income (per population) relative to other regions. Other factors for consideration include
415 local infrastructures, such as transport modalities and or financial means to support trade
416 within/across a particular region.
417 **iii. Food Utilization.** This pillar focuses on the entire supply chain and deals with the way in
418 which the food is handled from a safety perspective. It focuses on hygiene across primary
419 production, secondary processing, distribution, retail and household. This requires the
420 creation of efficient and safe usage of food and also the creation of nutritional awareness
421 across stakeholders to ensure that they become more nutritionally aware of different foods
422 and their respective benefits.
423 **iv. Food Stability.** This pillar focuses on stability mainly from a supply and access perspective.
424 Common factors with the potential to impact food stability include price, political stability and
425 the local economy. Other factors which cannot be ignored include weather patterns with a

426 negative impact on crop yields. It is generally accepted that the poorer the nation, household
427 or consumer, the more susceptible it is to external factors (FAO, 2015a).
428
429 As previously mentioned there is no single cause or solution to the issue of food security. The
430 following section will outline some of the wider cross cutting causes and/or factors affecting
431 global food insecurity.
432
433 **Population Increase:** As previously mentioned, the U.N. has predicted an 0.96% annual
434 increase in the global population between now and 2030 and thereafter a yearly increase of
435 0.63% through 2050 resulting in an overall global population increase from its current 7.3
436 billion (UNFPA) to 9 billion in 2050. This population growth is expected to occur mostly in the
437 lower income, developing countries, which traditionally have faced more significant food
438 security issues than developed countries.
439
440 **Urbanization:** By 2050 it is expected that more than 65% of the population will be living in
441 urban areas. This trend of urbanization will occur mainly in low-income countries and will be
442 a key driving force behind the creation of dense demand pockets throughout the world
443 placing increased demand on food supply chains.
444
445 **Dietary demands:** An increase in global agricultural and food products of 50% by 2030 and
446 110% by 2050 will be required to meet the demands of growing population and rising
447 incomes. As an example, it has been predicted that there will be a 40% increase in demand
448 (kg per person per year) for meat in higher income countries and a 69% increase in lower
449 income countries between 2015 and 2050. Similarly, the demand for dairy products is
450 expected to increase by up to 70% between 2000 and 2050 (Maggio et al., 2015). Globally,
451 the average annual increase of total food production between 1961 and 2011 was 122 MMT
452 (Million Metric Tonnes) (Dou et al., 2016)
453
454
455 **Natural resources:** This is collectively considered under a combination of urbanization, poor
456 water management and poor soil conditions, all of which are major factors contributing to
457 soil becoming unfit for agriculture. Similarly we cannot ignore other critical natural resources
458 such as energy utilization and fuel dependence, which also directly have the potential to
459 undermine global food security if not managed and monitored correctly. We should aim to
460 exploit renewables where possible to reduce out carbon output. It has been reported today,
461 humankind use roughly one-half of the planet's vegetated land to grow food (WRI, 2013).
462 Similarly, it is estimated that approximately 10 Million ha of land is lost each year through soil
463 erosion and a further 10 million ha due to irrigation related issues (Maggio et al., 2015). Water
464 is currently over-exploited and not treated as a valuable resource in the agri-food industry
465 which is responsible for 70% of global fresh water consumption. In practical terms, the NRDC
466 has reported that the volume of water consumed by running a domestic shower for 104
467 minutes is equal to the water required to produce a pound of chicken. Similarly the
468 production of 1 pound (0.45 Kgs) of tomatoes, bananas, white rice and beef requires 5, 42, 60
469 and 370 minutes, respectively, of running water from a domestic shower (NRDC, 2016).
470
471 **Climate change:** It is of common knowledge that local climate variations are exploited to
472 promote cultivation of certain products. Climate shifts and changes in weather patterns have

