WP3: Baseline Study

(Executive Summary to Follow)

Chapter 1: Introduction and literature review

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1. Introduction

Facing unprecedented risks of sea level rise, SalFar sets out to explore the options for farming and food production under increasingly saline conditions. This is essential to preserve natural capital and to strengthen the ecological and socio-economic development of the coastal and peripheral areas of the North Sea Region (NSR).

The overall aim of Work Package 3 is to develop essential baseline environmental information, data and available knowledge to ensure a consistent integration of methods, tools and information flows across work packages and to ascertain the scope for the development of salt-tolerant agriculture. The specific objectives of the Work Package are addressed in the subsequent chapters of this baseline report as follows:

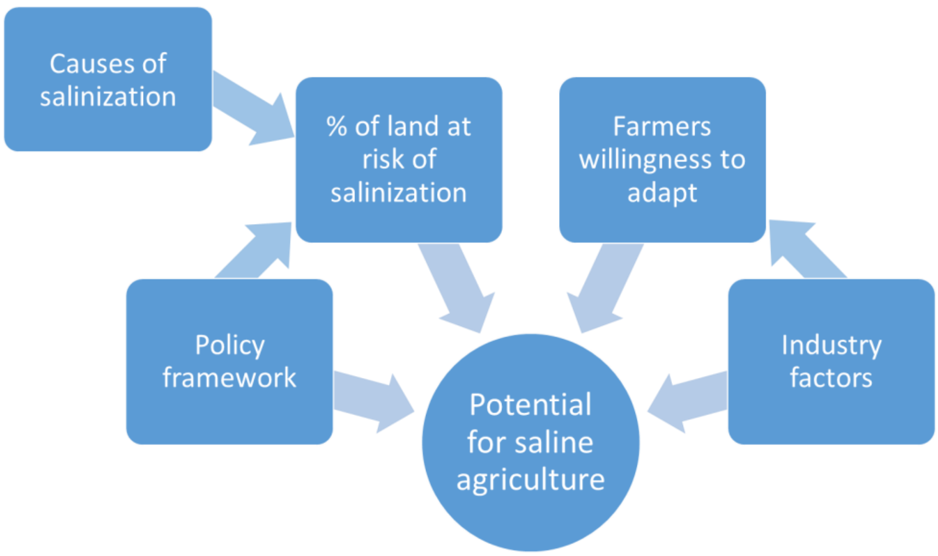
1. An assessment of the economic impacts of salinity-induced land degradation and adaptation options (Chapter 2)

2. A survey of relevant EU agri-environment policies and the development of an indicator framework (Chapter 3)

3. An inventory of the extent and severity of salinity-induced land degradation in the North Sea region (NSR), including the production of "salinization maps", to inform the scope for implementing innovations in salt tolerant and saline agriculture. (Chapter 4)

This Chapter sets out a review of previous research addressing causes and effects of soil salinity in different regions of the world, with particular reference to agriculture and food production. Focusing in on the EU, it summarises the findings of related research projects to inform the analytical components of the Baseline Study as well as the wider activities of SalFar. The last parts of the Chapter present the evidence of saline farming already practiced in some parts of the world as well as baseline data on the environmental footprints of different types of agriculture against which to compare new saline agriculture approaches. The potential of saline agriculture depends on a combination of factors shown in Figure 1.1.

Figure 1.1: Factors influencing the potential for Saline Agriculture



The causes of salinization are described in the SalFar Salinization Framework (Waegermaeker, 2019). These have been categorised into four dominant processes: irrigation; aerosol/wind-blown effects; flooding; and groundwater seepage into the soil. The different causes directly influence the amount of land that is at risk of salinization, as well as the likely intensity of contamination that might occur over time. This alone, however, will not determine the uptake of saline agriculture because the decisions taken by farmers will also be influenced by their own business attitudes, wider industry factors and policy responses. As we explain in Chapter 3, the current EU policy framework pays minimal regard to the threat of salinity for agriculture. A negative response towards salt-threatened lands, for example seeking to intensify production elsewhere to meet growing food demands, would reduce the scope for saline agriculture but SalFar is calling for more progressive thinking that promotes opportunities for saline agriculture.

The wider industry will play a role in determining whether saline products are considered to be commercially attractive. This is being addressed in WP5 and WP6 with work on a range of branding approaches to promote the quality and sustainability of saline products alongside wider awareness-raising campaigns around new salt-tolerant and halophytic crops. The final variable is that of the farmers themselves. Continuing research (Bosworth et al. 2018), is examining the innovative decision making of farmers and rural entrepreneurs and this will identify the key influencers and the factors that shape farmers' choices about new crops or alternative land uses when faced with the need, or opportunity, to innovate.

1.1 Climate threats to Agriculture in the North Sea Region

The wider context of SalFar has been shaped by inter-related and growing concerns over global food demand and climate change threats to agricultural land and production. The central goal of SalFar is to promote resource efficiency by (re)using degraded farmland and reducing fresh water consumption. This can be achieved through the development and marketing of crops that can grow in regions with salt-affected soils and in areas where fresh-water resources are scarcer but access to brackish water is more plentiful.

In order to underpin the work of SalFar and provide a baseline indication of the areas that might be most suited to saline agriculture, clearer mapping of the saline threats is essential. Central to this is the fact that sea level rises continue to lead to intrusion of highly saline seawater inland, posing a threat to coastal areas and an emerging challenge to land managers and policy makers. However, assessing the extent of salinization due to sea water intrusion at a global scale remains challenging (IPCC, 2019a).

Climate change is predicted to impact on coastal areas via three possible ways: (i) mean sea level rise, (ii) increase or decrease of river discharge into the sea estuary and (iii) increase of storm surge intensity that induces seawater overtopping (WGII, 2007). A rising sea level can affect the quality of present groundwater resources by shifting the seawater–freshwater interface position further inland. Increase or decrease of the river discharge into the estuary sea can affect the salinity of the sea water in the estuary, hence the saltwater intrusion into the coastal aquifer can be affected (Werner et al., 2013). Increase of storm surge intensity can result in seawater overtopping when the waves created are high enough to pass over the top of defence structures or when a flood defence fails (EurOtop, 2007). Therefore, flooding of the inland by seawater results in salinization of the superficial and subsurficial zones of the flooded areas (Yang et al., 2015).

Climate change models have investigated the warming during the last decades and the general consensus today is that this trend will continue for the current century (IPCC, 2014). Simulations of climate models have shown that by the end of the century climate patterns of Central and Northern Europe will recall the climate profile of Southern European latitudes as they are today. That is, warmer and dryers summers and milder and rainier winters (Ekström et al., 2005, Fowler et al., 2005, Palmer and Räisänen, 2002, Rowell and Jones, 2006). The predictions in reductions of summer rainfall in all NSR countries (Table 1.1), will result in less freshwater available in summer. This can lead to higher demands on the freshwater system, and as such, more potential for saltwater contamination, either resulting from saltwater intrusion through the groundwater or from the deliberate or accidental use of brackish irrigation water.

Sea level has been rising since the end of the Last Glacial Stage (10,000 years ago), which was then 100 m lower than today. The mean rate of global averaged sea level rise was possibly 1.5 to 1.9 mm/year between 1901 and 2010 and 2.8 to 3.6 mm/year between 1993 and 2010 (IPCC, 2014). Future sea level rise is uncertain but the IPCC (2014) provides a predicted range of 0.18–0.59m global mean sea level rise by the end of the twenty-first century (relative to the end of the twentieth century).

Using the A2 scenario from the IPCC, Table 5.1 presents the potential changes in annual temperature, annual precipitation and sea level for each partner country. The A2 scenario is based on a moderate growth in the economy and slow reduction in GHG (Greenhouse Gas) emissions. It describes a very heterogeneous world (IPCC, 2014).

Table 1.1. IPCC's Climate scenario A2 (year 2100)

	Denmark	**Germany**	**Netherlands**	**Belgium**	**Sweden**
Land					
Annual mean temperature (˚C)	+3.1	+2.9	+2 to +4	+3.6	
Winter temperature	+3.1	+3.6	+1.8 to 4.6	+1.5 to +4	+3 to +5
Summer temperature	+2.8	+2.7	+1.7 to +5.6	+2.4 to +7.2	+2 to +4
Annual precipitation					
Winter precipitation (%)	+43	+25	+7 to +28	0 to +6.4	+40mm to +50mm
Summer precipitation (%)	-15	-5	-38 to +6	-76 to -0	-30mm to +30mm
Max daily precipitation (%)	+21		+8 to +54	+20	
Sea					
Average wind (%)	+4	+5	-2 to +8	+15	-0.2 to +0.2
Max. water level at coast (m)	+0.45 to +1.05 (excl. land subsidence)	+0.94 (incl. land subsidence)	+0.35 to +0.85 (excl. land subsidence)	+0.7	See Figure 4.20 (Ch.4)

Sources: Torben Sonnenborg, GEUS (DK), Hans Sultzbacher, LIAG (DE), Gualbert Oude Essink, Deltares (NL) cited in Auken et al. (2011), Willems et al. (2009) (BE), Statens Offentliga Utredningar (2007) (SE).

