Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Faculty of Natural Resources and Agricultural Sciences

Rice Trade in a Changing Climate

- Using trade-based climate risk profiles to test the coverage of national adaptation plans

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Abstract

Adaptation strategies and policies often fail to take account of climate change impacts and their feedbacks in one country which have 'indirect impacts' for other countries and the global system. This thesis examines the risks posed by climate change to global rice trade and the possible impact on food security in nations dependent on rice imports. Rice is a staple food for half of the world's population and the most important calorie source for many of the world's poor.

This thesis develops a method to assess these risks for four nations depending on rice imports: Senegal, South Korea, the United Arab Emirates and the United Kingdom. Several data sets, such as rice trade data, climate scenario data and rice consumption data, are combined into a multi-step risk assessment. Thereby, this study examines the possible dynamics between climate change impacts in trade partner countries, namely in key rice producing countries in Asia, and the repercussions on domestic food security in rice import dependent countries. It further investigates the extent and how national adaptation plans acknowledge or address these indirect risks.

The thesis finds that all four case studies countries are sensitive to indirect climate change impacts on rice imports. The comparison between case study risks identifies the systemic nature of trade related climate risks. This means that risks can be magnified when multiple importing countries are exposed to the same risk and measures exacerbate the effects for other countries. This systemic nature of risk to the rice market raises the importance of internationally coordinated adaptation between countries to the systemic risk to enhance the resilience of food systems.

Keywords:
Adaptation; Climate Change; Climate Risk; Risk assessment; Indirect Impacts; Trade; Rice; Food security

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Abbreviations

APTERR	Association of Southeast Asian Nations Plus Three Emergency Rice Reserve
C_3	C_3 carbon fixation
CO_2	Carbon dioxide
Defra	Department for Environment, Food & Rural Affairs
e.g.	exempli gratia, for example
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAS	Foreign Agricultural Service, United States Department of Agriculture
GCC	Gulf Cooperation Council
GCM	General Circulation Model, Climate model
GHG	Greenhouse gas
GNI	Gross national income, formerly GNP (Gross National Product)
HHI	Herfindahl-Hirschman-Index
IPCC	Intergovernmental Panel on Climate Change
IRRI	International Rice Research Institute
KACCC	Korea Adaptation Center for Climate change
Kg	Kilograms
LICs	Low-income countries
LMB	Lower Mekong River Basin
MT	Tonne or metric ton (equal to 1000 kilograms)
NAPA	National Adaptation Programmes of Action
NGO	Non-governmental organization
O_3	Ozone
QFCA	Qatar Financial Centre Authority
SSR	Self-sufficiency ratio
SRES	Special Report on Emissions Scenarios
SREX	Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation
SRV	Senegal River Valley
UNFCCC	United Nations Framework Convention on Climate Change
UAE	United Arab Emirates
UK	United Kingdom
USDA	United States Department of Agriculture
WTO	World Trade Organisation
%	Percent

1 Introduction

Climate change factors pose a serious threat to rice production and hence to global food security (Aggarwal & Mall 2002; Wassmann et al. 2010; Iizumi et al. 2011; Gerardeaux et al. 2011; Jalota et al. 2012; Mainuddin et al. 2012).
The IPCC (2014) projects that climate change impacts on food production in Asia will result in that many areas may experience a decline in productivity, which is particularly evident in the case of rice production.

There is a growing attention for climate adaptation measures at farm level, while more comprehensive analyses including global market feedbacks are lacking (Mosnier et al. 2013). The assessment of climate change impacts in a hyper-connected world demands the inclusion of impacts which occur in one country in the first place but have repercussions for other countries and the global system (Bruce & Haites 2008). These repercussions are defined as indirect impacts and constitute "*impacts that are observed or expected in one place, but are brought about by climate change or extreme events somewhere else* (Benzie et al. 2013)", and could be understood as second order effects of climate change (Benzie et al. 2014, unpublished). National assessments of climate change impacts often neglect these indirect impacts, which may lead to inadequate coverage in adaptation and mitigation strategies (PwC 2013). According to Benzie et al (2013), indirect impacts are transferred along four main pathways across national borders, namely the bio-physical, finance, people and trade pathways; this study will focus on indirect impacts via the trade pathway, specifically on rice as a traded commodity. Climate change may indirectly affect the rice market through declines in global rice yields and extreme weather events causing sudden supply shocks.

Rice is a '*thinly traded*' commodity with only 4% of globally produced rice traded on international markets (Dawe & Slayton 2011); there is thus an uneven distribution of market power where five key countries are exporting more than two-thirds of the global volume (Oryza 2014a). Supplies are vulnerable to production shocks in key countries, as well as to economically or politically motivated national actions such as export restrictions (Defra 2010).
Rice is the world's most consumed food crop, serving as a staple food for half of the world's population and is the most important calorie source for the world's poor. Rice market turbulences in 2007/8 led to significant adverse effects on the welfare of the poor (Ivanic & Martin 2008; Zezza et al. 2008; Dawe et al. 2010).

Given the important status of rice in global food security, combined with the high sensitivity of rice production to changing climate factors and the volatility of global rice market, it is important that countries consider the trade dimension of food security in their climate change adaptation plans. The purpose of this study is to develop and test a method for assessing the trade dimensions of climate risks for a number of import dependent countries. Further the results of this risk assessment are used to investigate ~~how well existing~~ to which extent national adaptation plans address these risks.

The study will investigate the indirect impacts of climate change on four rice import dependent countries: Senegal, South Korea, the United Arab Emirates (UAE) and the United Kingdom (UK). These four countries are expected to differ in terms of vulnerability towards climate risks based on their individual characteristics:

- Senegal was selected as a highly – and increasingly – food import-dependent country that has been exposed by recent shocks in global rice markets. Additionally, Senegal is of interest as a low-income country that aims for increasing self-sufficiency in domestic rice production.
- South Korea was selected since it was expected to be a highly rice consuming country and also as a fast growing and industrialized economy. Besides producing a large share of rice consumed self-sufficiently, South Korea is a rice import dependent country.
- The UAE was selected as a regional rice trading hub (top rice re-exporting country in the world), which is highly rice import dependent due to the lack of arable land and water.
- The UK was selected as a rice import dependent country and as a global adaptation leader which has undertaken significant research into climate risks and the potential social justice implications of food price shocks.

Rice producing countries examined in this study are China, India, Pakistan, Thailand, the USA and Vietnam, which are also the key rice exporting countries in the world. These countries were identified as key trading partners for the selected case study countries based on recent rice trade data from UNcomtrade (2014).

The methodology applied was created for this study and can be framed as a '*bottom-up*' (otherwise known as '*policy-first*') or a '*vulnerability-based*' assessment (Ranger et al. 2010).
A bottom-up approach is conducted in this study by defining the rice trading system (four importing and six producing countries) and assessing its attributes; in this case, the food security and rice dependency of the four rice importing countries. These attributes are used to assess the systems risk to potential indirect climate change impacts on rice imports. Further, specific climate scenario projections on rice yield impacts in the key producing countries explore in what way this risks might change in the future. These climate risks are then compared to a range of relevant adaptation and non-adaptation documents to assess their coverage and treatment in national planning.
The bottom-up methodology defines the structure of this study and pursues the following research questions:

- ***How vulnerable are rice importing countries to climate induced trade disturbances?***

- ***To what extent and how do these import-dependent countries consider trade-related risks in their climate change adaptation plans?***

These research questions are answered within a multi-step risk assessment: **Step 1** is to explore rice trade volumes between each case study country and each of the exporting countries in order to get a picture of trade dependencies. **Step 2** investigates climate change impacts on rice yields in each of the rice producing country to project their impact on future production. Combining the results of Step 1 and 2 leads to a '**current trade profile**' for each importing country which reflects the sensitivity of rice imports for the respective case study country.

Step 3 assesses the magnitude of potential climate related impacts by considering the rice import dependency through evaluating consumers' income, past rice consumption trends and self-sufficiency of rice production in each of the case study countries.

Subsequently, the study establishes the overall '**climate risk profile**' for each import dependent country by combining the likelihood assessment from Steps 1 and 2 with the magnitude from Step 3.
A range of adaptation and other relevant 'non-adaptation' documents from each case study country are tested against the individual climate risk profile to examine the coverage of current adaptation strategies in **Step 4**.
Steps 1 to 4 are introduced during the Material & Method section and pursued in the Results and Discussion sections. The Literature Review provides a summary of climate change impacts in the key producing countries, as well as possible implications of these climate related impacts on the global rice market. Strengths and weaknesses of the developed methodology are evaluated in the discussion section 5.5.

By developing the methodology as an assessment tool, this study aims to:

- combine existing data on rice trade and climate impacts on rice production to explore the risks of future climate change to import dependent countries.
- draw attention to the indirect impacts and external dimension of climate risks, especially for import dependent countries.
- broaden perspectives on what constitutes 'climate change adaptation' and how climate vulnerabilities are shared between producer and consumer countries.

2 Literature Review

2.1 Definitions & Key concepts

Top-down & bottom-up adaptation
Dessai & Hulme (2004) present '*top-down*' and '*bottom-up*' as two opposing views which however are not contradictory. Both approaches aim to inform adaptation decision making and are even complementary, although they have different climate input data requirements (Figure 2.1) (Dessai & Hulme 2004).

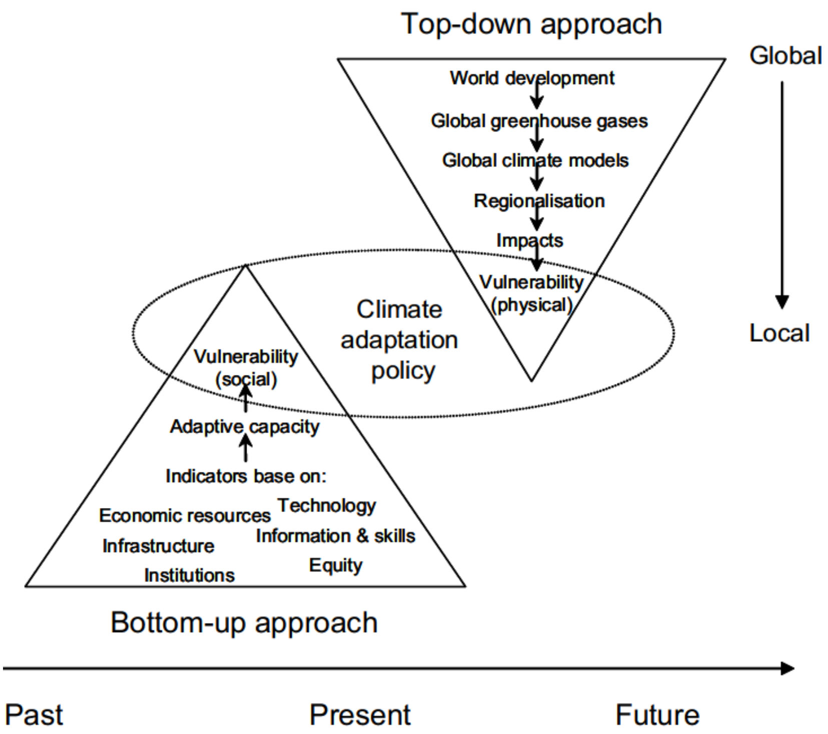


Figure 2.1 – *Illustration of top-down and bottom-up adaptation (Dessai & Hulme 2004)*

The **top-down** (otherwise known as '*science-first*'[1]) approach takes climate projections as the starting point for impact assessments and adaptation planning (Ranger et al. 2010). Further, top-down can be framed as an '*impacts-based*' process which takes a linear approach from evaluating expected climate impacts based on projections and ending in identifying adaptation options to reduce any resulting vulnerability (Ranger et al. 2010). The process focusses on Greenhouse Gas (GHG) emission levels as input to General Circulation Models (GCMs) whose results serve as input to impact models, which are then used as the basis within a given decision-making framework for anticipatory adaptation strategies (Parry & Carter 1998; Dessai & Hulme 2004).

Several studies criticize the top-down approach for the high dependence on climate models. Optimal decision-making is relying on the predictive accuracy of climate models which are dependent on high quality information and may otherwise produce inaccurate and imprecise information for decision-makers (Dessai et al. 2009).

[1] Based on Ranger et al. (2010), defined in the context of climate change adaptation in the UK.

Top-down assessments further tend to neglect the short-term goals of most governments (Pelt & Swart 2011). It is suggested that these assessments are more suitable for developed nations, but less appropriate for developing countries which do not have the resources to address probabilistic information on changing climate (Dessai & Hulme 2004).

Bottom-up (otherwise known as '*policy-first*') approaches start with the decision making system and ask: in what ways is this system vulnerable to today's climate and how might that change in the light of future climate change (Ranger et al. 2010)? Viable policy options for the adaptation problem are developed which are then tested against a set of objectives and future projections (Ranger et al. 2010). This approach therefore places greater emphasis on resilience and adaptive capacity based on present or recent historic climate variability rather than on exposure and seeing vulnerability as an inevitable effect (Dessai & Hulme 2004; Benzie 2014). Once the current vulnerability of a system has been assessed, specific questions can be asked of climate projections: will this vulnerability increase in future, if so how?