473 drastic effects on the productivity and economic prosperity at regional level and may in turn
474 lead to population displacement and resource depletion. This in turn has a significantly
475 negative effect on food security from a both a supply and demand perspective at global level
476 as a result of inconsistent supply channels to market.
477
478 **Food *versus* fuel debate:** Stakeholders have major concerns that food supply chains which
479 have been traditionally destined for food production may become redirected towards the
480 production of biofuels due to economic pressure. Traditional crops which have been
481 redirected for the production of biofuels include Maize, Oilseed and Sugar cane. This can
482 significantly decrease access to locally produced foods and can result in local populations not
483 being able to afford locally produced food (Tenenbaum, 2008).
484
485 **Infrastructure**: The issue of infrastructure spans the complete supply chain and is relevant to
486 all stakeholders. At primary production in more developed countries certain products are
487 grown in artificially created environments and require a high degree of control and
488 monitoring while other foods are grown in the traditional farm setting and at the mercy of
489 the weather during that season. At the secondary processing level the more developed
490 countries have the ability to automate and modernize the process or the environment to
491 increase production and in many cases achieve the required scale. Again, many regions do
492 not have highly automated production systems and rely on human effort. At the consumer
493 level the more developed countries can generally offer the consumer products in finely
494 presented and specific packages containing marketing and nutritional information, which also
495 help to extend the shelf life of the food. In less developed countries this is not always the case
496 and products are very much at the mercy of the immediate surrounding in which they are
497 transported and stored. It has been reported that is the same level of refrigeration used in
498 developed countries were to be applied to developing growths this would result in those
499 countries saving approximately 200 million tons (14 % of the countries consumption)
500 (Mercier et al., 2017) . As previously mentioned 31.7 percent of SSA's (Sub-Saharan Africa)
501 population, approximately 301 million people, are food insecure in 2017 which can be
502 attributed, in part, to weak currencies and / or disruptions along the food supply chain (ERS,
503 2017).
504
505 **Communication:**
506 Communication across all supply chain stakeholders is critical. It is well-established that an
507 ability to create information sharing channels across stakeholders can significantly increase
508 profits and reduce food waste (McMurray et al., 2013) (Mc Carthy et al., 2012). These
509 information sharing channels improve transparency across trading partners and increase the
510 amount of information available on the arrival date of particular goods, such as information
511 on its remaining shelf life and also significantly improve warehouse management and
512 logistical efficiency (Hertog et al., 2014).
513
514

515 # Future food Security - Global action plans and visions
516

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

563 summarizes the requirements for the development of a Food Security Framework as outlined
564 above.
565
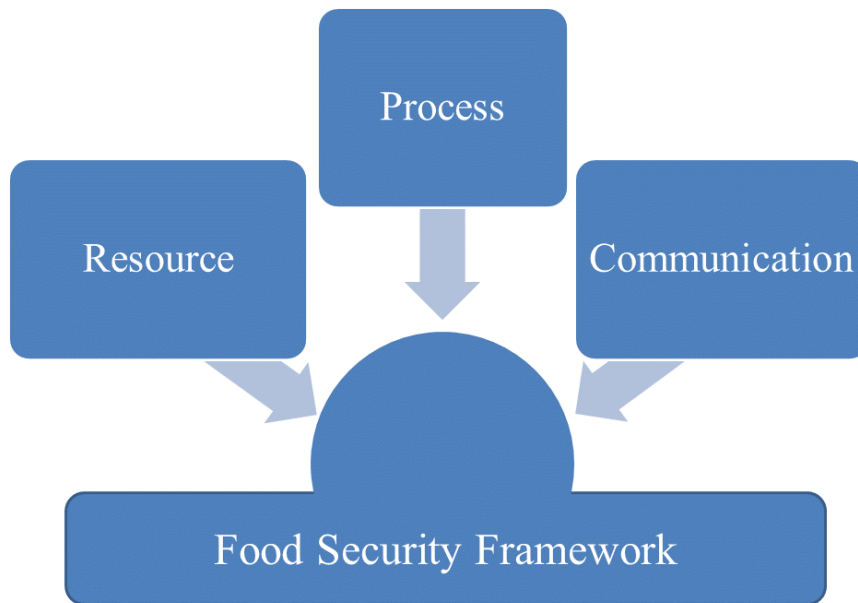
566
567 **<Insert Color Figure 3 here: 3 Food Security Framework>**
568
569 Generic strategies and areas of development in recent times with respect to food security
570 include, but are not limited to the following.
571