Global mean sea level is rising, with acceleration in recent decades due to increasing rates of ice loss from the Greenland and Antarctic ice sheets. Predictions of the pace and severity of climate change impacts at the global scale are far reaching. The latest projections from the Intergovernmental Panel on Climate Change (IPCC), with new models predicting the added effects of polar ice melt, point to a worst-case scenario where sea levels are likely to rise between 61cm and 1.1m by 2100 in the absence of policies to combat climate change (IPCC, 2019b).

With policies to limit global warming to 1.6 °C by 2100, global mean sea level is projected to rise by 0.39 m (0.26–0.53 m, likely range) for the period 2081–2100, and 0.43 m (0.29–0.59 m, likely range) in 2100 with respect to 1986–2005. The uncertainty at the end of the century is mainly determined by the ice sheets, especially in Antarctica (IPCC, 2019b: 23).

Some predictions indicate that The North Sea region will suffer more than others. Vousdoukas et al. (2017) project that the North Sea will to face the highest increase in extreme sea levels, amounting to nearly one metre under a high emission scenario by 2100, followed by the Baltic Sea and Atlantic coasts of the UK and Ireland. Coastal impacts in this region are anticipated to be intensified by climate extremes, storm surges and severe weather events in addition to sea level rise.

Given this uncertainty of the degree of impact, it is essential that SalFar provides mitigation options that can be implemented throughout an ongoing period of climate transition. It is not about the need for a solution to a problem that will hit Europe at some unknown time in the future, there is already a need for new agricultural techniques to address soil salinity challenges and the evolution of new technologies and crop selection needs to keep pace with environmental change.

1.2 Global Extent of Salinization

Soil is one of our most important natural resources that provides us with goods and services to sustain life but the health of global soils is threatened by a range of factors including soil erosion, organic carbon loss, nutrient imbalance, acidification, and various forms of contamination, including salinization. Soil salinization is defined as the accumulation of water-soluble salts in the soil to a level that impacts on agricultural production, environmental health, and economic welfare (FAO, 2015). Traditionally soil salinity is measured by testing the electrical conductivity of a solution extracted from a soil with its value given in unit of deciSiemens per metre (dS/m). Water is a poor electrical conductor but when salts are dissolved in it, its conductivity increases dramatically (Douaik, 2005).

Soil salinization one of the major soil degradation threats worldwide, especially in estuarine regions where combinations of ocean warming, sea level rise and tidal changes are projected to expand salinization (IPCC, 2019b). Salinity is both a land-use issue and a water resource issue; it can not only adversely affect plant growth and land productivity but also severely limit potential uses of affected groundwater. As such it a major factor limiting crop production and land productivity, particularly in coastal areas (Jones et al., 2012).

Awareness of the threats of salinity to agricultural production can be traced back over millennia and have even been linked with the decline of ancient civilisations in Sumeria and Mesopotamia (Letey, 2000). Declining yields and shifts toward cultivating more salt-tolerant crops paralleled increasing salinity and long-term degradation of the alluvial plain – a process that could, in Letey's view, be repeated in California. Such fears are extreme but recent estimates indicate that the global extent of primary salt-affected soils is about 955 Mha, while secondary salinization affects some 77 Mha (see section 1.3 for an explanation of primary and secondary salinization). It has also been observed that 58% of affected land is in irrigated areas and that almost 20% of all irrigated land has been reported to be salt-affected (Metternicht and Zinck 2003).

It is estimated that saline and sodic (alkaline) soils cover 932.2 Mha globally, with Europe contributing about 30.7 Mha or 3.3% of the global saline and sodic soils (Rengasamy, 2006). Global soil salinization hotspots include Pakistan, China, United States, India, Argentina, Sudan and many countries in Central and Western Asia. Many of these are in arid climates where salinization is intensified by rapid evaporation, surface water resources are scarce and poor irrigation practices, although offering short term food production gains, often lead to longer term land degradation (Barrica, 1972; Cui et al., 2019; Endo et al., 2011).

As well as these arid regions, soil salinity is also a major challenge in low-lying coastal regions, particularly the heavily populated river delta areas of South and South East Asia. In the monsoon zones, salt water intrusion and coastal tideland reclamation are the major causes, threatening lowland agriculture and especially rice cultivation (FAO, 2015). Coastal soil salinization is accentuated in some areas, notably Bangladesh by upstream abstraction for irrigation which reduces the freshwater flows to dilute and displace seawater. However, while these global threats are very real, and provide potentially important global markets for new crops, the focus of SalFar lies in Europe, and particularly the North Sea Region.

Soil salinity affects an estimated 1 million hectares in the European Union, mainly in the Mediterranean countries, and is a major cause of desertification (Machado and Serralheiro, 2017). Tóth et al. (2008) point out that pockets of soil salinization in North-western Europe are mainly caused by sea-level rise and surface seawater seepage. The EU Soil Geographical Database of Europe (SGDBE) presents, among other threats, salinity and sodicity as a major limitation to agricultural productivity (Tóth et al., 2008) in Europe. According to the FAO Land and Nutrition Management Service (2008), over 6% of the land globally is affected either by salinity or sodicity and their estimations are presented in Table 1.2..

There are different causes of soil salinization, both natural (primary) and human (secondary) that can induce accumulation of salt in soils and water resources. Human induced salinization is mostly associated with poor irrigation practices. The FAO estimates that 34 Mha or 11 percent of the irrigated area are affected by some level of salinity globally (Mateo-Sagasta and Burke, 2010). Pakistan, China, the United States and India represent more than 60 percent of the total (21 Mha). Soil salinity is a major cause of land degradation along the Mediterranean coast, mainly due to human activities, particularly intensive irrigation and excessive use of groundwater and the consequent sea-water infiltration into the groundwater sources (Geeson et al., 2003).

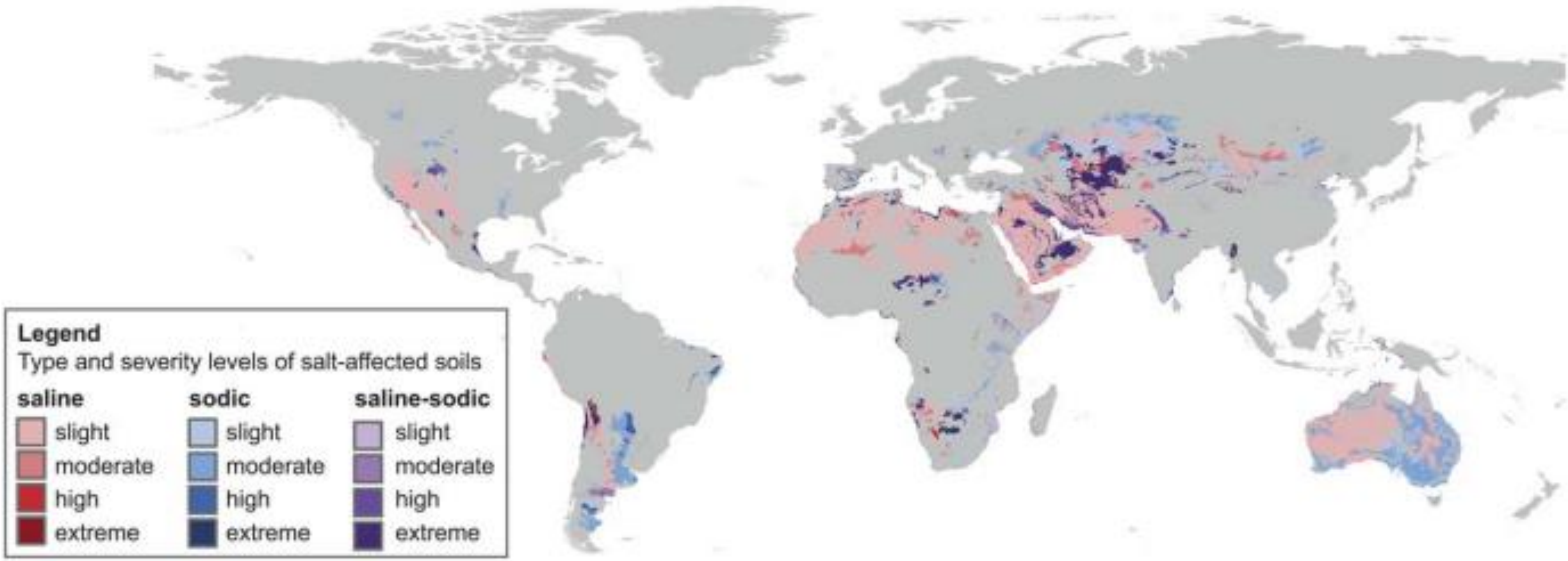
Table 1.2. Area of saline and sodic soils worldwide in million hectares (Mha). *Source: FAO Land and Nutrition Management Service (2008)*

		Saline soils		Sodic soils	
Regions	Total area Mha	Mha	%	Mha	%
Africa	1,899	38	2.0	34	1.8
Asia, the Pacific, and Australia	3,107	196	6.3	249	8.0
Europe	2,011	6	0.3	73	3.6
Latin America	2,039	61	3.0	51	2.5
Near East	1,802	94	5.1	14	0.8
North America	1,924	4	0.2	15	0.8
Total	12,782	399	3.12	436	3.41

The extent and location of salt-affected areas has also been studied by Wicke et al. (2011) who classified salt-affected soils in three categories of saline, sodic and saline-sodic soils: Saline soils are defined the soils with high ECe of the saturated soil extract but with a low exchangeable sodium percentage (ESP); Sodic soils refer to an excessive amount of sodium on the exchange complex of the soil (high ESP) while ECe is low; Saline-sodic soils refer to soils with high ECe and high ESP, while pH is generally below 8.5 (Lamond and Whitney, 1992). Figure 1.2 delineates the severity levels of saline and sodic soils based on the classification system of the US Salinity laboratory and defined based on ECe and ESP (US Department of Agriculture, 1954).