Restrictions of bottom-up adaptation have limited applicability outside their specific context and outside the range of recent experiences (Dessai & Wilby 2010; Benzie 2014), as well as they are not considering long-term climate change implications (Dessai & Hulme 2004). This latter point is based on the idea that future climate change may create new kinds of vulnerability that do not necessarily correlate present day vulnerability.
Raiser (2014) concludes that *"adaptation measures should focus primarily on bottom-up solutions"*, while *"climate scenarios provide a powerful technological tool to further our understanding of the possible implications of climate change"*.

Vulnerability
The two opposing adaptation approaches highlight the existing division in '*biophysical*' (top-down) and '*social*' (bottom-up) vulnerability (Dessai & Hulme 2004; Raiser 2014).
Brooks (2003) presents '*actual*' vulnerability as *"(i) in terms of the amount of (potential) damage caused to a system by a particular climate-related event or hazard"*, or '*expected*' vulnerability *"(ii) as a state that exists within a system before it encounters a hazard event"*.
Building on the concept of expected vulnerability, '**Risk**' is a term that has become central to climate adaptation planning in recent years (IPCC 2014a). It combines the likelihood that a climate related impact will occur with the magnitude of this impact in social, economic or environmental terms (Defra 2012a; Defra 2013).
The **likelihood** is used to describe the chance or relative frequency of a specific impact to occur (IPCC 2013; Defra 2013). The assessment of the likelihood is always subjective in the context of climate change, amongst others due to largely intractable reflexive human behaviour in the context of prediction (Dessai & Hulme 2004). Assessments of the likelihood are therefore an interpretation of climate projections and the expectations of other drivers leading to the occurrence of the climate impact in question.
Magnitude refers to the damage or harm that would be caused if the impact was to occur.

2.2 Indirect Impacts of Climate Change

"Climate change is a serious and long-term challenge that has the potential to affect every part of the globe (G8 Gleneagles 2005)".

The assessment of climate change impacts needs to take account of global interdependencies in a hyper-connected world since global networks of governance, finance, business, communications and communities imply that climate impacts are not confined by national borders (Bruce & Haites 2008; Foresight 2011a). Impacts of climate change in one country are likely to have consequences for other countries and the global system; likewise, the adaptation measures in one country can have both positive or negative effects on other countries (Bruce & Haites 2008). Therefore, climate risks and adaptation challenges are also influenced by the extent to which countries and companies are interconnected with other actors and networks (Benzie et al. 2014, unpublished).

These consequences are defined as *'***indirect impacts***'* and constitute "*impacts that are observed or expected in one place, but are brought about by climate change or extreme events somewhere else*" (Benzie et al. 2013). The European Commission (2012) describes these indirect impacts as '*spill over effects'* for Member States which can be created through not adequately addressed economic and social issues in another Member State of the EU. The assessment of climate change impacts often neglects these indirect impacts, which may lead to inadequate coverage in adaptation and mitigation strategies (PwC 2013).

Indirect climate change impacts are transferred along four main pathways such as biophysical, trade, finance and people pathways, as well as via climate-driven change in the global security context (Benzie et al. 2013). Biophysical pathways consist of environmental flows from transboundary ecosystems like rivers, oceans, cross-border spread of species and pathogens; the trade pathway is characterized by international flows of commodities and products; finance comprises investments abroad as well as global insurance schemes and remittance flows; people represents human migration, tourism and transboundary human health risks; and global security context deals with climate related impacts on security and conflict, global governance and political stability (Benzie et al. 2013).

2.2.1 Trade pathway

This study will focus on the trade pathways and examine the risk for four rice import dependent countries, regarding their possibilities to secure rice supplies. Comprehensive analyses of global market feedbacks are lacking in the climate adaptation context, hence there is a need to assess unevenly distributed climate change impacts and adaptation responses in a context of regions interconnected through trade (Mosnier et al. 2013). Adaptation planning that focuses on the national and local level not only threatens to ignore important indirect impacts, and may also lead to policies and measures that impair food security in other regions, for example by enhancing self-sufficiency or protectionism and thereby reducing the risk spreading potential of trade (Mosnier et al. 2013). In some cases it may therefore be necessary to think of coordinated international adaptation efforts.

Trade offers opportunities to spread risks against short or long term variations in supply and demand, but can also have negative side-effects in case a country is highly dependent on particular imports or export markets (Benzie et al. 2014, unpublished). Climate change could affect the rice market through extreme weather events causing shocks in markets and supply chains, or slow effects leading to changes in yields and global production. According to Benzie et al. (2014, unpublished), a countries' vulnerability to import-related climate risks – for example those related to rice imports – is determined by the reliance on climate-sensitive imports which is further influenced by the substitutability; the negotiation power in relation to key trading partners and within global decision making fora; and by the gross national income (GNI) per capita i.e. the ability to cope with price shocks and to switch to other more expensive suppliers.

Climate change impacts are expected to be widespread, complex, geographically and temporally variable, and profoundly influenced by socio-economic conditions (Vermeulen et al. 2012). Developed countries are generally expected to experience a greater size of stress from indirect impacts as they often rely on resource imports from other countries, many of which may be developing countries that are particularly vulnerable to climate impacts (PwC 2013). The size of indirect impacts might even exceed the direct impacts for developed countries (PwC 2013). Northern countries may on the other hand benefit from more favourable climatic conditions and thereby gain a competitive advantage in agricultural production over southern countries (Rosenzweig & Parry 1994; Nelson et al. 2010).

Rice is a suitable commodity for the assessment of indirect impacts via trade pathways because it is highly relevant in terms of global food security as a major food staple, and also because of its market characteristics. Only 4% of globally produced rice is traded on international markets (Dawe & Slayton 2011) making it a thinly traded commodity which is only exported by a small number of countries (Figure 2.2), and therefore particularly sensitive to climate-related supply declines.

2.3 Climate change impacts on key producing countries

This section examines the direct climate change impacts on rice production in the key producing countries. Climate change impacts differ between different cultivation regions. Several studies expect a general decline in rice yields in many countries in south Asia due to increased heat stress (Hossain 2008; Auffhammer et al. 2012; Jalota et al. 2012), leading to exceeded temperature tolerances of the crops (Gerardeaux et al. 2011). Rice cultivated in tropical regions shows adverse temperature effects at a 2°C average temperature increase (Gerardeaux et al. 2011), whereas rice in more temperate regions is significantly affected at >3°C (IPCC, 2014a). Table 2.1 provides an overview over past, present and future climate related yield impacts in key producing countries based on relevant studies.

Table 2.1 – *Summary of direct climate impact studies for key producing countries.*

Country / Area	Climate change yield impacts	Source
China, north-east	Northeast Chinese rice production increase by **approximately 1.7 %** during the years of **2020-2040**.	(Zhang et al. 2014)
China, Taihu	From the **1980s to 2000s**, climate change caused a decline in rice (Oryza saliva L.) productivity which is estimated to be **-19.5%.**	(Liu et al. 2013)
China, north-east	During 1981-2009, climate warming and decrease in solar radiation changed the yield of early rice in the middle and lower reaches of Yangtze River (MLRYR) by **-0.59 to 2.4%**; climate warming during reproductive growth period increased the yield of late rice in the MLRYR by **8.38-9.56%**; climate warming and decrease in radiation jointly reduced yield of single rice in the MLRYR by **7.14-9.68%**; climate warming and increase in radiation jointly increased the yield of single rice in the North Eastern China Plain by **1.01-3.29%**.	(Tao et al. 2013)

China, east	Change on average by **7.5% to 17.5%** (−10.4% to 3.0%), **0.0% to 25.0%** (−26.7% to 2.1%), and −**10.0% to 25.0%** (−39.2% to −6.4%), with and (without) consideration of CO_2 fertilization effects, by 2020s, 2050s, and 2080s.	(Tao & Zhang 2013)
China, north-east	Positive correlation of **3.60%** rice yield increase for each **1**°C rise in minimum temperature in the growing season.	(Zhou et al. 2013)
China, north-east	Results show a **2.8%** yield increase from **1959-2008** in Northeast China.	(Zhou et al. 2012)
China, eight typical stations	**Without CO_2 fertilization**, the results from the assessment explore negative impacts on rice yield at most rice stations and have little impacts at Fuzhou and Kunming from 2071 - 2090. **With the CO_2 fertilization**, rice yield increase in all selected stations.	(Yao et al. 2007)
India	Results show a **continuous reduction in rice grain yield** from present years to **2020, 2050 and 2080** and for rising temperature of ≥ 0.8 °C.	(Satapathy et al. 2014)
India	Irrigated rice yields decline by **~4% in 2020** (2010–2039), **~7% in 2050** (2040–2069), and by **~10% in 2080** (2070–2099). Rainfed rice yields decline by **~6% in 2020**, but decrease only marginally in **2050 and 2080** (**<2.5%**).	(Soora et al. 2013)
India	Drought and extreme rainfall caused a **1.7% rice yield reduction** in predominantly rainfed areas during 1966-2002. Warmer nights and lower rainfall further reduced yields by nearly **4%**	(Auffhammer et al. 2012)
India, North	Maximum temperature may cause the **reduction** in yield of rice by **1.0 to 1.1%** per ha by **2020**, while minimum temperature may **decrease the yield of rice by 1.5 to 1.9%** per ha in Eastern Uttar Pradesh.	(Kumar et al. 2011)
India, east	The **yield reduction was to the extent of 27% and 14%** at Kharagpur and **17% and 7%** at Purulia for the cultivars Lalat and Swarna, respectively.	(Swain 2009; Swain 2010)
India	Most scenarios indicate an **overall positive** climate change impact or do show significant effects on India's agriculture **until 2050**. By **2080**, when temperature rise is highest, the **rice yields will be reduced the most**.	(Mall et al., 2006)
India	**Pessimistic scenarios** show an increase of yields between **1.0 and 16.8%,** depending upon the level of management and model used. **Optimistic scenarios** project an increase of **3.5 and 33.8% rice yield** in optimistic scenarios.	(Aggarwal & Mall 2002)
India, state of Kerala	Rice yield is **increase** by **12%**, and **6%** in yield increase if temperature is considered exclusively. Timeframe from 2040-2049 with respect to the 1980s.	(Saseendran et al. 2000)
India	By the middle of the 21st century in **Central and South India** will experience an **increase** in rice yield, while yield in North West India will **decrease** under irrigated conditions	(Rathore et al. 2001)
India, north-west	Results show an increase of **15% rice yield** under **doubled CO_2 levels**. However, a 3°C (2°C) rise in air temperature nearly offsets the positive effect of elevated CO_2 on rice yields (**4% under irrigation**). Water shortages will decrease rice yields by about **20% net decline**.	(Lal et al. 1998)

Pakistan	On an average with the elevation of CO_2 up to 550 ppm, paddy yield increased by 1.53% to 4.48% at different locations. However, paddy yield was **decreased at all locations through higher temperature**.	(Ahmad et al. 2009)
Thailand, north-east	Scenarios for the periods 2020-2029, 2050-2059 and 2080-2089 indicate a **reduction in rice yields by 17.81, 27.59 and 24.34% for the 2020s, 2050s and 2080s**, respectively, in comparison to average yields from 1997-2006.	(Babel et al. 2011)
Thailand & Vietnam	Results suggest a significant **rice yield increase** in the upper part of the Mekong basin in **Thailand** and a **decrease** in the lower part in **Vietnam** for rainfed rice.	(Mainuddin et al. 2012)

Table 2.2 provide an overview of the model predictions for these key producing countries based on a study by Iglesias & Rosenzweig (2010).

Table 2.2 – *Climate change impacts on rice production in key producing countries based on model data from Iglesias & Rosensweig (2010).*

Producing Countries	Scenario Data from Iglesias and Rosenzweig 2010							Average	Standard Deviation	Scenario Range
	A1F	*A2a*	*A2b*	*A2c*	*B1a*	*B2a*	*B2b*			
Country	*% in rice yield change by 2020*									
China	-0,92	-1,18	-0,24	-1,31	-0,67	-1,68	-1,78	-1,11	0,55	-0,24; -1,78
India	-6,1	-4,23	-3,78	-4,8	-3,68	-6,62	-4,93	-4,88	1,13	-3,68; -6,62
Pakistan	-5,78	-4,39	-4,68	-5,85	-4,09	-5,62	-5,33	-5,11	0,71	-4,09; -5,78
Thailand	0,75	1,54	0,57	1,46	-0,4	0,78	0,22	0,70	0,68	1,54; -0,4
USA	2,08	2,63	0,25	1,47	-0,95	-0,54	-0,14	0,69	1,38	2,63; -0,95
Vietnam	-0,7	0,09	0,11	0,04	-0,78	-1,43	-1,12	-0,54	0,63	0,11; -1,43

Table 2.2 shows projected rice yield impacts for 2020 for the six rice exporting countries according to seven different SRES scenarios. The average column is the computed mean value of these seven scenarios; the standard deviation column was computed for the scenario as an indicator for the conformity between scenarios, representing the variation between the SRES model data; and the scenario range column summarizes the lowest and highest scenario rice yield impacts.