Standardized Food traceability systems

573 Traceability is defined as "*the ability to access any or all information relating to that which is*
574 *under consideration, throughout its entire life cycle, by means of recorded identifications*"
575 (Olsen and Borit, 2013). It is important to note that traceability needs both "tracing" and
576 "tracking" capabilities. According to (Petersen and Green, 2005), tracing is the backward
577 process where the product's origin is identified by history and/or stored records in supply
578 chain and tracking is the forward process where the end users and trading partners are
579 identified by location in supply chain. Tracking requires the ability to monitor the location of
580 an asset in real or near real-time (McCarthy et al., 2011). Collectively, both elements provide
581 the basis of a successful traceability system (Van Dorp, 2002). To function correctly and
582 efficiently, a traceability system must also be both scalable and standardized. The system
583 must be scalable in order to meet the requirements of the modern day global consumer and
584 also standardized to ensure that the items being tracked do not become hindered by
585 challenges including language barriers and or counterfeit product.
586 The unfortunate reality is that current traceability systems are characterized by their inability
587 to link food chains records, information inaccuracy and errors in records, which delays the
588 transmission of essential information during time of food recalls (Badia-Melis et al., 2015).
589 Effective traceability systems should have the ability to address the recall by firstly identifying
590 potentially at risk products and then withdrawing the unsafe ones. Such systems therefore
591 need to be flexible and responsive. While being essential in the battle to attain food security
592 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

686　since 1980s, IoT is, at its core, a modern and holistic redescription of Internet connected
687　devices and cyber-physical systems (Michalski, 1983, Weiser, 1999). In fact, considered as one
688　of the "founding fathers" of machine learning, Michalski initially worked on computer
689　algorithms to recognize handwriting as early as 1960s, and wrote the first volume of his
690　landmark work "A Theory and Methodology of Inductive Learning" in 1983 which developed
691　the framework for many more algorithms to follow (Michalski, 1983) (Vapnik, 1998). Building
692　on Michalski's research Vapnik introduced data centered supervised learning on statistical
693　principles in his book titled "Statistical Learning Theory". Since then, a myriad of machine
694　learning algorithms and principles have followed mainly divided into four main categories: i)
695　supervised learning which assumes completely labeled data in terms of input-output pairs to
696　train an individual algorithm, ii) unsupervised learning which tries to find structures in
697　unlabeled data, iii) semi-supervised learning operating on a mix of labeled and unlabeled data,
698　and finally iv) reinforcement learning which is based upon the idea to maximize a reward
699　function by optimizing specific actions in a given parametric setting (Mohri et al., 2013).
700　Popular traditional algorithms include artificial neural networks (ANN), k-nearest neighbor
701　classifiers (kNN), support vector machines (SVM), classifier ensembles, Bayesian networks,
702　and hidden Markov models (HMM) among many others (McClelland and Rumelhart, 1988,
703　Dudani, 1976, Cortes and Vapnik, 1995, Zhou et al., 2002, Friedman et al., 1997, Rabiner,
704　1989). In recent years, the concept of "deep learning" has gained significant traction, which
705　attempts to find abstract structures in data without relying on explicit feature extraction
706　common to many supervised learning schemes (Deng and Yu, 2014). As more, or "big" data
707　has become available, it has become practically more feasible to successfully apply algorithms
708　such as convolutional deep belief neural networks, deep Boltzmann machines and sparse
709　auto-encoders for a wide range of applications (Hinton et al., 2006, Lee et al., 2009,
710　Salakhutdinov and Hinton, 2009, Coates et al., 2011).
711
712　Similarly, IoT concept, although gaining mainstream attention only recently, was introduced
713　as far back as 1991 in Weiser's article "The Computer for 21st Century" where he famously
714　claimed "Specialized elements of hardware and software, connected by wires, radio waves
715　and infrared, will be so ubiquitous that no one will notice their presence." (Weiser, 1999).
716　Considered by some as a mere redescription of computing devices connected to the Internet,
717　IoT examples are widespread (Li et al., 2015). For instance, a wireless sensor network can
718　easily be considered as an IoT framework as long as at least one sensor node has access to a
719　remote server (Dargie and Poellabauer, 2010). Recent developments in radio frequency
720　identification (RFID) domain and its wide-scale adoption in retail and supply chain can easily
721　be considered as modern applications of IoT where Internet connected RFID readers
722　communicate with RFID tags with unique identifiers attached to objects in the environment
723　(Welbourne et al., 2009). Sometimes defined as Web 3.0, which signifies the next generation
724　of ubiquitous computing web, IoT presents remarkable challenges and opportunities at the
725　same time (Gubbi et al., 2013).
726　Many of these technologies are currently being adopted in the agriculture and food sectors
727　globally. One of the key drivers of this is based on the aforementioned need to increase global
728　food production on an ever shrinking finite resource. Initially this started with enhanced
729　automation, robotics, vision systems and in / on line analytical technologies being
730　incorporated to enhance production visibility and increase operational competitiveness. Such
731　technologies and systems are now being deployed across all sectors of the Agri-food sector
732　globally. It is now common place to deploy a suite of sensors across produce sites and place