Figure 1.2 Global salt-affected soils, by type and severity *(based on data from the HWSD (FAO, 2008b))*

This map indicates the location of salt-affected soils worldwide but does not properly represent their areal extent as a result of multiple soil units per mapping unit of the HWSD. Multiple soil units are defined because mapping units are not generally homogeneous in soil characteristics. Up to nine soil units may be defined per mapping unit, and the map depicts the whole mapping unit to be salt-affected even if only one of the soil units is salt-affected. Source: Wicke et al. (2011)



Under future climate scenarios, sea level rise and the frequency of storm events is projected to increase, leading to higher occurrence of coastal flooding (Brecht et al., 2012, IPCC, 2007) and subjecting new areas of the globe to greater threat. At particular risk is the North Sea region of Europe, where low lying coastal areas of The Netherlands, Belgium, Denmark, Germany and the United Kingdom (Daliakopoulos et al. 2016) host dense populations, key industrial hubs and highly productive agriculture. For example, in the Mediterranean region, soil salinization affects 25% of irrigated agricultural land (Geeson et al., 2003, Mateo-Sagasta and Burke, 2010). For example, about 3% of the 3.5 Mha of irrigated land in Spain and 9% of the 1.4Mha of irrigated land in Greece is affected by soil salinization due to sea water intrusion. Furthermore, projected changes associated with climate change (temperature increases, changes in precipitation and sea level rise) are likely to exacerbate the problem of salinization in the region (Koutroulis et al., 2013).

The European Soil Data Centre (ESDAC) maintains data on a range of threats to soils across Europe. This illustrates a significant acceleration of soil salinity which in turn provides evidence for the need to develop new agricultural practices to overcome these challenges. The most recent attempts at mapping soil salinity in Europe (Daliakopoulos et al, 2016 – see ch. 4) also sought to identify additional increased risks of salinity by including secondary risks to agricultural and points of seawater intrusion.

In their report for ESDAC, Tóth et al. (2008) noted the limitations of current European and global soil databases and called for additional research to predict the extent of salt affected soils more accurately. We are not aware that the ESDAC or any other organisation has yet acted upon this recommendation and our own efforts to capture new data at the national and regional scale has encountered multiple challenges relating to inconsistent measurement approaches by different stakeholders and many regions with no measurements at all. Therefore the first, and most pressing recommendation from the SalFar baseline study is:

RECOMMENDATION: *To lobby for systematic recording of soil and groundwater salinity, starting with coastal agricultural regions of the NSR and Europe more widely.*

The results of our research into the extent and location of salt-affected areas is set out in more detail in Chapter 4, *Mapping soil salinity in the North Sea Region*.

1.2.1. Measuring soil salinity

SalFar is calling for a more robust, consistent and continuous collection of data to support future work in this field. In particular this should include measurements of both the occurrence of saline groundwater and of saline soils. This is important for extending the coverage and accuracy of salinity risk mapping as well as for informing subsequent attempts to model resulting economic risks.

A number of methods and techniques have been used to characterize salt-affected lands, such as analysis of soil samples in the laboratory or monitoring and mapping via remote-sensing tools (Ivits et al., 2013; Metternicht and Zinck, 2003). Monitoring of salinity identifies the places where salts concentrate and detects the temporal and spatial changes of different salt concentrates. Regular monitoring of soil salinity is considered essential for efficient soil and water management and the conservation of agricultural lands (Bilgili et al., 2011). In relation to soil sample analysis in the laboratory, electrical conductivity (EC) has been well established to measure the ability of soil solution to conduct electricity. Soil salinity is estimated in terms of the total concentration of the soluble salts as measured by the EC of the solution but these methods are time-consuming and costly.

More efficient and economical technologies such as remote sensing (RS), Geographical Information Systems (GIS) modelling, geostatistics and advanced electromagnetic induction are also used for soil salinity assessment, mapping and monitoring. In general, remote sensing operates by using the electromagnetic energy reflected from targets to obtain details about the earth's surface. Therefore, the spectral reflectance of salt features at the soil surface has been used as an indicator for soil salinity assessment and mapping (Allbed and Kumar, 2013). However, high soil moisture or invisible salt crust makes detection of salinity harder which leads to unreliable results. This problem can be solved by detecting soil salinity indirectly using the reflectance from vegetation. Usually, unhealthy vegetation has a lower photosynthetic activity, causing increased visible reflectance and reduced near-infrared reflectance (NIR) from the vegetation (Weiss et al., 2001). Rapid advances in the cultivation of halophytic crops could lead to indices such as the Normalized Difference Vegetation Index (NDVI) requiring some adjustments (Singh et al., 2010). To overcome this problem the Soil Adjusted Vegetation Index (SAVI) and other indices have been developed and with the Generalised Vegetation Index (GDVI) that should allow more sophisticated mapping of soil salinity (Wu, 2014).

1.3 Causes and types of salinization

There are two main drivers or types of salinization; (i) Primary salinization is closely related to the long-term accumulation of salts in the soil profile and, subsequently, in groundwater, but it could also occur as a result of a one-time submergence of soils under seawater (ii) Secondary salinization is caused by human interventions such as the use of salt-rich irrigation water, ill-suited irrigation practices and poor drainage conditions (Tóth et al., 2008).

Each of these main categories are reviewed in the subsequent sections. Focusing down to the North Sea Region, SalFar has produced a separate framework of salinization processes (Waegemaeker, 2019) which can be accessed online here:
https://northsearegion.eu/media/9190/salfar_framework_salinization_processes_finalreport.pdf

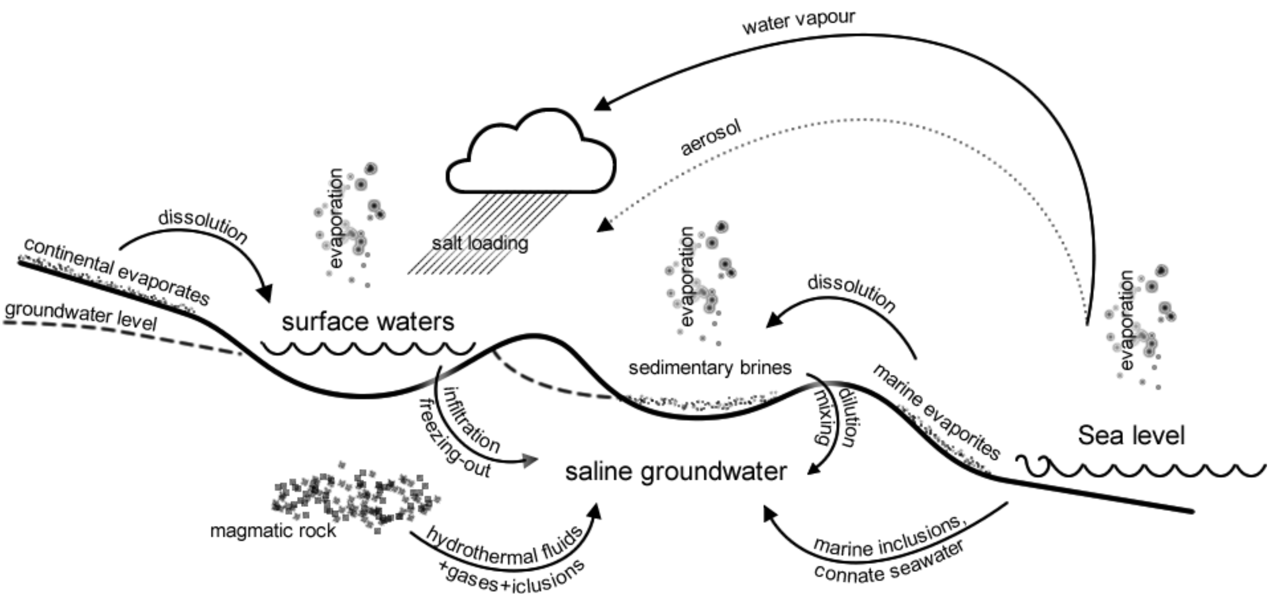
1.3.1 Primary salinization

Primary salinization of soils is closely related to the long-term accumulation of salts in the soil profile driven by natural processes.

In arid and semi-arid regions of the world, climatic conditions are the major driver of soil salinization. In particular, evapotranspiration contributes to a steady and gradual build-up of saline soils, exacerbated by a lack of rainfall which preclude consistent flushing and refreshing of the soil. Consequently, the soil accumulates water soluble salts both in the upper and lower layers. In addition, the salt solution in the lower layers rises to the upper layers by capillarity as a result of evaporation. This type of salinization in Europe occurs mainly in the Mediterranean regions where evapotranspiration often reaches 8-10mm per day (Geeson et al. 2003). In addition, wind in coastal areas can blow moderate amounts of salts inland (Jones et al. 2012).