The studies concerning Chinese climate change impacts on production mainly indicate increased yield but also vary by location and through the selected timeframe. The model from Iglesias & Rosensweig (2010) projects more adverse changes in Chinese rice yields.
The study by Ahmad et al. (2009) confirms the overall negative direct climate change impacts of increasing temperature for Pakistan and therefore agrees with the high impact rating based on the climate scenario data.
Studies for Thailand present opposing results: Babel et al. (2011) predicts a significant decline in rice yield, while studies by Mainuddin et al. (2011; 2012) suggest a significant increase in rainfed rice production in the upper Mekong basin. The model data indicates low climate change impacts for Thailand.
There are no suitable studies for climate change impacts on rice production in the USA.
The studies by Mainuddin et al. (2011; 2012) state a decrease in rainfed rice production for Vietnam, while model data indicates a lower, medium imact.

Generally, study and model results suggest a likely global decline in rice yields in the short-term (before 2050) and a virtually certain and even higher reduction in yields until 2080 (IPCC 2013; IPCC 2014a). Besides the fact, that impacts will vary between growing regions, there will be a

net negative climate effect on the key producing countries considered. Further, Iglesias & Rosensweig (2010) project declines in global yields[2] in the 21st century ranging from 1,96 to 3,96% in 2020, 1,08 to 3,27% in 2050 and 0,05 to 5,58% in 2080.
For the analysis, the model data from Iglesias & Rosensweig (2010) will be used since the data enables comparability between all producer regions of interest to the current study, due to equal experimental conditions. Despite its limitations, (see discussion section 5.6), it is considered preferable to use Iglesias & Rosensweig (2010) as opposed to the results of multiple (perhaps more robust) studies covering different producer countries, given the inconsistent and wide variety of factors, assumptions and scope between other rice productivity-climate model studies.

2.3.1 Shifts in rice cultivation areas

Rice cultivation areas are expected to shift with climate change throughout Asia (IPCC 2014a). Especially southeast Asian regions provide currently very suitable warm and wet climate conditions for rice, while other areas might become more favourable in the future (Foresight 2011a).

A number of studies provide examples for the importance of climate change for the spatial distribution of rice. In China, single rice cropping systems may expand further north, and double rice cropping is expected to move to the northern portion of the Yangtze River as a consequence of changing climatic conditions (Xiong et al. 2009). Tang et al. (2012) describes the tendency of rice spatial distribution to extend to north dramatically in the Northeast China Plain where temperature is the main factor for planting in higher latitude regions.
Sea-level rise and salt water intrusion particularly threaten the rice production in coastal and deltaic areas in Asia like the Mekong River Delta (Wassmann et al. 2010). Thailand and Vietnam are located in the Lower Mekong River Basin (LMB) and produced 51% of global rice exports in 2008, mostly in the LMB (Mainuddin et al. 2011). As a consequence of rising sea-level, around 7% of agricultural land might be lost in Vietnam and has to shift to other areas (Dasgupta et al. 2009).

Rice production in Asia is culturally embedded and of substantial importance for rural communities as the largest numbers of food-insecure people are located in South Asia (IPCC 2014a). Regional differences in crop production are likely to increase through time and causing significant polarisation effects, with substantial risk of food shortages amongst the most marginalized economies (Rosenzweig & Parry 1994; Parry et al. 2004; Parry et al. 2005). Shifting rice production to other more favourable climatic regions bears other problems outside the production context which are impossible to oversee. The size of agricultural movements to other areas might have a significant effect on the global rice system, but based on available information a more qualitative statement is not possible.

2.4 Global Rice Market Implications

Rice is the world's most consumed food crop, serving as a staple food for half of the world's population – particularly from Asia and some parts of Africa and Latin America (Sawano et al. 2008; Mainuddin et al. 2012; Soora et al. 2013). The demand for rice is expected to continue to grow in the light of future population development (Peng et al. 1997; Mainuddin et al. 2012).

[2] Based on climate change impact projections on all countries (n=165) considered in the model and computed based on the average value for all seven SRES scenarios; the range describes the lowest and the highest scenario results.

In 2010, 90% of global rice was produced in Asian countries and half of the amount in China and India (Wassmann et al. 2010; Soora et al. 2013).

Regional differences in crop production are likely to increase through time and cause significant polarisation effects, with substantial risk of hunger amongst the most marginalized economies (Rosenzweig & Parry 1994; Parry et al. 2004; Parry et al. 2005). Low-income countries (LICs) and poor communities are disproportionally affected by food price volatility (Foresight 2011b). People in already impoverished subtropical countries are facing an increased risk of malnutrition and starvation (Peng et al. 1997), as rice yield decreases are especially substantial (up to 30%) in Africa and parts of Asia (Parry et al. 2004). Currently, more than 800 million people are food insecure, while the situation is likely to be exacerbated by climate change (Wassmann et al. 2010). The largest numbers of food-insecure people are located in South Asia (IPCC 2014a). Poverty in Asia may also be impaired (Skoufias et al. 2011) due to climate change impacts on rice crops and resulting increases in food prices and costs of living (Hertel et al. 2010; Rosegrant 2011).

Therefore, global food insecurity is likely to increase with time due to increasing rice consumption trends and projected adverse direct climate change impacts on rice yields (Parry et al. 2005). These trends are likely to increase market rice prices: Results from Chen et al. (2011) suggest a reduction in global rice yields by 1,60% to 2,73% while global rice prices increase by 7,14% to 12,77%.
Based on a number of studies (Hertel et al. 2010; Baldos & Hertel 2013; Calzadilla et al. 2013; Lobell et al. 2013; Nelson et al. 2013), the IPCC (2014a) concludes that *"it is very likely that changes in temperature and precipitation, without considering effects of CO_2, will lead to increased food prices by 2050, with estimated increases ranging from 3-84%"*. On the other hand, including *"the combined effect of climate and CO_2 change (but ignoring O_3 and pest and disease impacts) appears about as likely as not to increase prices, with a range of projected impacts from -30% rice yield reduction to +45% yield increase by 2050"* (IPCC 2014a).

The Food and Agriculture Organization of the United Nations (FAO) pronounces that world food production would need to rise by 70% by 2050 compared to 2005-7 levels in order to meet the demand of 9 billion people, the increase in world food per capita and dietary change towards meat (FAO 2009a). Higher prices give an incentive to increase production but the prices might not be affordable for the poorest, which in turn can alter the incentive of investments due to a smaller consumer base and reduced marketing opportunities (Defra 2010). Poor consumers spend most of their income on food and are accordingly disproportionately affected by increasing prices (FAO 2011c). The World Bank estimated a net increase of 44 million people in extreme poverty resulting from higher food prices since 2010 (Ivanic et al. 2011).

Rice trade is somewhat disconnected with markets for other cereals as it is produced on different types of soil in different regions and consumed by different groups of consumers (Dawe & Slayton 2011). Only a fraction of the globally produced rice (4%) is traded on international markets (Dawe & Slayton 2011). This thinness of the rice market shows, that most rice producing countries are using rice for domestic consumption instead of trading it on international markets (e.g. China which is the biggest producer of rice globally) (Oryza 2014a). Market power is unevenly distributed in the rice market since five key countries are exporting more than two-thirds of the global volume (Oryza 2014a, Figure 2.2). This leads to a high sensitive of the rice market to country specific production shocks as well as to economically or politically motivated national actions such as export restrictions (Defra 2010).

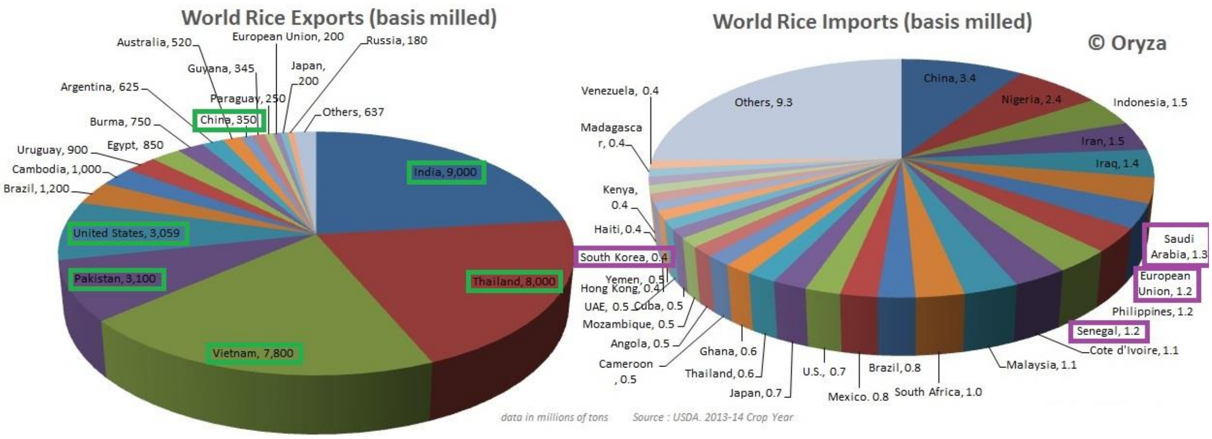


Figure 2.2 – *World Rice Exports and Imports by country in 2013 (Oryza 2014a), case study countries are marked in purple, key producing countries considered in this study are marked in green. The UAE and the UK are represented by Saudi Arabia and the European Union, and only account for a share of the amount stated in the figure.*

Price volatility in the rice market is further increased through several factors like *"poorly articulated local markets, increased incidence of adverse weather events and greater reliance on production areas with high exposure to such risks, biofuel mandates, and increased links between energy and agricultural markets* (World Bank 2012)". The IPCC (2014a) report acknowledges recent price changes caused by increasing crop demand due to biofuel production related both to energy policy mandates and oil price fluctuations (Roberts & Schlenker 2010; Wright 2011; Mueller et al. 2011). The IPCC (2014) further reports *"several periods of rapid food and cereal price increases following climate extremes in key producing regions, indicating a sensitivity of current markets to climate extremes among other factors".*

2.4.1 Climate change in the context of the 2007/8 rice crisis

The crisis from 2007/8 was not caused by climate related impacts on rice production or low rice stocks but by several other external factors such as rising oil prices since 2004, a weak United States Dollar, biofuels mandates, tariffs contributing to rising maize and soybeans prices and weather-induced decline in world wheat production (Defra 2010; Dawe & Slayton 2011). These price increases of other commodities created an atmosphere of concern and thus contributed to policy decisions and panic by key rice trading countries (Figure 2.3) (Defra 2010).

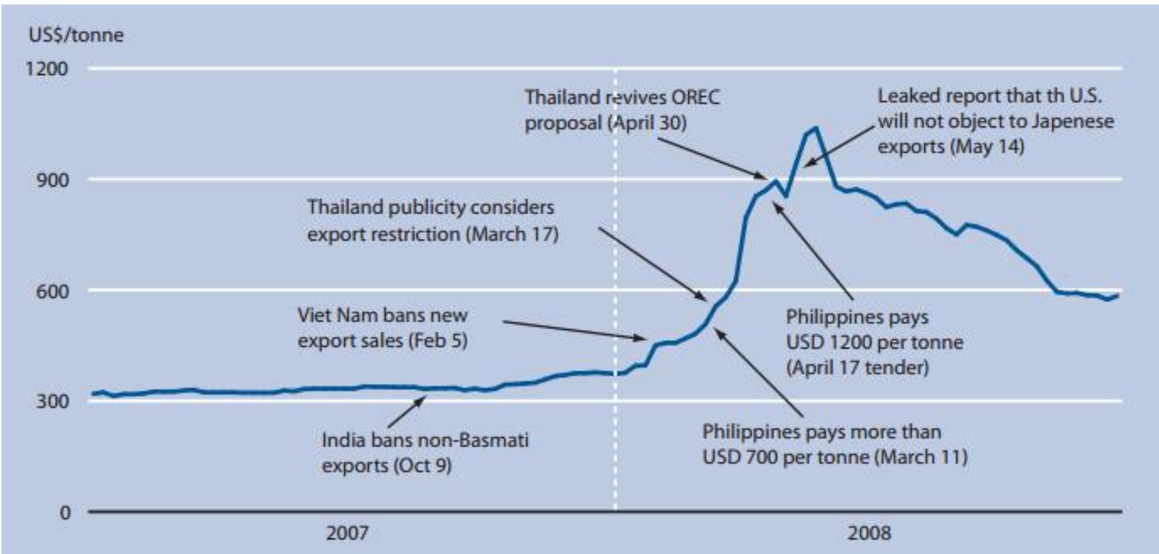


Figure 2.3 - *Timeline of government actions during world rice market turbulence (Dawe & Slayton 2011).*

India, which was the second largest rice exporter of rice at that time, banned all non-basmati exports in October 2007 with the aim to stabilize domestic rice prices (Dawe & Slayton 2011). Other major rice exporting countries like Vietnam, China, Pakistan, Cambodia and Egypt followed by also restricting exports between late 2007 and early 2008 (Demeke et al. 2011). These government interventions by key rice trading countries created uncertainty and encouraged hoarding and panic purchases of other governments (e.g. Philippines), farmers, traders and consumer (Defra 2010). The large role of governments in international trade is problematic in this thin market, as the domestic policy reactions of a few players with high market power will amplify international price responses (IPCC 2014a). During the international food crisis, commodity prices (e.g. for wheat, rice, palm) increased sharply and subsequently fell sharply in the second half of 2008. Between October 2007 and April 2008, the market price of Thai 100% B tripled from 335 US$ per tonne to over 1000 US$ per tonne (Dawe & Slayton 2011). After the crisis, all agricultural commodity prices are broadly similar with the levels over the last two decades, except the rice price remains significantly above (Defra 2010).