733 sensors on animals monitoring a vast array of event for analysis, forecasting, and planning
734 (Adrian et al., 2005) (Stephens et al., 2017).
735 Similarly whereas advanced analytics and machine learning has been used in the past for
736 general supply chain studies such as demand forecasting, or automatic setup of supply chain
737 network, its applications specific to cold supply chains have unfortunately been very limited
738 (Carbonneau et al., 2008) (Piramuthu, 2005). Again considering the fact that in the United
739 States alone, more than 40% of all produced food is never even consumed; there is a
740 significant margin for improving sustainability and food (Gunders, 2012). Majority of data
741 analytics studies and wireless sensor applications surrounding food supply chain focus on
742 transportation, storage and distribution of perishable food items – commonly called as the
743 cold chain (Regattieri et al., 2007, do Nascimento Nunes et al., 2014, Jedermann et al., 2006,
744 Abad et al., 2009, Hertog et al., 2014). Researchers have proven time and again the incredible
745 potential of reducing food losses by intelligent logistics such as shelf-life prediction and using
746 first-expired-first-out (FEFO) instead of industry standard first-in-first-out (FIFO) (Hertog et
747 al., 2014, Jedermann et al., 2014a). This is made possible through a unique combination of
748 IoT frameworks such as RFID wireless sensor networks and data analytics. The biggest
749 challenge for wide-scale adoption of IoT and associated smart data analytics solutions for the
750 global food cold chain is the cost of implementation (Kelepouris et al., 2007, Angeles, 2005,
751 Jedermann et al., 2009). For example, the most important segment, albeit the weakest link of
752 the food cold chain is transportation from field to the warehouses and stores. It is well-known
753 that the temperature distribution inside a shipping container is anything but uniform, which
754 means perishable products placed at different locations inside the container will ultimately
755 have different qualities, nutritional values, and even bacterial concentrations (James et al.,
756 2006). Hence, in order to truly benefit from an IoT/big data solution, higher-resolution
757 monitoring of the shipping container is necessary which requires more sensors and a higher
758 cost of implementation which is an insurmountable barrier for many
759 packers/shippers/retailers. Recent advances in machine learning can help surpass this
760 limitation by achieving reliable and complete temperature mapping inside, for instance, a
761 refrigerated sea container using only a single container sensor (Badia-Melis et al., 2016).
762 However, as future direction, more research needs to be conducted to i) generalize such
763 findings to different types of containers and ii) more importantly study different types of
764 produce to improve the robustness of the estimation models to a level which is acceptable by
765 the industry as a whole.

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

778 Equally as important is to successfully merge state-of-the-art research with informed high-
779 level policy across a diverse range of populations and food types. From the complex issues
780 surrounding food security presented herein it is important to remain open to the fact that a
781 sustainable solution to food security will facilitate the improvement and transformation of
782 food supply systems and will provide a level of enhanced transparency (RFID, WSN, IoT), never
783 before experienced in the sector. It will also provide a provision of actionable data (IoT, Big
784 Data) on which more informed decision can be actioned to improve both business and
785 planning decisions.
786 This must be set within an economic reality, capable of solving a global issue while also being
787 designed to deliver changes locally. It is obvious that a mere increase in production to meet
788 demand is no longer sufficient and a long-term perspective must be adopted and should
789 consider both environmental and social perspectives as well as its financial implications.
790 For any large scale challenge, it is important to gain a complete understanding of the issue
791 and underlying causes prior to attempting to implement a solution – and food security is no
792 exception. One proposed and widely appraised solution for food insecurity is found in the
793 ability to correctly address the four pillars, food availability, access, utilization and stability,
794 and each of their specific issues. A diverse portfolio of challenges one might expect would be
795 weather extremes including flooding and droughts, political instability leading to supply issues
796 and both product and resource overuse.
797 Between now 2050 and beyond, global value chains are facing a number of major challenges
798 which need to be addressed to ensure a sustainable and secure supply of food for the world
799 population. As previously mentioned, to achieve global food security, it is most essential that
800 one adopt a strategy of resource efficiency. Resource efficiency aims to ensure that
801 production is sustainable across the entire value chain. It provides an ability to monitor,
802 evaluate and correct any value loss streams while at the same time leveraging the value
803 adding for all relevant stakeholders.
804
805

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