Soil may also be rich in salts due to parent rock constituents such as carbonate minerals. A closely related phenomenon is that geological events can increase the concentration of salts in groundwater and consequently in soils. This can occur when saline groundwater rises and salts dissolved in the soil moisture accumulate at or near the surface after evaporation of water (Geeson et al., 2003).

Figure 1.3. Primary soil salinization process. Source: Daliakopoulos et al (2016)

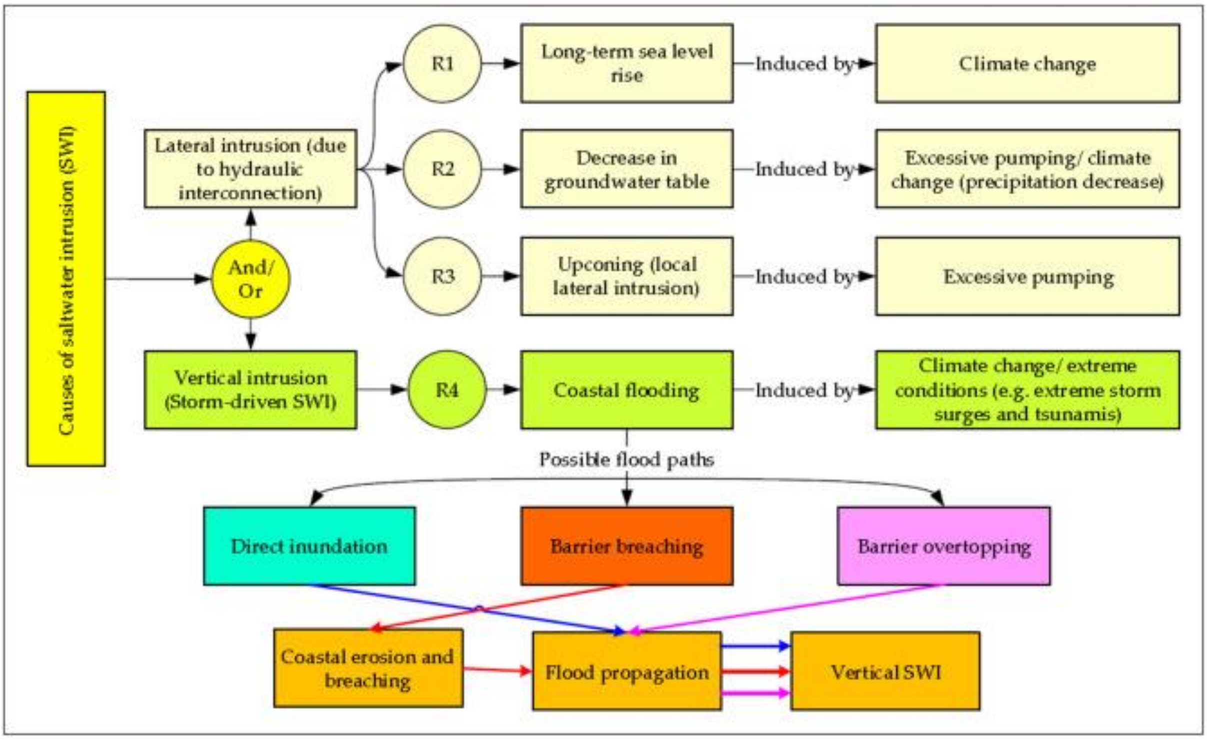


Primary salinization also occurs as a result of the one-time submergence of soils under seawater. Sea level rise may cause flooding of coastal land, either for a long period (sea water intrusion) or for short periods, linked to extreme weather and storm surge events. However, sea level rise and coastal flooding linked to contemporary climate change may be seen as a secondary cause of salinization. Research suggests that sea-levels may rise by one metre or more in the 21st century (Brecht et al. 2012), partly as a result of climate change. Furthermore, a rise in sea levels can cause seawater intrusion into coastal aquifers that are hydraulically connected to the sea, a situation which in the long-term causes the salinization of agricultural water resources, a process frequently exacerbated by excessive groundwater extractions for agriculture (Mateo-Sagasta and Burke, 2010). Sea level rise also induces seepage into areas lying below the sea level (e.g. Netherlands) (Tóth et al., 2008).

Seawater intrusion is caused by prolonged changes (or in some cases severe episodic changes) in coastal groundwater levels due to mainly four reasons: Sea level rise, a decrease in the groundwater table, uwards intrusion and coastal flooding. These are show as R1-R4 in Figure 1.4 and can be induced by various climate variations or sea-level fluctuations, as well as human effects such as excessive pumping and land-use change (Werner et al., 2013; Elsayed & Oumeraci, 2018). Long-term sea level rise decrease in groundwater table and upcoming lateral intrusion are associated with the hydraulic interconnection (like a U-tube manometer) between seawater and groundwater. In the case of long term seal level rise, induced by global warming, the interface between seawater and fresh water moves landward to satisfy again the hydrostatic equilibrium; (Elsayed & Oumeraci, 2018) . This type of intrusion is called lateral intrusion and applies also in the case of a decrease in groundwater table (R2) usually induced either by reduced rainfall rates or by human activities such as excessive pumping.

Upcoming (local) later intrusion represents a special case of R2, which is mainly induced by excessive pumping causing a local lowering of the groundwater table leading to a local shift of the interface that often takes the form of an inverted cone (Werner et al., 2013). The last cause of seawater intrusion is related to coastal flooding and represents the most complex type of intrusion where multiple different flood paths may be possible, variable defences may be in place.

Figure 1.4: Common reasons and involved processes in saltwater intrusion (SWI) into fresh coastal aquifers. Source: (Elsayed & Oumeraci 2018)



1.3.2 Secondary salinization

In contrast to primary salinization, secondary salinization is driven by human activities. These include (a) irrigation with saline water often coupled with poor drainage systems, and (b) over-exploitation of ground water, often for agricultural use. This can be compounded by poor coastal zone management where intensive pumping of groundwater for agricultural use (for example, the coastal aquifers of India, Indonesia and Mexico) and the depletion of coastal aquifers can result in saline intrusion. Furthermore, sea level rise and inadequate coastal protection increases the risk of sea water encroachment into coastal aquifers. (FAO, 2011). Other minor or location-specific causes of salinization driven by human activities include disposal of saline water from industrial operations, use of waste water rich is salts for irrigation, contamination of soils with salt-rich waters and industrial by-products, and periodic application of de-icing agents in temperate industrialized countries contributes to the accumulation of *(a) Irrigation Salinity*

Intensively irrigated agriculture is a major driver of secondary salinization. According to Van Camp et al. (2004), approximately 4 Mha of European soils are assessed as having a moderate to high degree of degradation due to secondary salinization. Although irrigation development has played a vital role in raising agricultural production worldwide, the negative impacts of intensive irrigated farming on soil and water have also been substantial. On-farm, salinization and waterlogging are the main problems. Irrigation induced salinization may come about when irrigation releases salts already in the soil, or when irrigation water or mineral fertilization brings new salts to the land. Waterlogging is a related problem which also often leads to salinization of soils. In almost all countries where land salinization is a major problem, it is accompanied by water salinization (FAO, 2011).

Table 1.3 shows the regional distribution of agricultural land salinized by irrigation and countries with the largest areas salinized. It indicates that, globally, 34 Mha are now impacted (11 percent of the irrigated area).

Table 1.3. Area salinized by irrigation by region (Source Mateo-Segasta & Burke, 2010)

Region/Country	Million ha
South Asia	10.30
East Asia	6.70
Western Asia	6.12
Northern America	5.34
Central Asia	3.21
Southern America	0.95
Sub-Saharan Africa	0.68
Northern Africa	0.68
Australia and New Zealand	0.20
Total	**34.19**

According to a FAO commissioned study (Mateo-Sagasta and Burke, 2010), major irrigation-related salinity problems have been reported in Pakistan, China, United States, India, Uzbekistan, Iran, Iraq, Argentina, Sudan and many countries in Central and Western Asia. Pakistan, China, the United States and India represent more than 60 percent of the total (21 Mha). An additional 60–80 Mha are affected to some extent by waterlogging and related salinity. Although no global assessment exists, the use of saline or sodic water is a common practice in many countries such as Bangladesh, China, Egypt, India, Iran, Pakistan, Syria, Spain and the United States, notably for the irrigation of salt-tolerant plants and trees (Mateo-Sagasta and Burke, 2010). In Mexico, an estimated 20% of irrigated agricultural land (6 Mha) is affected by salinity and sodicity problems. This has led researchers to estimate significant threats to coffee (Brigido et al., 2015) and maize (Terrazas-Mendoza et al., 2010) yields in the coming decades.

Focusing in on Europe, and particularly the North Sea region, the dominant causes of soil salinization are irrigation and sea-level rise combined with seawater seepage into the groundwater. The FP7 project RECARE, presented the regional threats of salinization identifying the following countries at risk under each of three broad causes of salinization illustrated in Table 1.4.