The crises in 2007/8 is not directly related or triggered by climate change impacts but can serve as 'a sign of things to come' (HMG 2010). Climate change effects can trigger rice market shocks through globally declining rice yields and more frequent damages from extreme weather events (Mall et al. 2006; Bruce & Haites 2008). Globally declining rice yields are likely to lead to higher prices due to general shortage which might feature short term shocks and price volatility because countries are more inclined to implement protectionist measures and start hoarding. Extreme weather events have been a trigger of previous rice production shocks and can therefore be expected to be contributing factors to future shocks. The 1972/3 crisis can be attributed to a major climatic event, a large drought in Southeast Asia, and led to a quadrupling of international rice prices compared to pre-crisis prices (Timmer & Dawe 2010).
Recent examples of a weather extremes impairing food security are the Russian heat wave 2010 and the drought in California in 2014. To ensure adequate domestic supplies, Russia implemented an export ban subsequent to the heat wave which contributed to a doubling of global wheat price by the end of the year (Nelson et al. 2010; IPCC 2014a). In California, a prolonged drought caused a reduction in irrigation water supplies and led to a substantial decline in rice production (FAO 2014).

The diverse external factors that triggered the financial crises in 2007/8 were part of complex market dynamics which are more or less impossible to address by a single country (e.g. acting on food price bets and avoid a 'prisoner's dilemma'[3]). It has to be acknowledged, that climate change is just one factor between many others to trigger a market shock, and also that addressing the range of factors is very challenging because of complex market dynamics. Similarities between the financial crises and climate change impacts are country responses like protectionist measures and hoarding as a consequence of short market supplies. In both cases, climate and non-climate related, supply shortages in the global rice market might feature protectionist measures as demonstrated by described past crises.

[3] where each producing country reacts rationally to volatility and increased future risk with protectionist measures to secure and stabilize domestic supplies.

3 Material & Methods

Risk assessment has emerged as one of the dominant decision making frameworks for climate change adaptation planning (Willows & Connell 2003; PROVIA 2013). The IPCC has focussed more on risk-based approaches in recent years, for example with the so-called '*SREX*' (Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation) report on extreme events and disasters (IPCC 2012) and the greater emphasis on risk in the most recent IPCC Assessment Report (IPCC 2014b). Several national level adaptation assessments adopted risk-based approaches (ADB 2005; Swart et al. 2009; see Defra, 2010 as an example).
A risk-based approach enables decision makers to recognise the uncertainties associated with future climate projections and impacts, whilst providing a structure that helps decision makers to assess and rank potential risks in ways that support adaptation planning.

This study adopts a risk-based approach to assess the potential impacts of climate change on rice imports for a range of selected case studies by creating a risk profile for each country. In line with standard climate change risk assessment methodologies (ADB 2005; Swart et al. 2009), this profile is based on assessment of the '*Likelihood'* and '*Magnitude'* of potential climate-related impacts on rice imports.
For the climate risk profile, the indicator data is described and summarised in chart form and rated based on 'traffic lights':

 = High

 = Medium

 = Low

Risk indicators applied in this study are summarized in Table 3.1. The choice of rating will be explained in most cases and especially if it is not straight forward.

Table 3.1 – *Risk indicators to assess the likelihood and magnitude of potential climate-related impacts on rice imports.*

	Indicator	**Evidence**
Likelihood	Rice trade profile	Recent rice trade data (UNcomtrade 2014)
	Climate change impacts on rice production	Based on GCM model linked with SRES scenario output (Iglesias & Rosensweig 2010)
	Trade partner concentration	Recent 5 year trade data (UNcomtrade 2014), calculated using the Herfindahl-Hirschman-Index (U.S. Department of Justice 2010)
Magnitude	Income (GNI) per capita	Proxy indicator: national income (Nelson et al. 2010), data from The World Bank (2014a)
	National consumption of rice	Proxy indicator: dependency on rice, data from IRRI (2014)
	Self-sufficiency of domestic rice production	Computed using the formula by FAOSTAT (2014), data collected from USDA (2014).

The unit of analysis in this study is the country level, since rice trade is mostly determined by governments and countries instead of companies (Siamwalla & Haykin 1983; Defra 2010). Furthermore, climate change adaptation planning occurs primarily at the national level, for example within the United Nations Framework Convention on Climate Change (UNFCCC).

The data quality and reliability will vary in this assessment, as several sources are used to create an as broad picture as possible. Data quality will be discussed in the specific section and data sources have been carefully selected to ensure they are fit for purpose. Official databases such as UNcomtrade (2014), USDA (2014) and IRRI (2014) provide most of the data analysed. Relevant climate change adaptation strategy papers will be used to assess the adequacy of national adaptation strategies regarding the consideration of indirect trade-related impacts.

To the author's knowledge, there are no comparable assessments of trade-related climate risks in the literature. This lack of comparable studies necessitated the selection and definition of the described risk indicators (Table 3.2) as part of the method development. The selection of indicators was made based on the following two criteria:

1. Relevance: The extent to which the indicator accurately reflects the characteristics of the system which is being assessed (i.e. likelihood of occurrence and magnitude of indirect climate change impacts)
2. Data availability: The existence of a full dataset covering all countries; preference was awarded to data sources that are well-used in research and analysis at the global level as an indicator of reliability.

Table 3.2 – *Summary of the rationale for the selection of risk indicators included in this study.*

	Indicator	Rationale
Likelihood	Rice trade profile	It is necessary to know where countries import their rice from in order to assess the climate risks associated with these imports.
	Climate change impacts on rice production	It is necessary to compare the potential impacts of climate change on rice production in key producing countries; a consistent data source was needed to compare future climate impacts across all of the relevant producer countries.
	Trade partner concentration	The underlying assumption is that high import concentration heightens climate-related risks to food security; alternatively, that diverse imports hedge or spread the risk of shocks.
Magnitude	Income (GNI) per capita	The study selected income (GNI) per capita as a risk indicator based on the assumption that ability-to-pay determines an importer's range of available choices for switching strategy for food security during or in response to a crisis. A country with a high GNI per capita has the ability to adapt to changes or shocks in rice trade and thereby to reduce the magnitude of future indirect trade-related climate change impacts.
	National consumption of rice	Based on the assumption that a country who consumes more rice will be more affected by price shocks if they occur.
	Self-sufficiency of domestic rice production	Based on the assumption that a country that has a high level of self-sufficiency will be less affected by price shocks if they occur.

Alternative indicators that were considered but not included in the methodology are listed below:

- No data were available on the likelihood of future extreme events at either the global or producer-country scale. From the perspective of the study methodology this is an unsatisfactory situation, given the direct relevance of climate-driven shocks to the behaviour of the rice market. Data is only available for climatic rice yield impacts for the producing countries, which does not consider extreme events or shocks.
- No reliable data were available on future rice (or general agriculture) policies in the key producer regions. These data would have helped to improve the robustness of the assessment of likelihood of future shocks and future production in producer countries, if available.
- No reliable, easily accessible and comparable data were available for future socio-economic projections in the importing countries, which would have helped to compare the risk of future climate-related trade risks, for example where population trends are likely to increase (leading to higher demand and therefore higher magnitude of indirect climate impacts), or where future economic growth would increase a country's ability-to-pay for high rice prices during shocks.
- There was a lack in data availability to determine the adaptive capacity for the selected case studies and for indirect climate change impacts. Adaptive capacity requires the analysis of factors enabling and constraining possible 'actions' to apply changes in order to reduce risk which are highly dependent on global market relations. This complex and contested concept would have been very beneficial for the analysis as an expressive indicator for the risk magnitude and further through enabling the conversion of risk into the '*end point vulnerability*' (see section 2.1).

Despite the limits of available data, the indicators selected in this method represent a suitable range of factors that can be used to describe both the likelihood and magnitude of future climate-related impacts on food security of rice for the selected countries. The choice of indicators and the methodology will be evaluated based on experiences from applying the method in the discussion section 5.5.

3.1 Justification of case studies

The case study countries examined in this study are Senegal, South Korea, United Arab Emirates (UAE) and the United Kingdom (UK). These countries represent a broad range of environmental and socio-economic characteristics which can be combined with varying dependencies on rice imports and lead to very diverse climate change risk profiles. The case studies are selected because of their different vulnerabilities to indirect impacts and to enable a comparison of how these different vulnerabilities are dealt with in national adaptation planning.

The **UK** is a global adaptation leader and demonstrates advanced awareness and thinking in various climate change related reports. Within the last decades, rice consumption in the UK has steadily increased; one important driver is immigration. In the middle of the 1980s, 90% of foreign foods (amongst others rice) were consumed by minority ethnic groups but over time indigenous population started to integrate ethnic foods (like rice) into their cooking (Panayi 2002; Jamal 2003; Crang & Cook 2003). There is no rice production in the UK, all rice is imported.
The UK is a wealthy country but there are high income inequalities. Low income and social marginalisation are sometimes concentrated in certain immigrant populations. Low income households (of all backgrounds) are more vulnerable to changes in the price of food, including climate-related food price shocks. Social justice therefore plays an important role considering the risk of increasing rice prices. Social justice is becoming an increasingly important objective of national adaptation policy in the UK (see (Banks et al. 2014; Benzie 2014)). It will be tested whether the social justice aspects of (indirect) climate change impacts are already addressed in the most recent (2013 and before) adaptation strategies.

The **UAE** is highly dependent on rice and food imports, due to a lack of arable land and water. Rice trade plays an important role for the country's economy since the UAE is the world's largest rice re-exporter ("*queen of rice*") (Oryza 2014b). The UAE is pursuing to boost its role as regional rice trading hub further, e.g. by building a processing mill to increase the processing capacity (Oryza 2014b). In 2011, the value of rice trade in the UAE was $2 billion with exports to 80 countries (Oryza 2014b).
One potential adaptation strategy is to reduce dependency on global food commodity markets by investing in agricultural land abroad. Furthermore, the UAE tries to diversify its rice imports and enhanced negotiations with Pakistan, Cambodia and Vietnam (Oryza 2014b).

South Korea was selected because of its high expected rice consumption. South Korea is producing most of the rice consumed themselves (approx. 90% over the last 5 years). Present food policies aim to achieve total self-sufficiency on rice. Nevertheless, South Korea imports substantial amounts of rice per year (Table 4.2) and therefore qualifies as a rice import dependent country.
South Korea is generally dependent on food imports, including for grain such as wheat and maize (Lyddon 2012). Hence, national adaptation strategies might focus on indirect climate impacts on other food commodities and general food security besides rice.
The country has been one of the fastest growing and industrialized economies and can be considered to be a relatively developed and wealthy country (Lyddon 2012).

Senegal differs from the three other countries in terms of socio-economic characteristics. It is one of the Least Developed Country group and highly food import dependent.

Senegal was one of the countries that suffered most under the price spikes associated with the global food crisis in 2007/8. Rice imports have increased over the last years to meet increasing domestic consumption (Oryza 2014c). Despite the arid conditions in much of the country and its particularly high vulnerability to direct climate impacts, there are increasing efforts under the National Rice Self-Sufficiency Program to achieve self-sufficiency of rice by 2018 (Oryza 2014c).

3.1.1 Producing countries

The producing countries examined in this study are China, India, Pakistan, Thailand, the USA and Vietnam. These countries were identified as key trading partners for the case study countries based on recent rice trade data from UNcomtrade (2014). Further, these key countries are the major rice exporting countries in the world and account for more than two-thirds of global rice exports (Figure 2.2). Accordingly, these producing countries are the key players on the rice market and climate change impacts on these countries will have substantial implications for the global rice market.

India, Thailand, Vietnam, China and Pakistan all restricted rice exports during the 2007/8 crisis (Dawe & Slayton 2011; Demeke et al. 2011). However, these export restrictions were implemented for low quality rice with the aim to secure domestic availability, while high quality rice (like basmati) exports were maintained (Dawe & Slayton 2011). Senegal imports mainly 100% broken rice which is considered to be of inferior quality on international markets (Brüntrup et al. 2006), leading to substantial crisis effect on Senegal.

The results from the literature review regarding climate change impacts on yield (section 7.2) suggest, that the direct climate change impacts will vary significantly between producing countries. Based on study results from Iglesias & Rosensweig (2010), India and Pakistan are predicted to face severe yield reduction; China and Vietnam medium, while the USA and Thailand are expected to experience no significant rice yield impacts or might even benefit from more favourable climatic conditions.

3.2 Likelihood of climate change impacts on rice imports

Figure 3.1 summarizes the important analytical steps conducted in this multi-step risk assessment.

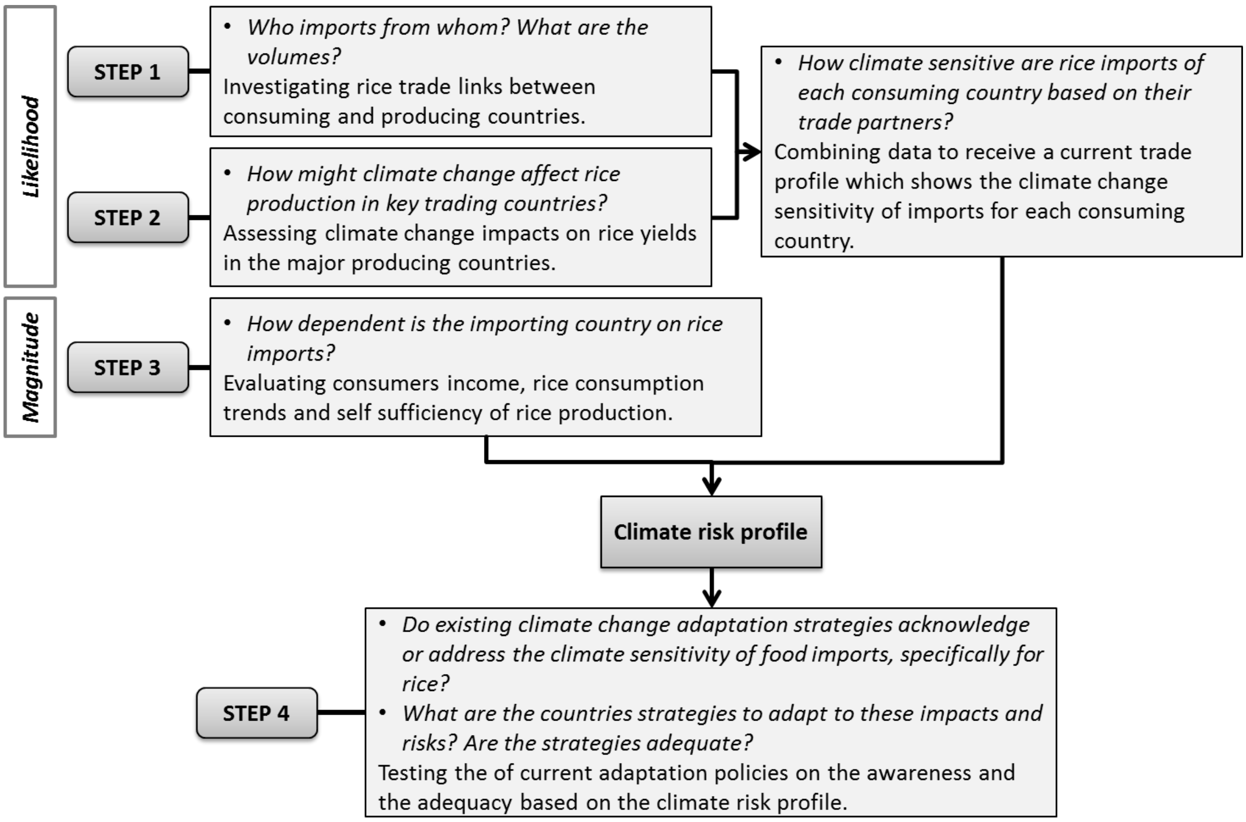


Figure 3.1 – *Summary of analytical steps conducted in this study.*

3.2.1 STEP 1 - Rice trade profile

- *Who imports from whom? What are the volumes?*

Creating a trade profile is the first step of assessing the climate sensitivity of rice imports. Collected rice trade data is used to establish a representative and interconnected network of trade flows between consuming and producing countries considered in this study (see section 4.1.1).

This network is displayed through a Sankey diagram. These diagrams are a commonly used method to visualize energy or material transfers between elements of a system and can be used to identify inefficiencies and potential savings (Schmidt 2008). In this study, a Sankey diagram is used to map value flows in the rice trading system and thereby illustrating trade relations between exporting and importing countries. The arrow width of these diagrams proportionally represents the flow quantity, which in this case is the import share in percent of the producing countries for the respective importing country.
In order to calculate the percent wise share of imports for each importing country, the average five year import quantity from each exporting country is divided by the total rice imports of the respective importing country over the same period and multiplied by 100.

All rice trade data analysed in this step is extracted from the United Nations Commodity Trade Statistics Database (UNcomtrade). The UNcomtrade database provides annual trade data reported by statistical authorities of close to 200 countries or areas and is considered the most comprehensive trade database available (UNcomtrade 2014).
The trade commodity rice is reported in 'milled rice', the units declared are 'Net Weight (kg)' and 'Trade Value ($)'. For the analysis, the Net Weight is used since other databases are not reporting the Trade Value (lack of comparability) and the focus of this study lays on the total amount of rice flows instead of monetary flows. However, during the data collection both units are gathered and listed in the Table 7.1 to 7.4 (see Appendices 7.3).

Data from this database is used to both establish the current trade profile as well as to assess the market concentration in a trading partner concentration analysis. The recent 5 year trade average (2008 – 2012) is a suitable data timeframe because it includes repercussions of the rice crisis in 2008 and further reflects most recent import trends. Considering only the latest year (e.g. 2012) would disguise interannual changes in trading partners and neglect longer term trading relations.

Using data from an online database introduces uncertainties and the reliability of the data extracted needs to be questioned. The following limitations and sources of error are reported for the database (UNcomtrade 2014) (Table 3.3).

Table 3.3 – *Data limitations in the UNcomtrade (2014) database and their implications for the analysis.*

Database limitations	Effects of data limitations for this study
Confidentiality of trade data prohibits the report of detailed trade so that detailed data does not necessarily sum up to the total trade value for a given country. Import flows between specific countries are considered to be detailed data and are therefore unlikely to sum up to the total import for the country (imports from World).	Import percentage shares reported in the results may not be entirely correct but a slight deviation of 1 or 2 percent (very unlikely to be higher) does not affect the indicator rating. Using the average over 5 years (e.g. for import shares in the current trade profile) has the same effect for each country so that the proportions remains the same and overall results are not altered.
Trade statistics may not be reported for each year altering the quality of aggregated data (no estimates on size of missing data).	This is not a serious limitation for the data in this study since no aggregated data is used except the 'Worlds' imports and exports. This might also affect the import percentage shares reported in the results. As stated above, a small deviation in percentages does not affect the overall indicator rating. However, this limitation might limit the data from USDA as this database exclusively states aggregated data. USDA data is used to calculate the SSR based on production, import and exports.

Countries may use an outdated commodity classification causing data misinterpretation (no estimates on size of missing data).	This limitation has no effect because there is only one category of rice in UNcomtrade and USDA.
Import data reported by one country do not coincide with exports reported by its trading partner. Various factors are causing these differences, including valuation, inclusions and exclusions of particular commodities and timing. Further deviation might originate from countries that are secretive about their imports and exports.	The gap between declared imports of partner-country statistics and exports was significant during the data collection.

The Foreign Agricultural Service (FAS 2014) reports similar variations between imports and exports of commodities but states two differing explanations: small quantities of import, export and production are often not included in the database but their sum can cause variations between stated import and export amounts of countries. Large changes in production of commodities that are produced in the southern hemisphere can be listed as exports in one marketing year and as imports in another.

A study by Yeats (1995) argues that partner-country statistics (imports) are unreliable and therefore not suitable substitutes for export data. However, the argumentation is based on the fact that *"many developing countries fail to report trade statistics to the United Nations"* (Yeats 1995). Most exporting countries considered in the analysis are developing countries, altering the reliability of their declared export data and therefore supports the use of trade partner (import) data (higher developed countries). Additionally, some sources of error described in the study are not applicable as they are connected to valuation differences or problems associated with exchange-rate variations, which are neglectable because rice quantities were used in the analysis instead of prices in fiat.
Generally, the trade partner-data seems to be more adequate throughout the analysis (both sources were analysed which in the first place revealed the differences), only the UAE revealed partly lower data quality. Accordingly, import data will be used in all database search queries in this study as a trade proxy and to guarantee consistency between and within databases.
These described limitations are inevitable, but they have to be stated and can be considered in the rating of indicators. Generally, the differences are unlikely to alter the results of this analysis significantly as all consuming countries are affected by the same limitations.

The third risk indicator considered in the likelihood of climate change impacts on rice imports is the market concentration of trade partners. A concentration on only a few producing countries increases the sensitivity of an importing country towards climate related yield impacts in partner countries. The market concentration for each consuming country is evaluated by using the Herfindahl-Hirschman-Index (HHI). The HHI is calculated using the formula $H = \sum_{i=1}^{N} s_i^2$ where s_i is the market share of firm *i* and *N* the number of countries in the market.
The market concentration is computed based on current (average recent five years) trade data and hence does not consider possible future shifts in trading partner composition which are indicated for the UAE (UAE 2012) and the UK (Defra 2013; PwC 2013).
The HHI further requires dividing missing percentages in trade shares among equally sized producers. It has been assumed that missing trade percentages are divided between 5 other

producers which seemed an appropriate amount because of the thin rice market. This assumption has varying implications for the consuming countries as the investigated producer countries (China, India, Pakistan, Thailand, USA and Vietnam) in this study cover different shares: Senegal imports are covered to 73,9%, 26,1% are accordingly divided on five countries; South Korea is covered by 98,8%; the UAE by 98,6% and the UK by 85,9%. Hence this has the strongest implications for Senegal and some implications for the UK while there are no significant implications for South Korea and the UAE.

The result is categorized in one of three categories: <0.15 indicates an unconcentrated market; between 0.15 to 0.25 indicates moderate concentration and >0.25 indicates highly concentrated markets (U.S. Department of Justice 2010). A low index value accordingly indicates a competitive and diverse market with no dominant player while a high index value reveals dependencies on dominant players (U.S. Department of Justice 2010).
The described index ranking is used for the traffic lights valuation for the market concentration indicator.

3.2.2 STEP 2 - Climate change impacts on rice production

- *How might climate change affect rice production in key trading countries?*

This section aims to further define the climate sensitivity of rice imports for the consumer countries by assessing the climate change impacts on rice yield on the respective producers. Using the data from (STEP 1), the study identifies the key producing regions for each importing country and assesses the climate sensitivity of rice production in those key producer countries in order to assess the overall climate sensitivity of imports.

Data concerning future climate change impacts on rice yields is provided by Iglesias & Rosensweig (2010). The data set states rice yield changes based on HadCM3 (coupled atmosphere-ocean General circulation models (GCMs) model output which is linked to GHG concentrations from seven different Special Report on Emissions Scenarios (SRES).
This climate change model set considers implications of temperature variations and changes in precipitation along with physiological effects of CO_2 fertilization (Iglesias & Rosensweig 2010). Furthermore, possible adaptation measures are included by determining the optimal crop yield. Optimal crop yield is the maximum yield that can be achieved in an area by excluding all possible limiting factors such as water, fertilizer use or management constraints. Adapted yields are considered as a fraction of the optimal yield for each country, based on the evaluation of the extent to which it might be possible to overcome the limiting factors (Iglesias & Rosensweig 2010). Further information on how these adaptation measures are incorporated in the model is not available.

The selection of climate change factors and the implementation of adaptation measures lead to the assumption that the resulting data is positively biased. The model neglects a number of negative climate change impacts on yield such as sea level rise, increased pest and diseases and tropospheric ozone formation. Other studies stated that the impacts of ozone, pests and disease are likely to offset the positive effects of CO_2 fertilization (IPCC 2014a). Sea level rise is a major threat to some rice producing countries, particularly Vietnam.
Countries emitting larger amounts of GHGs and air pollution are expected to suffer from increased ozone damages as CO_2 emissions are accompanied by precursors for tropospheric ozone formation (IPCC 2014a). India and China are particularly exposed to O_3 impacts (Van

Dingenen et al. 2009; Avnery et al. 2011). Several studies state that the counteractive effects on C_3 plants (like rice) may compensate each other (Taub et al. 2008; Ainsworth et al. 2008; Gillespie et al. 2012), however these effects are not represented in the data from Iglesias & Rosensweig (2010).

Generally, equilibrium-based models are susceptible to a number of limitations deriving from the representation of global climate change as linear global mean temperature; the representation of climate related impacts on agriculture such as CO_2 fertilization, incomplete crop models, assumed linearity with global mean temperature; the failure to account for devastating effects by implying manageable losses even at extreme levels of climate change; a poor treatment of uncertainty in general; unrealistic adaptation by assuming perfect or unlimited adaptation; and neglecting socio-economic changes (Benzie et al. 2014, unpublished). These limitations in modelling tend to lead to an underestimation of the size of climate risks.