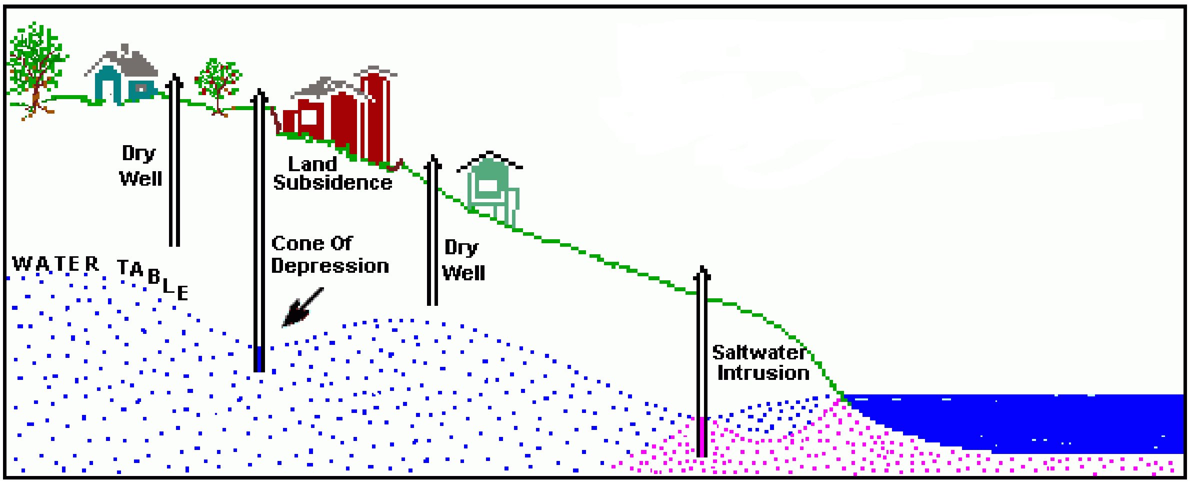
Table 1.4. The distribution of causes of salinization across Europe.
Source: https://www.recare-hub.eu/soil-threats/salinization

Salinization Causes	Locations
Naturally induced saline soils	Spain, Hungary, Slovakia, Greece, Austria, Bosnia, Serbia, Croatia, Romania and Bulgaria
Artificially induced salinization, such as irrigation	Italy (e.g. Campania and Sicily), Spain (e.g. the Ebro Valley), Hungary (e.g. Great Alfold), Greece, Cyprus, Portugal, France (West coast), the Dalmatian coast of the Balkans, Slovakia and Romania. Also in North Europe countries (e.g. Denmark, Poland, Latvia, and Estonia)
Sea-level rise and surface seawater seepage and seawater infiltration into the groundwater	Western Netherlands, Belgium, North-eastern France, and South-eastern England

(b) Groundwater overexploitation and groundwater depletion

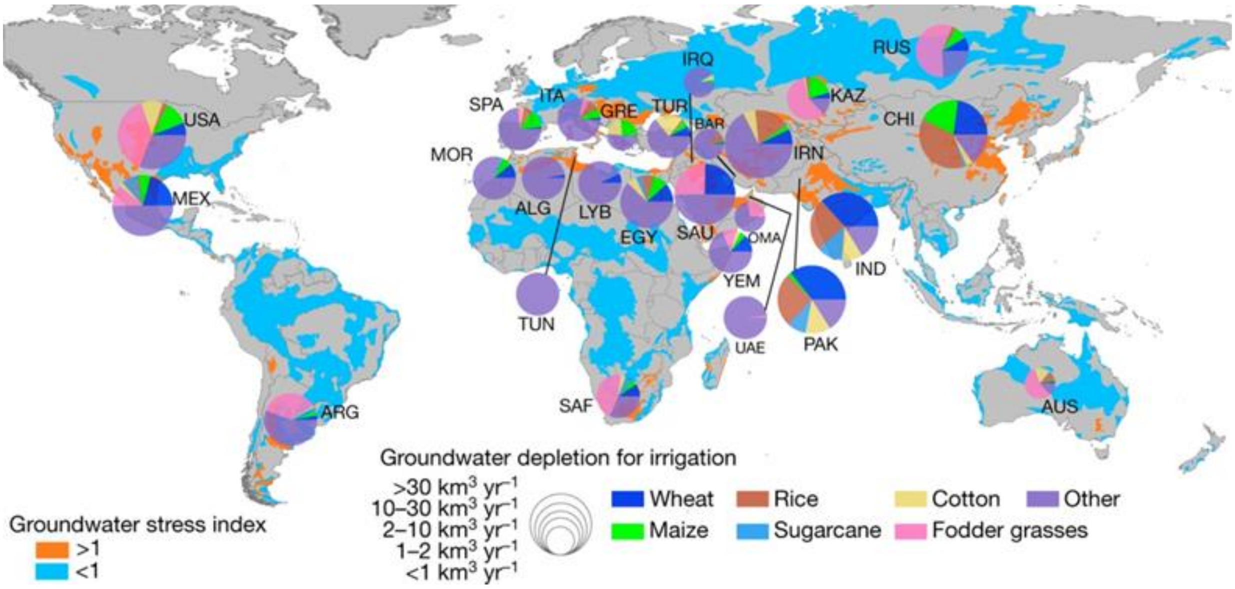
Although ground water abstraction has provided an invaluable source of ready irrigation water, there is increasing global concern over unsustainable use of ground water resources. A global inventory of groundwater use in agriculture conducted by FAO (Siebert & Döll, 2010) indicates that almost 40 percent of the global irrigated area is now reliant on groundwater. However, groundwater depletion as a consequence of intensive agriculture is a rising problem which has led to depletion of key coastal aquifers and the concomitant problem of salinization of groundwater resources. Key food-producing regions around the world (such as north-western India, the North China Plain, the central USA and California are facing the problem of groundwater depletion (Famiglietti, 2014, Wada et al., 2012). This may occur when saline irrigation drainage water percolates to an aquifer. Salty groundwater may also contribute to salinization, when the water table rises (e.g. following irrigation in the absence of proper drainage), the salty groundwater may reach the upper soil layers and, thus, supply salts to the root zone.

Figure 1.5. Impacts of overpumping of groundwater and groundwater depletion Source: *US Geological Survey (2016)*



Global groundwater depletion (GWD) has increased by 22% in ten years, from 240 km^3 in 2000 to 292 km^3 in 2010. Over this period, global GWD has increased mostly owing to rises in India (23%), China (102%) and the USA (31%). India has the largest GWD for wheat and rice (31.3 km^3 yr−1 and 21.3 km^3 yr−1, respectively), and China and the USA dominate GWD for maize (4.7 km^3 yr−1 and 3.0 km^3 yr−1, respectively). The pie charts in Figure 1.6 show fractions of groundwater depletion for irrigation of major crops by country, and their sizes indicate total GWD volume. The background map shows groundwater stress index (corresponding to overexploitation when larger than one) of major aquifers (Gleeson et al., 2012). Some countries have overexploited aquifers but no pie chart is shown because groundwater use is not primarily related to irrigation.

Figure 1.6. Crop-specific contribution to groundwater depletion worldwide in 2010 Source: *Dalin et al. (2017)*



This framework recognises Irrigation, Seepage (from groundwater), Flood and Aerosol (wind-blown) processes as the four principal routes through which saline water can contaminate agricultural soils.

1.4 Impacts of soil salinity

A useful summary of the scope of wider impacts of salinization is provided by the FAO and summarised in Table 1.5. This section proceeds to review physical impacts before moving on to previous economic impact studies that inform our own calculations of the economic risks of increasing salinization in Chapter 2.

Table 1.5. A summary of the impacts of salinization, sodication and waterlogging (FAO, 2018)

Impacts on Crop Production	Impacts on living conditions of farmers and the economy	Impacts on ecosystems	Impacts on the quality of natural resources
Decline in soil productivity and crop yields	The reduction of yields results in less income and less food supply, especially in subsistence farming	Reducing the diversity of organisms	Salt-affected soils are fragile and more prone to other forms of degradation, e.g. wind and water erosion
Increased requirement and use of inputs including seeds, water and fertilizers	Working with salt-affected soils requires more labour to reclaim soils	Reducing the efficiency of nutrient cycling	Wind-born salts can reach and damage vegetation, soils and water in nearby areas
Low crop yield per unit of input used	The use of more inputs and the reduction of yields result in less returns	Reducing population sizes of previously dominant species	Water draining out of agricultural fields can increase the salt contents in groundwater and other surface water courses
Less choice in cropping systems, as farmers are forced to cultivate salt-tolerant crops which might not always be high income cash crops	Lowered income and loss of land are often factors for the migration of farmers to cities	Increasing the populations of salt tolerant organisms	Wastewater from reclamation of salt-affected soils, if not disposed of safely, can contaminate other soils and water bodies
Reduced water use efficiency	Soil reclamation programmes are costly	Changing disease patterns and prevalence in different species of plants, terrestrial and aquatic animals and increasing vector-borne diseases	In the case of sodic soils, the loss of organic matter weakens the strength of soil aggregates, increase the loss of nutrients in run-off, and increase carbon dioxide emitted to the atmosphere.
In cases of severe salinization and sodication land cannot be used anymore for production	Rehabilitation programmes to improve the living conditions of those affected require high investments	Salt-affected areas result in sparse vegetation that in turn leads to wind-blown dust storms.	Extreme conditions in sodic soils (pH and sodium salts) decrease water infiltration due to surface sealing and promote runoff during storm events

1.4.1 Physical impacts

The adverse consequences of salinity generally vary, depending on the form and stage of salinization; in its early stages of development reduces soil productivity, but in advanced stages it kills all vegetation and consequently transforms fertile and productive land to barren land (Jones et al., 2012). Thus, salinity is a major factor limiting agricultural productivity and soil quality, particularly in coastal areas. In general, salinity becomes a land-use issue when the concentration of salt or sodium adversely affects plant growth or degrades soil structure. It becomes a water issue when potential uses of water are limited by elevated salt concentration levels.

As alluded to earlier, climate change and a future warmer climate will contribute to variations in the hydrological circle (Vautard et al. 2014), rising sea levels and coastal flooding which, in turn, will increase soil salinity and expansion of salt affected areas. Furthermore, associated with the impacts of climate change is the “dual problem” of (projected) increase in irrigation water consumption with higher global mean temperature (Haddeland et al. 2013) and higher salt content in irrigation water due to evaporation, a situation that is projected to accelerate soil salinization and desertification. An intensified hydrological circle may also trigger an increase of floods and flash floods, thus causing greater release of dissolved salts into the soil in areas with saline geological substrates (Mateo-Sagasta and Burke, 2010).

To date, much of the research into the impacts of salinization, whereby soils contain an excess of water-soluble salts, has focussed on arid and semi-arid regions of the globe (Pitman & Läuchli 2002). These are regions where high rates of surface evaporation, use of salt-rich irrigation, and poor or inappropriate drainage drive salt accumulation in topsoil, resulting in large scale desertification (FAO 2015). In Northern Europe, rainfall rates and lower evaporation are likely to lessen salt accumulation in topsoil, provided adequate soil drainage management is in place. Nonetheless, predicted increases in coastal flooding and rising groundwater salinity of low-lying lands, we anticipate greater salt-damage to maritime climate soils, particularly through the deposition of sodium ions. High sodium levels have direct effects on crop yields by reduced plant nutrient uptake (Abrol et al. 1988), and also has severe consequences for longer term soil function.

Agricultural land degradation is expected to be intensified in saline areas by the impacts upon microorganisms that play a crucial role in soil organic matter mineralization and nutrient cycling. This is because the activity and diversity of microorganisms determine the stability and function of agro-ecosystems, and as a consequence of soil fertility and crop productivity (Leogrande and Vitti, 2018). While many studies have shown that microbial communities and biochemical processes are adversely affected by soil salinity under arid conditions, it is also recognised that salinity may have differing impacts in differing environmental contexts so further research is required to fully understand the impacts on soils (Leogrande and Vitti, 2018).

RECOMMENDATION: *Where brackish irrigation is used, continue to monitor the impacts on soils linked to saline concentration levels.*

1.4.2. Economic Impacts

The economic impacts are set out in Chapter 2 with the principal costs focusing on yield losses to farmers, but also multiplier effects within the agri-food sector, particularly in regions where salinity is a higher risk and where agriculture is a major industry. As with indications of the extent of salinity in groundwater and soils, economic impacts to data have proven to be very challenging to measure. There is a wide variation of yield impacts between and within crop types, (Qadir et al. 2014) making assessments of income effects equally tricky. Nevertheless, looking at previous studies, where annual income losses from salt-affected irrigated areas alone have been estimated to be US$ 27.3 billion (Ghassemi et al. 1995; Qadir et al. 2014), demonstrate that there is a huge potential for new saline innovations to fill an important need in global agriculture.

Economic studies on the impact of soil salinization are even more limited in Europe and again present very broad estimates: e.g. €158–321M based on research in Spain, Hungary and Bulgaria on yield losses plus damages to infrastructure and the environment (Montanarella, 2007) or €600M of direct economic impacts to agriculture focusing on selected rivers and deltas, mostly borne by the delta regions of Germany, the Netherlands and France (Bosello et al., 2012; Richards and Nicholls, 2009). To add to the existing evidence base, Chapter 2 of this Report presents economic impact predictions based on likely future scenarios with increasing soil and groundwater salinity across "at-risk" case study areas of the North Sea Region.

1.5 Agricultural Innovation

Innovation in agriculture is the main driver for improving productivity and delivering growth (OECD, 2013). There is a demand from the European Union's European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI, 2014) for competitive and sustainable farming which 'achieves more and better for less'. This 'sustainable intensification' of farming places emphasis on productivity rises in European agriculture and this innovation needs to be an ongoing activity (Leaver, 2010).

While innovation has traditionally been judged based on Research and Development spending, technology and patents, more recent views recognise that innovation is more collaborative, involving various influences and actors that can change processes and outcomes in different ways (Klerkx et al., 2012). This concept of innovation demands networks through which good practice and new ideas can spread and SalFar has a key role in building local collaboration and wider networks to maximise awareness of saline agriculture as well as widening the testing of new products in different regions. Whichever approach we take, however, there is a clear agreement that knowledge is at the heart of innovation processes (Lapple et al., 2015) and therefore cross-disciplinary and cross-sector partnerships are essential to support developments in saline agriculture.

Farmers operate in an increasingly competitive environment with profit margins squeezed by combinations of increasing input costs and downward pressure on prices through the retail food chain. Environmental challenges form part of the external challenges that will drive innovation in the sector. As a result, farmers have implemented a number of methods to sustain their businesses, including new sources of off-farm income, a range of farm diversification activities (Bosworth and McElwee, 2010) and the intensification and expansion of agricultural production. Agricultural innovation encompasses a range of activities throughout the food supply chain, where farmers can cultivate new crops, apply new land management and improvement techniques, add value to farm produce and even innovate with activities that lie beyond agriculture, as evidenced by increasing pluriactivity and farm diversification across Europe.

Methorst (2016) developed a concept of "perceived room for manoeuvre" to explain the different ways in which farmers perceive different business opportunities. Leaving out the category of "ending farm production", the other three categories which focus on intensification ad production maximisation; optimising the use of on-farm resources; and structuring the farm business around diversified income streams can be aligned to the different innovation pathways that occur on farms. Although Methorst's research was focused on the dairying sector, the concepts are transferable to other types of agriculture. In particular, linking farmers' perceived room for manoeuvre to their networks and their other business skills highlights some important differences. Those pursuing a strategy of maximisation and intensification tended to have a technical and financial outlook on farming with stretched network relations and an industry-scale perspective on competition and value chains. By contrast, those who seek to optimise their on-farm resources are more locally embedded, both in terms of natural and social capitals. The situation is more varied among the diversifiers, and this will depend to a large extent upon the connections between the diversified activities and the traditional agricultural production on the farm (McElwee & Bosworth, 2010).

If farmers are perceiving opportunities differently, it is reasonable to expect that their openness to new innovations will vary in line with the reach of their networks. Building on opportunity-centred approaches to understanding entrepreneurship (Rae, 2015), the nature of new entrepreneurial activity will depend upon combinations of external (the wider economic, location and environmental context) and internal factors (the attitudes and perceptions of farmers). The attitudes and networks of farmers also shape their capacity for entrepreneurial learning (Seuneke et al., 2013), which is essential for farmers seeking to develop their business beyond core agricultural activities. Understanding these issues and capturing the motivations of farmers is essential to inform the marketing messages of SalFar as it is both growers and end-consumers that need to be convinced of the quality of the produce.

RECOMMENDATION: *Ensure that farmer cafés build and strengthen networks and capture the motivations of farmers around innovation and their perceptions of barriers to adopting new crop types.*

1.6 Saline agriculture

Saline agriculture is an innovative strategy for enhancing land and water availability through the use of salted soils and salted water. This strategy is known for the last three decades, for example, the use of seawater for crop production in coastal deserts has already been suggested (Boyko, 1966, Epstein et al., 1980, Glenn et al., 1995, Glenn et al., 1997). Using saline land and saline irrigation water has the potential to achieve better production through a sustainable and integrated use of genetic resources (plants, animals, fish, insects, and microorganisms) avoiding expensive soil recovery measures (Aslam et al., 2009). As well as increasing the cultivation potential of coastal soils, saline agriculture offers scope to innovate with lower inputs and more ecologically sustainable production methods.

As discussed previously, salinity problems are generally most pronounced in arid and semi-arid regions because of insufficient annual rainfall to flush accumulated salts from the crop root zone. These regions are in need to use saline water for irrigation due to the limited water resources and increasing population at the same time. The methods and experiences of using saline water for crop irrigation vary among countries in the Near East and North Africa region (Abou-Hadid, 2003). In Tunisia, for example, saline water is used to irrigate different crops, especially fruit trees. Their experience has shown that irrigating with saline water containing 4g per litre salt affects positively the growth and productivity of some fruit trees such as olives, pistachio, and pomegranate which resulted in a higher and earlier production. In the arid lands of Jordan crops such as barley and onion have grown using saline water too. In Pakistan, quinoa (Chenopodium quinoa) grew and produced well under saline and marginal soil where other crops would not grow (IPCC 2019a).