Climate scenarios from Iglesias & Rosensweig (2010) where chosen over projections from other studies since they provided the widest range of scenarios as they used all seven available SRES scenarios. Further, this was the only study which provided data for all six key producing countries considered in this study and more data to project global rice yield development based on climate scenario yield projections for 165 countries.

In order to establish the climate change sensitivity of rice imports for each consuming country, the direct climate change impact on each respective producing country is assessed and rated ( ). The rating is based on the scenario projections by Iglesias & Rosensweig (2010) for 2020 and based on the average and range of values of the seven climate scenarios applied. Using the average value of the scenarios and stating the range of values is the basis to evaluate the size of the climate change impacts.
This grading method is a simplification that was necessary due to a lack of other options. A more robust way would be to grade the scenarios on their current likelihood (compare with present data, i.e. how likely it is that the world will realise a given SRES emissions scenario based on recent and current development trends) and exclude or weigh unlikely scenario results. This requires an in depth analysis where each scenario specifically and also the overall scenario projections are investigated in order to make a qualified assumption. However, this research would be time consuming. Additionally, the scenario data is of low quality and is only used to create a qualitative rating so that this simplified method is sufficient.

Data from 2020 is used instead of data for 2050 or 2080 for several reasons. In the first place, the data is the most robust as uncertainties increase over time. Particularly the positive bias of the scenarios is magnifying over time as negative not considered factors are amplifying over time, e.g. sea level rise. The robustness of results in Iglesias & Rosensweig (2010) beyond this period can be questioned given the substantial positive yield effects that they predict. Assessing a country's current trade profile is likely to be adequate to some extent up to 2020, while trade relations may have changed significantly by 2050 and thereafter.

The 'World' in the current trade profile represents the share of imports percentages which are not covered by the key producing countries. This is particularly important for Senegal and the UK (see end of the previous section). Climate change impacts on the world are rated as high ( ) since the model projects an overall rice yield decline of 2.8 % as average over all seven scenarios by 2020. This rice yield decline is computed in relation to an average baseline yield over the years from 1970 to 2000.

Afterwards, the major producing countries are summarized for each consumer country with the aim to establish a risk rating. The import share is an important indicator for the significance of the producing country. Based on the import share and the vulnerability of the associated producing countries, the consuming country is rated (✔!✖). In the cases of Senegal and South Korea, the projected climate change impacts on the own national rice production system are also considered (see Table 4.5 and Table 4.6 in the result section 4.1.2). These two countries are both growing a major share of their consumed rice within their borders and aim for self-sufficiency in the near future. Hence, direct climate change impacts on domestic yields are an important factor to consider. The UK and UAE are not producing any rice themselves.

A decline in global rice yields is very likely to affect the rice market system and thereby each of the case study countries (section 2.4). Global rice yield projections are based on the computed average of climate scenario projections of rice yields for 165 countries based on data from Iglesias & Rosensweig (2010). This climate change effects on the global rice yield are acknowledged in the analysis through including the 'World' yield development as a separate risk indicator in the likelihood assessment.
This analysis focuses on declining global rice yields which can amplify the risk of market shocks due to expected generally increasing shortages in rice supplies (section 5.5).

3.3 STEP 3 - Magnitude of climate change impacts on rice imports

- *How dependent is the importing country on rice imports?*

The magnitude of indirect climate change impacts on rice imports is evaluated based on the country's Gross National Income (GNI) per capita, its dependency on rice as a staple food and its import dependency (SSR).

A higher likelihood of climate change impacts on global rice production will reduce the availability of traded rice and increase price volatility (Foresight 2011a; Defra 2013). The GNI per capita is used as a proxy for the country's ability to cope with changing prices since the income determines the ability of consumers to purchase rice (Nelson et al. 2010). Generally, wealthier countries are less sensitive to price increases since they have the ability to substitute supplier countries and thereby reduce the magnitude of climate change impacts (at least at the national level; on sub-national level, increasing prices might affect vulnerable consumer groups also within rich countries).
The per capita income and the domestic prices determine the consumer's ability to purchase food; an average consumer in a low-income country (LIC) obtains only two-thirds of food calories available in the developed countries today (Nelson et al. 2010). Accordingly, a low per capita income limits the calorie availability and alters the substitutability of staple foods like rice in times of price shocks.

Higher income production systems are potentially more resilient towards direct climate change impacts as they are able to invest in new technologies and management systems that are costly at the beginning but have big productivity and resilience payoffs (Nelson et al. 2010). This has to be considered regarding countries aiming for rice self-sufficiency like Senegal and South Korea. Senegalese farming system are mainly smallholder systems, lacking the ability of investing greater amounts of money (Demont & Rizzotto 2012; Elbehri 2013; Diagne et al. 2013). South Korean farmers on the other hand are supported by the government through subsidies, access to long-term credits, as well as favourable rice prices and income compensations for farmers (USDA 2006).

GNI per capita (formerly GNP per capita) data is published by The World Bank (2014a), providing specific recent data (2012) for each consuming country. The GNI per capita is calculated using the gross national income converted to US$ and divided by the country's midyear population (The World Bank 2014a).
The World Bank (2014b) income group classification is used for the income rating of the countries (✅⚠️❌). The income groups are divided according to the 2012 GNI per capita into low-income ($1,035 or less), lower middle income ($1,035 - $4,085), upper middle income (4,086 - $12,615) and high income ($12,616 or more) (The World Bank 2014b). The lower and middle income groups are combined in one category in this analysis to enable the traffic lights classification. This reduction in categories has no implications for the results since Senegal is categorized as a LIC and the other three countries are high income countries.

The dependency on rice as a staple food for domestic consumption is evaluated based on the present domestic rice consumption and the trends over the last ~50 years in each case study country.
The higher the share of rice in the calorie intake is, the more difficult is it for the country and its respective consumers to substitute rice with other foodstuff in times of market shocks (Prakash 2011). Hence, a high consumption is equivalent to a high dependency on rice. Particularly in LICs where calorie sources are less obtainable (two-thirds compared to developed country), a loss or decrease of a major calorie source like rice has severe implications for the national food security (Prakash 2011).

Further, consumption trends over the past ~50 years also indicate future importance. However, consumption patterns change over time associated with income growth, urbanization, market development, and trade liberalization and determine global and local food security and preferences (Kearney 2010).

Consumption data was extracted from the International Rice Research Institute (IRRI) (2014) database. The IRRI consumption data is computed based on FAOSTAT data (FAOSTAT 2014). There is no further information available on how the computation was conducted. Rice consumption is expressed in Rice Calorie Intake in percent of total per day from 1961 to 2009 (48 years) for each consuming country.

The sensitivity towards indirect climate change impacts on rice imports is significantly influenced by the self-sufficiency ratio (SSR). The SSR is a method to assess the level of import dependency and calculated with the formula: $SSR = \frac{Production*100}{(Production+Imports-Exports)}$ (FAOSTAT 2014). Accordingly, a high SSR indicates a low import dependency and vice versa. A country that is importing a major share of its food commodities (e.g. rice) and only producing a small share on its own is highly import dependent. The import dependency is amplifying the risk factor and the vulnerability to indirect climate change impacts via the trade pathway.

The data used for computing the SSR is collected from the USDA database (USDA 2014). It is necessary to employ a second database in the USDA database since the UNcomtrade database does not feature data on country specific production.
The USDA database is administrated by the Foreign Agricultural Services (FAS) division of the United States Department of Agriculture. As sources of data, the "*USDA uses official country statistics, reports from agricultural attaches at U.S. embassies, data from international organizations, publications from individual countries, information from traders both inside and outside a country, and other available information* (FAS 2014)."
In the subcategory 'Production, Supply and Distribution', general information about country specific rice production, consumption, import and export are available.

The commodity used for the search queries is 'milled rice'. All rice statistics are shown on a milled rice basis, comprising threshed seeds of all types (excluding wild) and gathered in the dry, unprocessed state upon plant maturity (FAS 2014).

In the calculation, the SSR for the past 5 years available (2009 to 2013) is calculated using production, import and export data from USDA (2014). Afterwards, the average SSR over this time is computed and used for the classification of the indicator.
For the UAE and the UK, the calculation could not be conducted since there is no domestic production (data), and the SSR is accordingly set to 0.

The study acknowledges that all three magnitude indicators are subject to uncertainty and might change significantly in the future. However, this study evaluates the current 'status' of each of the three indicators since a consideration of possible future shifts would be highly challenging to conduct adequately.

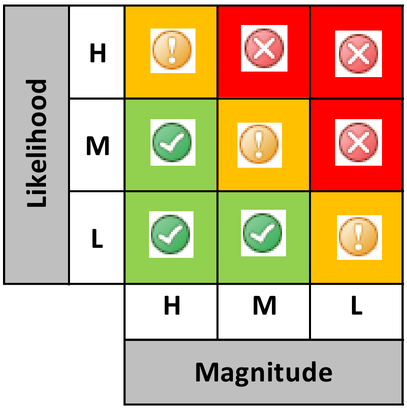
3.4 Climate risk profile

The 'Likelihood' and the 'Magnitude' of indirect climate change impacts each comprise three risk indicators as presented in the previous section. Each indicator will be rated using the traffic lights system . For the overall climate risk profile, a total score for both the Likelihood and the Magnitude is needed which requires the combination of three indicators to one classification for each country.
The risk indicators are combined applying the following method:

Indicator Rating	Score
	0
	1
	2
overall range: 0 to 6	

The score of all three risk indicators will be summed and range from -3 to 3. The results for the Likelihood and Magnitude will be rated as  if it is 0 or 1, as  if it is 2, 3 or 4 and as  if it is 5 or 6. These scores for the Likelihood and Magnitude will be also presented as a figure (Figure 4.3) to illustrate the differences between the importing countries.
Risk is the product of likelihood and magnitude. In order to establish an overall risk score, the ratings of the Likelihood and Magnitude are combined by using a 3x3 risk matrix (Table 3.4).

Table 3.4 *–3x3 risk matrix.*



A range of adaptation documents and other relevant non-adaptation documents of each case study country are tested against the resulting climate risk profile to examine the coverage of current adaptation strategies.

3.5 Adaptation policy analysis

After identifying the likelihood and magnitude of future indirect climate change impacts on rice imports, the extent to which these indirect impacts are reflected in the policies is tested using a two-step analysis:

1. Exploration of the extent to which the importing countries acknowledge or address climate sensitivity of food imports, specifically for rice.
   - Do the respective adaptation policy papers mention the risks associated with climate change impacts?
   - To which extent are 'indirect climate change impacts' such as impacts on imports, food security and food price volatility, covered in the adaptation policies?

2. Analysis of the existing or planned adaptation measures.
   - Which adaptation measures are currently described in the documents? How do these measures relate to the ODI (2010) framework (Figure 3.2)?

A range of relevant documents, adaptation documents and other relevant non-adaptation documents are gathered and reviewed in a literature search. The adequacy of adaptation strategies is assessed applying an analytical framework by ODI (2010) to evaluate the measures identified and adaptation gaps. The framework presents major options to deal with climate change impacts on rice imports and its consequences in a three points approach (Figure 3.2). The ODI framework could be interpreted as a set of options to '*spread risks'* associated with the climate change impacts on rice imports.

The **first** point of possible action is to prevent, mitigate or compensate for climate change impacts on rice production. Measures to achieve this target would be to 1. Increase the climate resilience of the production systems (e.g. through technology upgrades, new rice varieties and improved breeding or changes in management systems); 2. Promote national agriculture (e.g. by increasing technological efficiency, increased fertilizers application or increasing farmland); or 3. Hold more stocks (storage of sufficient amounts of rice above a critical threshold of stocks-to-use) like internationally coordinated public grain reserves or regional and national reserves (ODI 2010).

The **second** point of possible action is to prevent or mitigate the transmission of climate related impacts on global trade and particularly imports: 1. Tame futures markets by controlling the markets through trading unions and the creation of virtual reserves for counter trading; 2. Limit export restrictions through internationally and regionally improved trade coordination (probably under WTO rules); 3. Border measures like reduced import tariffs and export restrictions; 4. Trade measures such as import facilitation, barter, hedging on futures and options markets and exploiting the scope for regional trading; 5. Market interventions through controlled prices by fiat, releasing private or public stocks, prevent hoarding, and reduce food taxes or subsidise staple food prices; 6. Macroeconomic measures like rising exchange rates (ODI 2010).