While there is ample evidence globally that a number of crops can tolerate and even thrive in saline conditions, the mainstream adoption of saline agriculture techniques requires further understanding. To promote innovation and adaptation in the sector, Salt Farm Foundation have identified the four pillars of saline agriculture yield as a guide for growers (Salt Farm Foundation, 2018):

- crop and cultivar choice
- irrigation
- fertilization
- soil management

The choice of **crops and cultivars** is very important, because different crop species differ in their tolerance to salinity. Some species, such as beans, are very sensitive and struggle to survive with salinity levels about one-tenth that of seawater. On the other extreme, salt-tolerant and salt-loving species (halophytes) can survive and reproduce at seawater salinity levels but some of these crops remain niche products within the food chain. Therefore, the challenge to food producers is to raise the profile of these vegetables through marketing and educational campaigns.

Irrigation in saline farming is achieved using combinations of fresh water and brackish water. In both cases it is crucial to irrigate regularly because salts tend to accumulate in the soil when the amount of water decreases due to evapotranspiration. It is expected that clay soils will be less receptive to brackish irrigation due to the impacts on the soil structure but SalFar will carry out trials on a range of soil types to add to the evidence base. Table 1.6 gives a simplified version of the possible scenarios when we combine the presence or absence of soil salinity, two types of soil (sand or clay) and if the irrigation water is fresh or brackish.

Table 1.6. Different combinations of soil type, soil salinity and irrigation water to lead to different forms of agriculture, conventional and saline agriculture. Source: Salt Farm Foundation (2018)

		Irrigation water	
Soil type	**Soil salinity**	**Fresh**	**Salt/brackish**
Sand	Yes	Good possibilities	Good possibilities
Sand	No	Conventional agriculture	Good possibilities
Clay	Yes	Tricky	Not recommended
Clay	No	Conventional agriculture	Not recommended

Fertiliser application in saline agriculture can be problematic in certain cases. For instance, fertilisers can possibly increase the osmotic stress of crops, which is already high due to high EC of the soil. Therefore, the use of foliar fertilizers, applied directly to the leaves of plants, may alleviate this problem. Salinity may cause specific mineral deficits in crops, which may require the application of higher volumes of fertilisers in saline farming than in conventional agriculture (Salt Farm Foundation, 2018). Therefore, the next section sets out the input uses of conventional farming to allow comparisons across the SalFar trials.

Soil management is a broad term capturing a range of other farm level practices including the management of organic matter in the soil, soil tillage practices, bed shape and size, and the application of soil additives. Salinized soil may require certain additives at the start of the growing season, such as gypsum, to alleviate salt stress. A soil management regime should be developed to optimise production in line with local characteristics and factoring in the other 3 variables outlined above.

Drawing from these guidelines, it is essential that the wider SalFar networks recognise the need to adapt methods across different regions and continue to feedback their learning about the efficacy of growing different crops under different conditions.

RECOMMENDATION: *SalFar to instigate a repository of saline agriculture information on crops types and performance, to complement enhanced data on soil and groundwater salinity*

1.7 Eco-footprints of Conventional Agriculture (against which to compare SalFar trials)

Agriculture accounts for 5% of the entire energy used worldwide (Plantis et al. 2019). Modern agricultural practices face criticisms of excessive input use (fertilisers, pesticides and water) as well as challenges to reduce waste products and greenhouse gas emissions. To fully assess the potential for saline agriculture as a sustainable solution for coastal agriculture, we must also consider a range of ecological impacts.

The concept of an ecological footprint was first introduced into the scientific community by Rees and Wackernagel (1994). Subsequently, a variety of footprint indicators have been proposed, including energy footprints (Wackernagel and Rees, 1998), water footprints (Hoekstra and Hung, 2002), carbon footprints (Wiedmann and Minx, 2008), phosphorus footprints (Wang et al., 2011), and nitrogen footprints (Leach et al., 2012).

The ecological footprint is defined as the area of productive land and water required by the ecosystem to produce resources and assimilate the wastes (Cerutti et al., 2013). Ecological footprint indicator is an appropriate index for agricultural production and a good criterion for evaluating energy consumption, greenhouse gas emissions, nitrates' contamination from fertilizers and pesticides, land and water use in agriculture.

1.7.1 The Water Footprint

The water footprint (WF) concept has created awareness of sustainable water use following a global assessment of national production, consumption and international trade (Hoekstra and Mekonnen, 2012). The water footprint is used to compare water use of regions, sectors, commodities and nations. The water footprint has three components:

- Green water footprint is water from precipitation that is stored in the root zone of the soil and evaporated, transpired or incorporated by plants. It is particularly relevant for agricultural, horticultural and forestry products (Ercin et al., 2016).
- Blue water footprint is water that has been sourced from surface or groundwater resources and is either evaporated, incorporated into a product or taken from one source and returned to a different source, or returned at a different time. Irrigated agriculture, industry and domestic water use can each have a blue water footprint. It shows consumptive use of water (Ercin et al., 2016).
- Grey water footprint is an indicator for pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants to meet existing ambient water quality standards (Ercin et al., 2016).

The total volume of water used globally for crop production is 6,390 Gm3/yr at field level. Rice has the largest share in the total volume water used for global crop production. It consumes about 1,359 Gm3/yr, which is about 21% of the total volume of water used for crop production at field level. The second largest water consumer is wheat (12%) (Hoekstra and Hung, 2002).

Mekonnen and Hoekstra (2010) estimated the global irrigated (blue) water footprint of wheat production for the period 1996–2005 is footprint was estimated to be 204 Gm3/yr. The largest water footprints were calculated for India (81 Gm3/yr), China (47 Gm3/yr), Pakistan (28 Gm3/yr), Iran (11 Gm3/yr), Egypt (5.9 Gm3/yr) and the USA (5.5 Gm3/yr). By comparison, Germany (0 Gm3/yr), the UK (2 Gm3/yr) and Denmark (30 Gm3/yr) had the lowest water footprints for wheat production. In this study the water footprint for the rest of the NSR countries was not calculated.

Table 1.7. Production blue water footprint of agricultural sector. Source: Ercin et al. (2016)

Water Footprint of agricultural production (Mm^3/y)									
Country	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**Average**
Belgium	54	54	54	55	57	52	52	50	54
Denmark	104	106	103	107	109	110	104	101	105
Germany	553	551	553	554	547	553	551	552	552
Netherlands	151	159	167	166	167	159	157	166	162
Sweden	51	49	48	47	46	46	46	45	47
UK	266	265	259	269	257	253	254	250	258

The European Environment Agency (EEA) has reported that water resources are already under pressure in many parts of Europe (Werner and Collins, 2012). While, the World Business Council for Sustainable Development (WBCSD) highlights that groundwater is being used at a faster rate than it can be replenished in 60% of the European cities with more than 100,000 inhabitants.

The water footprint was calculated for irrigated crops, such as, grain maize, potato and sugar beet for several European countries (Gobin et al., 2017). Results from the water footprint showed that the lowest irrigation amounts were for potato in the Netherlands (72 ± 47 mm), grain maize in Belgium (92 ± 63 mm) while largest needs in irrigation water were found in drier countries like Italy (Gobin et al., 2017).

The volume of irrigation water varied between the different European regions, reflecting different climatological environments, soil types and growing seasons. This makes it impossible to present a single figure for the North Sea Region but we recommend that any saline agriculture innovator refers to local data on the eco-footprints of conventional agriculture for the purposes of environmental benchmarking.

Calculations can be made based on the water need of crops to meet the water loss through evapotranspiration. The crop water need, assessed under optimal conditions, mainly depends on the climate (sunshine, temperature, humidity and wind speed), the crop type and the growth stage of crop. This has been carried out using data from 2016 for the Wash region (Lincolnshire, UK) generating an estimated water need for potatoes of 422.56mm during that growing season and 212.52mm for wheat in the same growing season. The detailed approach is set out in Appendix 1.

1.7.2 Energy use per crop

Modern agriculture is heavily dependent on fossil resources. Direct energy use (e.g. gasoline, diesel, electricity and natural gases) for crop management and indirect energy use for fertilizers, pesticides and machinery production have contributed to the major increases in food production since the 1960s (Woods et al., 2010). In 2008, the European Council adopted the Climate and Energy Package, in order to deal with climate change and improve the EU's energy security and competitiveness. For instance, among its targets for 2020 was the aim to reduce the EUs GHG emissions by 20% below 2005 levels, to increase by 20% the energy produced by renewable resources and to improve the EU's energy efficiency by 20% (EC, 2010). Therefore, the potential for salt tolerant crops to reduce the energy consumption from agriculture can contribute to the EU's energy target.

A bottom-up approach has been used by Warwick and Park (2007) to estimate direct energy use in agriculture in the UK, with 2005 as the baseline year. They utilised data from Climate Change Levy (CCL) returns, professional surveys and best available professional knowledge. Figure 1.7 shows that cereals with 25% and protected crops with 26% are the largest consumers of direct energy in agriculture in the UK.