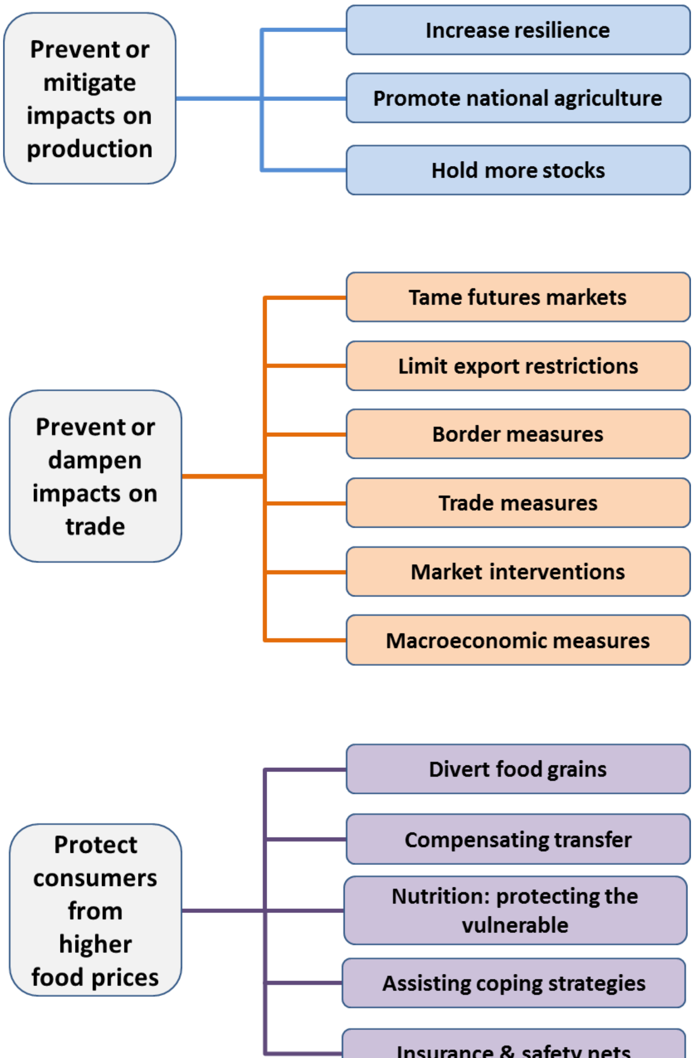


Figure 3.2 - *Analytical framework for current adaptation policies based on the framework by ODI (2010), modified.*

Policy options to protect vulnerable consumers (**third**) are 1. Diversification of food grains to enhance the calorie availability for consumers; 2. Compensating transfers like cash for food, work or training and raise wages; 3. Nutrition for the vulnerable through school feeding, supplementary feeding to infants, young children and mothers, micronutrient supplements and home gardens; 4. Assisting coping strategies like facilitating and increasing of credit availability; 5 Introduce or scale up insurance & safety nets to protect consumers from adverse developments in prices (ODI 2010).

The options described in this broad overview are markedly different in terms of their suitability –including their efficiency and feasibility - for the case study countries examined in this study because of their varying profiles and domestic characteristics. The framework will be employed to evaluate country measures and identify gaps in the respective adaptation strategies.

When applied to the context of the methodology employed in this study, the first point of action in the ODI framework represents adaptation measures which aim to prevent the indirect climate change impacts on rice imports and hence address the likelihood of climate change impacts on rice production. The second and third points of action comprise measures to reduce the magnitude of the indirect climate related impacts when they occur.

4 Results

4.1 Likelihood of climate change impacts on rice imports

4.1.1 STEP 1 - Rice trade profile

This section states the results of the steps described in the section 3.2.1.
Figure 4.1 illustrates the network of trade flows between the case study and their key producing countries. The Sankey diagram (Figure 4.1) provides an overview of rice flows between the countries considered in this study and establishes a representative rice trading network. The diagram is used to map value flows in the rice trading system and thereby visualize trade relations between the countries. The arrow width displayed in the diagram reflects the import share in % of the producing countries for the respective importing country.

Data used for calculating the import shares is based on data from the UNcomtrade (2014) and computed for the recent five year average. The recent five years available in the database are the years 2008 to 2012, however, there was no available data for the UAE in 2012 (data used from 2007 to 2011).

The Sankey diagram (Figure 4.1) illustrates average data over a five year timeframe; hence it does not show variations between years. Therefore, bar diagrams are used subsequently in this section to display annual trading dynamics based on the same data.

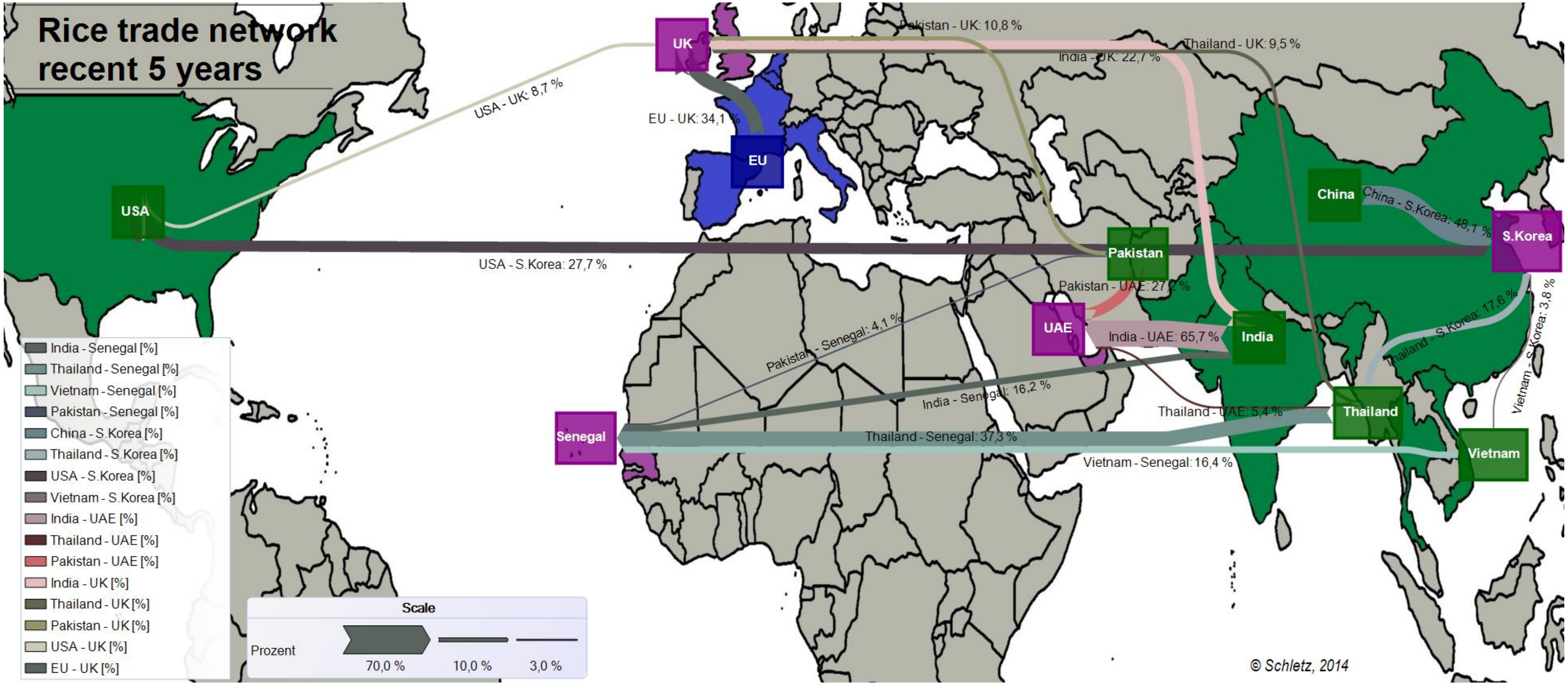
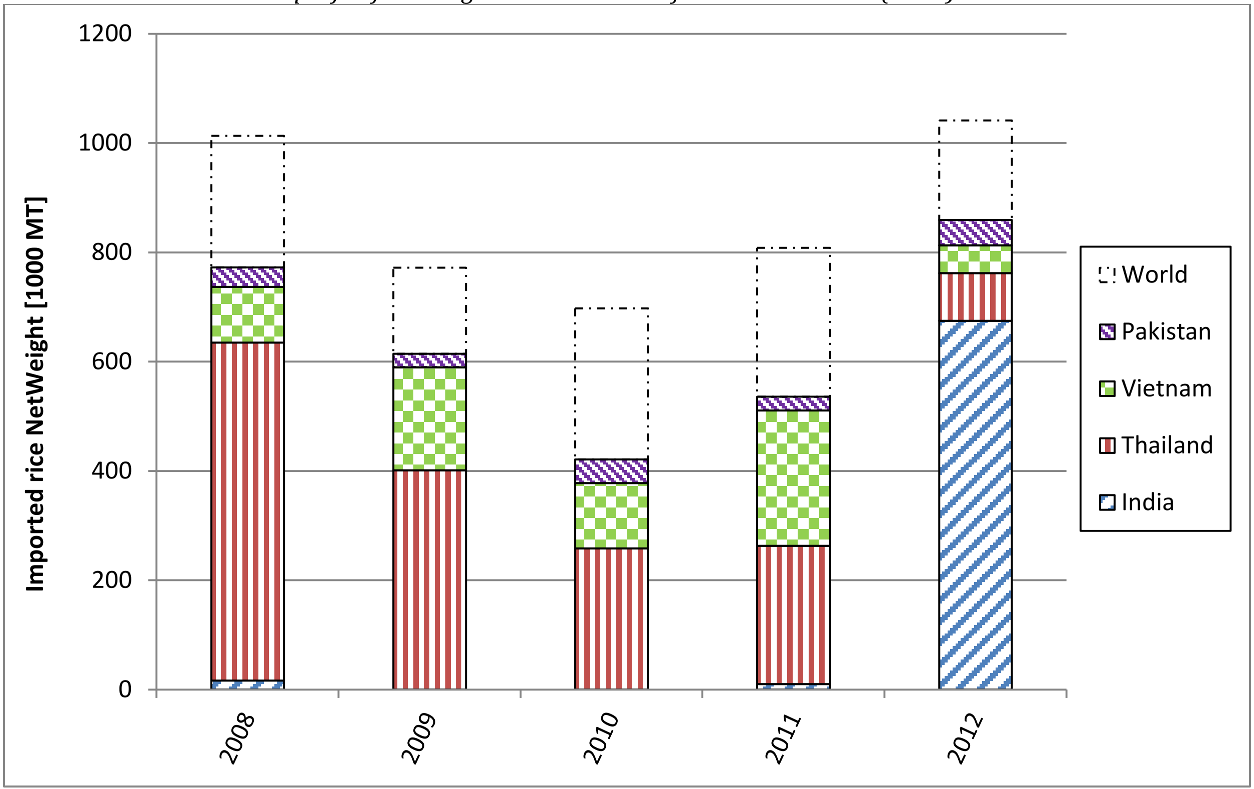


Figure 4.1 – *Trade network of selected producer (green) and consumer countries (purple) indicating the magnitude of trade flows of rice over the recent five years. European countries are marked in blue as they are mainly acting as trade intermediaries.*
Arrow sizes of the trade flows between countries represent the share (in %) the producing/intermediary country account for in the total rice imports of the importing country. Data used: UNcomtrade (2014), software used: e!Sankey (ifu hamburg 2014).

All trade data is based on rice imports from the consumer country and stated in 1000 Metric Tonnes (MT). The 'World' represents the missing amounts from other producing countries in the subsequent tables (Table 4.1 to Table 4.4) and is based on total import values subtracted with the values of the producing countries.

4.1.1.1 Senegal rice trade profile

Table 4.1 - *Current trade profile for Senegal. Data collected from UNcomtrade (2014).*



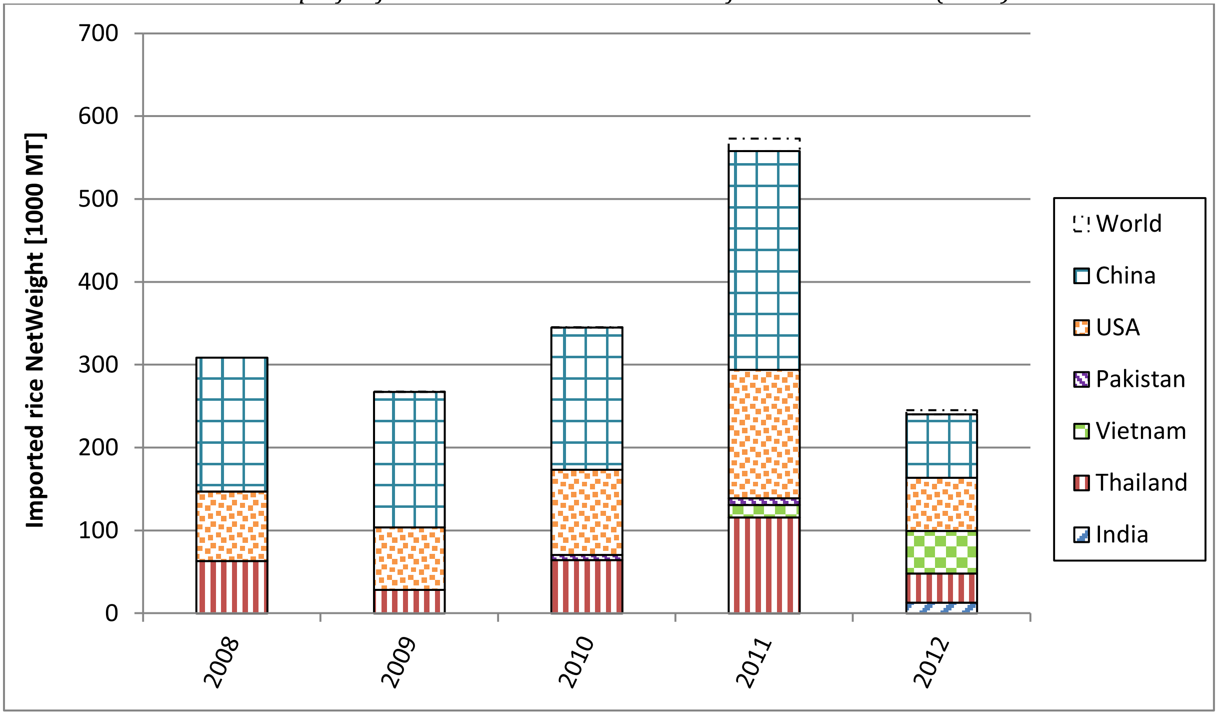
Senegal's major trading partners over the last 5 years are Thailand (37,3% import share), Vietnam (16,4%), and India (16,2%) and Pakistan (4,1%) which are contributing 73,9% of total rice imports over the recent period (UNcomtrade 2014).