Defra statistics showed that the UK arable crop area was 4.3 million hectares in 2005, which in 2017 increased to 4.7 million ha (DEFRA, 2018), with cereals accounting for 68% of this, oilseed rape, sugar beet, peas, beans, linseed etc. 28%, and potatoes 3% (DIT, 2006). Table 1.8 presents the energy input per hectare and the total energy use for arable crops in the UK. The estimates by FEC Services Ltd in relation to electricity use in cereals were based on the assumption that 50kWh/tonne for low-temperature grain drying (50% of the tonnage), 5 kWh/tonne for high-temperature drying and the maintenance of storage temperatures, and 2 kWh/tonne for the operation of assistant equipment such as, conveyers and stirrers. Estimates of static energy inputs in potato (Williams et al., 2006) are for the storage of 90% of the main crop harvest, approximating to 40% of the total potato yield. Yields in 2005 are estimates from the British Potato Council (Warwick and Park, 2007). Primary electrical use in Table 1.8 is derived using estimates of 247 kWh/tonne to run refrigeration plant and to operate fans. Additionally, 5 kWh/tonne is typically input for heating using other fuels.

Figure 1.7. Direct energy use in agriculture in 2005 (20,387 GWh expressed in primary terms), broken down by agricultural sector and use. Source: (Warwick and Park, 2007).

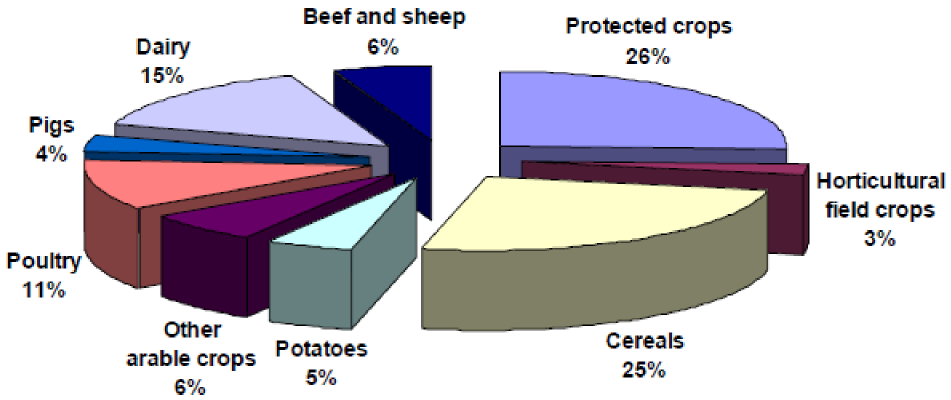


Table 1.8. Baseline energy indicators for conventional crops. *Source: Warwick and Park (2007)*

Crop		Energy inputs (kWh/ha)			Total Energy use (GWh)
	Area (ha)	Electricity	Other static	Mobile machinery	
Potatoes	137	4,208	85	3,230	1,031
Wheat	1,868	621	203	1,078	3,553
Barley	942	449	146	942	1,448
Oats	91	451	150	1,078	153
Other arable	1,211	trace	trace	1,074	1,301

The energy inputs per hectare given in Table 1.8 can be used as an eco-footprint indicator against which to compare the energy inputs of the salt tolerant crops grown in field experiments. However, as with the caveat for water footprints, local data should be gathered for optimal "like -for-like comparisons.

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APPENDIX 1: Calculating water needs for potatoes and wheat in the Wash

The water need in crops (ET crop) is defined as the amount of water needed to meet the water loss through evapotranspiration. Hence, it is the amount of water required by various crops to grow optimally. Crop water need refers to a crop grown under optimal conditions, e.g. free of diseases, favourable soil conditions, actively growing etc. The crop water need mainly depends on: the climate (sunshine, temperature, humidity and wind speed), the crop type and the growth stage of crop (Brouwer and Heibloem, 1986).

In the present report, crop water requirement (ETc) was determined on daily basis by multiplying daily reference evapotranspiration (ETo) with crop coefficient (Kc) value (Doorenbos, 1975). The average Kc values for the various crops and growth stages were taken from (Brouwer and Heibloem, 1986). In fact, the Kc is also dependent on the climate and, in particular, on the relative humidity and the wind speed.

*ETc = Kc * ETo* (4.1)

*The Blaney-Criddle formula: ETo = p (0.46 * T mean +8)* (4.2)

(Brouwer and Heibloem, 1986: http://www.fao.org/3/S2022E/s2022e00.htm#Contents)

Where:
ETo = Reference crop evapotranspiration (mm/day) as an average for a period of 1 month,
T mean = mean daily temperature (°C),
p = mean daily percentage of annual daytime hours. The values of p are taken from Brouwer and Heibloem (1986).

The estimations of the water need for potato in the Wash are based on data for rainfall and temperature for year 2016, which was not an extreme year in in terms of climatic conditions. The annual precipitation for 2016 was 652.6 mm taken from a weather station in the Wash area, where the field trials will be conducted in England.

Kc values for each crop and for each of the four growth stages have been identified by Brouwer and Heibloem (1986). Considering that in general English farmers plant their potatoes late March-beginning of April and the growing period lasts 140 days, the Kc values for each month of the growing period of potato are estimated (**Error! Reference source not found.**).

1.4.1 *Values of the crop factor (Kc) for crops and growth stages*

Crop	**Initial Stage**	**Crop dev. Stage**	**Mid-season stage**	**Late season stage**
Potato	0.45	0.75	1.15	0.85
Barley/Oats/Wheat	0.35	0.75	1.15	0.45

Table 1.4.2 Estimation of Kc, ETo and ETc for potato in 2016

Potato	April	May	June	July
Kc (daily)	0.45	0.75	0.91	0.56
ETo (daily)	3.67	4.90	5.80	6.06
ETc (daily)	1.65	3.67	5.31	3.43
ETc (monthly)	49.5	110.1	159.3	102.9

Therefore, estimating the water need ETc for the whole month and adding the values of each month, the total water need for growing potato in 2016 was 422.56mm per growing season.

In order to calculate the irrigation water needs there is a need to estimate the effective rainfall (Table 4.4). Effective rainfall (Pe) is defined as the total rainfall minus runoff, minus evaporation and minus deep percolation. Hence, only the water retained in the root zone can be used by the plants, and represents what is called the effective part of the rainwater.

For the purpose of this manual only two simple formulas are provided to estimate the fraction of the total rainfall which is used effectively. These formulas can be applied in areas with a maximum slope of 4-5%:

Pe = 0.8 P - 25 if P > 75 mm/month
Pe = 0.6 P - 10 if P < 75 mm/month
Where, P = rainfall or precipitation (mm/month)

Table 1.4.3 Calculate the effective rainfall for the following monthly rainfall in 2016, the Wash

Months	P (mm/month)*	Formula	Pe(mm/month)
January	59.6	Pe = 0.6 P - 10	25.76
February	44.8	Pe = 0.6 P - 10	16.88
March	68.8	Pe = 0.6 P - 10	31.28
April	51.6	Pe = 0.6 P - 10	20.96
May	40.8	Pe = 0.6 P - 10	14.48
June	120	Pe = 0.8 P - 25	71
July	43.8	Pe = 0.6 P - 10	16.28
August	46	Pe = 0.6 P - 10	17.6
September	42	Pe = 0.6 P - 10	15.2

**Met office data*

The results for irrigation water need of potato are reported in Table 3.4. The difference of effective rainfall and evapotranspiration for each month of the growing season of potato are shown in the bottom row of Table 3.4. Therefore, the total amount of irrigated water needed to grow potato in the Wash throughout its growing season is 299.08 mm.

Table 1.4.4 Results for Irrigation water needs (ETc – Pe) of potato 2016

Potato	**April**	**May**	**June**	**July**	**Total**
ETc (mm/month)	49.5	110.1	159.3	102.9	421.8
Pe (mm/month)	20.96	14.48	71	16.28	122.72
Irrigation water needs (ETc – Pe)	28.54	95.62	88.3	86.62	**299.08**

The exact same procedure can be followed for more crops like wheat. Considering that the growing season of wheat regularly starts end of March beginning of April until mid-August (Sylvester-Bradley et al., 2008), Table 3.5 presents the estimation of crop water requirement, daily reference evapotranspiration and crop coefficient. Taking the Kc values from (Table 4.2) the daily wheat Kc values for each month are presented in the first row of Table *1.4.5*. In order to calculate the irrigation water needs for wheat, the values for effective rainfall are taken from and the results are presented in Table *1.4.6*. Therefore, the amount of irrigated water needed for wheat per growing season is 212.52 mm.

Table 1.4.5 Estimation of Kc, ETo and ETc for wheat in 2016

Wheat	April	May	June	July	August
Kc (daily)	0.35	0.51	0.78	0.45	0.14
ETo (daily)	3.68	4.90	5.80	6.06	5.32
ETc (daily)	1.29	2.50	4.53	2.72	0.74
ETc (monthly)	38.63	75	135.76	81.86	22.34

Table 1.4.6 Irrigation water needs (ETc – Pe) of wheat (2016)

Potato	**April**	**May**	**June**	**July**	**August**	**Total**
ETc (mm/month)	38.63	75	135.76	81.86	22.34	353.57
Pe (mm/month)	20.96	14.48	71	16.28	17.6	122.72
Irrigation water needs (ETc – Pe)	17.67	60.52	64	65.58	4.75	**212.52**