The amount of the total imports is declining from 2008 (the year of the rice market crisis:(Slayton 2009; Dawe & Slayton 2011)) to 2010 and then recovering to the previous level in 2008 by 2012. Thailand and Vietnam were major trading partners over the period from 2008 to 2011, while India is the main source in 2012 (64,8% alone in 2012). India banned non-basmati rice exports in 2007 for four years (FAO 2011b).
In September of 2011, India relaxed the ban on non-basmati rice exports and released 1.5 million tonnes of rice to foreign markets (FAO 2011a; FAO 2011b). Subsequently in 2012, Senegal switched back to India as main trading partner which mainly proves the dependence on Indian rice imports.

Senegal's rice imports consist almost entirely of broken rice which is a by-product of rice processing (Brüntrup et al. 2006). Broken rice is considered to be of inferior quality and therefore cheaper than whole rice which is imported by the other three case study countries (Brüntrup et al. 2006).

4.1.1.2 South Korea rice trade profile

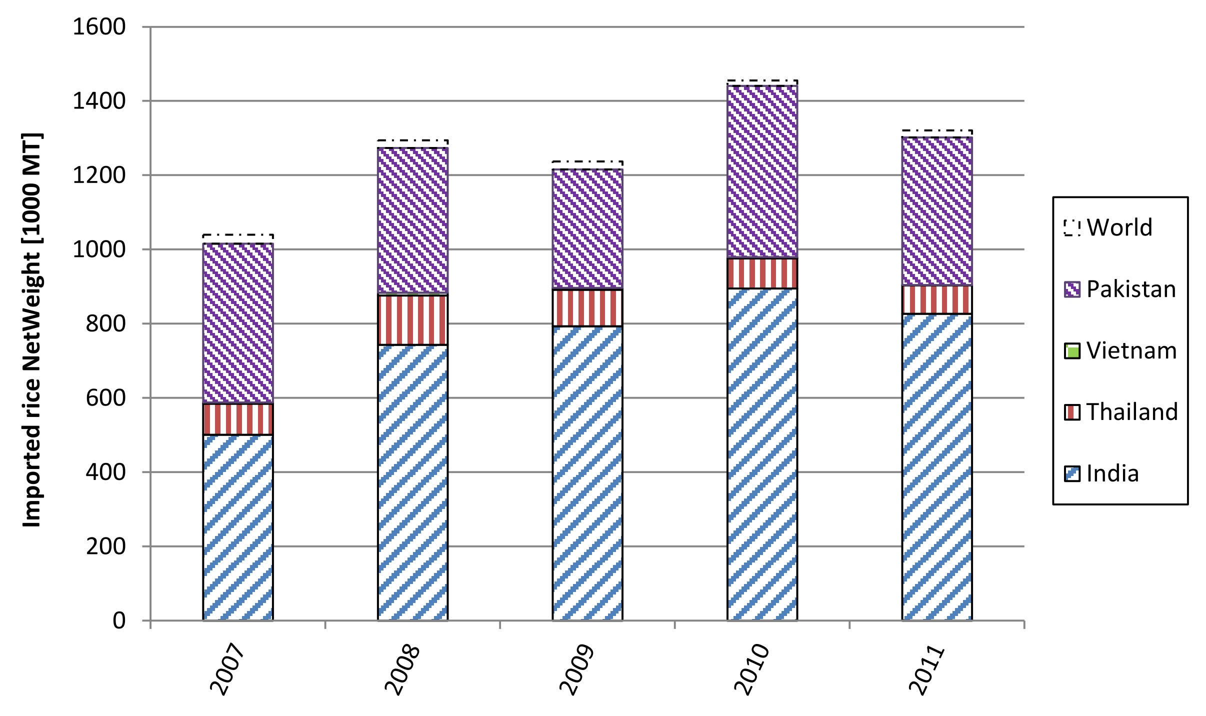
Table 4.2 – *Current trade profile for South Korea. Data collected from UNcomtrade (2014).*



South Korea's major trading partners over the last 5 years are China (48,1% import share), USA (27,7%), Thailand (17,6%), Vietnam (3,8%), Pakistan (0,8%), and India (0,7%) which are contributing 98,8% of total rice imports over the recent period (UNcomtrade 2014).
In 2011, there is a huge increase in rice imported, while the imports from 2008 to 2010 are relatively stable. The reason for this increase might be the implementation of the ASEAN plus three rice storage scheme where South Korea pledged a major share with 250,000 MT of rice (Briones et al. 2012).

4.1.1.3 United Arab Emirates rice trade profile

Table 4.3 – *Current trade profile for the UAE. Data collected from UNcomtrade (2014).*



The UAE's major trading partners over the last 5 years are India (65,7%), Pakistan (27,2%), Thailand (5,4% import share) and Vietnam (0,2%) which are contributing 98,6% of total rice imports over the recent period (UNcomtrade 2014). Only two countries account for 92,9% of total imports over the recent 5 years (2007 – 2011), with nearly two-thirds of the rice imports originating from India alone.

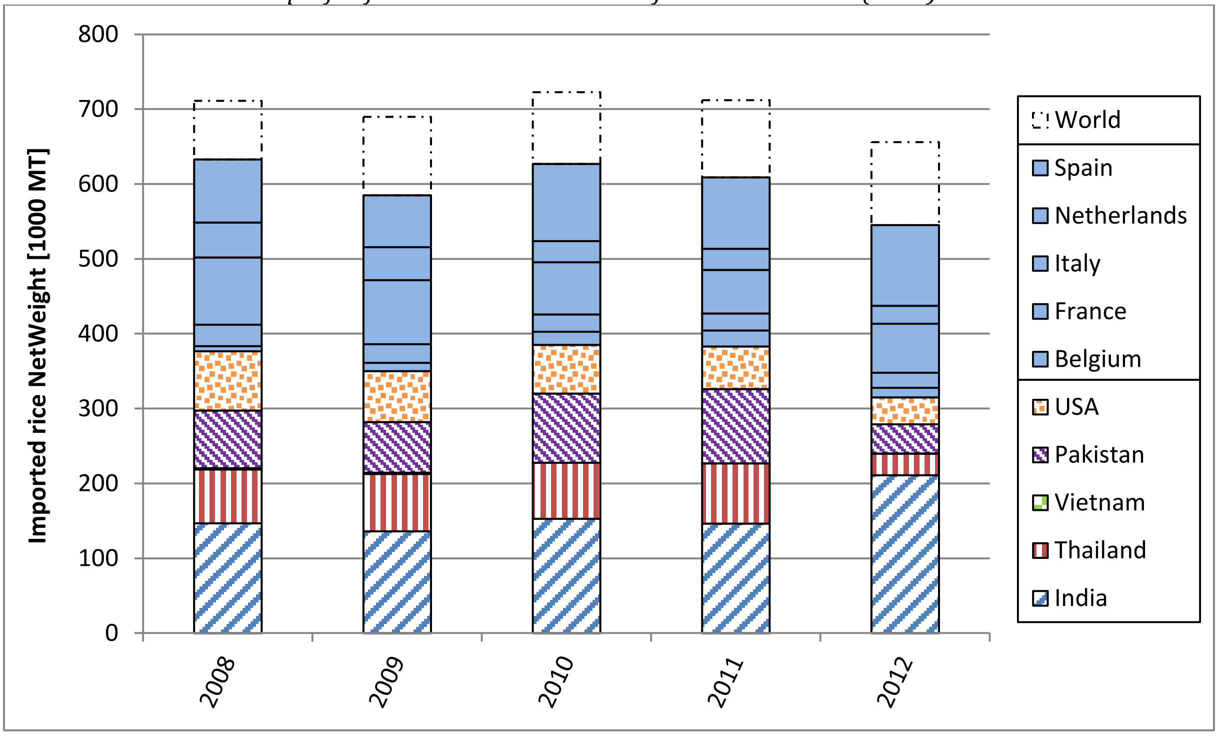
The food crisis in 2007/8 and the Indian ban of non-basmati rice export did not affect the rice trade between the UAE and India. The UAE is importing exclusively basmati (premium rice) and the major re-export partner Iran is the world's largest importer of basmati rice.

The UAE is importing the highest total amount of rice of the four case study countries. Approximately one-third of the rice imported is re-exported over the last years (2005 to 2011) (UNcomtrade 2014), making the UAE the world's largest rice re-exporter (mainly to Iran) (Oryza 2014b).

The timeframe of the data is different (2007 – 2011) from the timeframe of the other countries (2008 – 2012), which is due to missing data for UAE trade in 2012.
Furthermore, the data for 2009 and 2010 is based on trade value in $ instead of the Net Weight in 1000 MT which was missing in the dataset (see Table 7.3, Appendices). Instead of using the Net Weight of imports for each producing countries and total imports to calculate the share percentage-wise, the $ value was used as both kinds of data are available in the UNcomtrade database.

4.1.1.4 United Kingdom rice trade profile

Table 4.4 – *Current trade profile for the UK. Data collected from UNcomtrade (2014).*



The UK's major trading partners over the last 5 years are India (22,7%), Pakistan (10,8%), Thailand (9,5% import share), USA (8,7%) and Vietnam (0,1%) which are contributing 51,8% of total rice imports over the recent period (UNcomtrade 2014).

The EU countries Spain, Netherlands, Italy, France and Belgium combine for 34,1%. These countries are mostly acting as trade intermediaries for the UK since only Spain, Italy and France are produce rice. The trade data available is not sufficient to locate the origin of rice traded by EU countries, which is why the EU countries are listed as a separate category in the one colour in Table 4.4.

Trade concentration calculated and categorized after the Herfindahl-Hirschman-Index (HHI) are: Senegal (0,208; rating), South Korea (0,341; rating), the UAE (0,509; rating) and the UK (0,119; rating). A relatively high value (like South Korea and UAE) reveals a high dependency on a few trading partners which is assumed to heighten climate-related risks to food security, while a relatively low value (like UK) shows a diverse trade partner composition which spreads the risk of food security.

Senegal's trade profile shows substantial and long-term repercussions from the 2007/8 crises while the other three countries are not significantly affected (compare Appendices 7.3, Figure 7.3). The three wealthy countries are all importing premium rice from countries, which did not restrict the export during the crisis. Senegal on the other hand is a major importer of 100% broken rice which is regarded to be lower quality on the world market and hence is sold at a lower price. Export restrictions during the crisis were implemented on low-quality rice with the aim of securing domestic rice availability, while trade of valuable premium rice was maintained (see section 2.4.1).

4.1.2 STEP 2 - Climate change impacts on rice production

This section presents the climate change sensitivity of rice imports for each case study country by examining direct climate change impacts on the relevant producing countries.

The 'World' in the following tables (Table 4.5 to Table 4.8) is used to represent the shares of other producing countries which are not considered in this study. The import share of producing countries is based on the average 5 year import average over the latest years (similar to previous section).

Table 4.5 – *Climate sensitivity of Senegalese rice imports based on yield impacts on key trading partners.*

Senegal	Scenario Data from Iglesias and Rosenzweig 2010								Standard		Rating	Import share [%]
	A1F	*A2a*	*A2b*	*A2c*	*B1a*	*B2a*	*B2b*	Average	Deviation	Range		
Producer	*% in rice yield change by 2020*											
India	-6,1	-4,23	-3,78	-4,8	-3,68	-6,62	-4,93	-4,88	1,13	-3,68; -6,62	⊗	16,2
Thailand	0,75	1,54	0,57	1,46	-0,4	0,78	0,22	0,70	0,68	1,54; -0,4	✓	37,3
Vietnam	-0,7	0,09	0,11	0,04	-0,78	-1,43	-1,12	-0,54	0,63	0,11; -1,43	!	16,4
Pakistan	-5,78	-4,39	-4,68	-5,85	-4,09	-5,62	-5,33	-5,11	0,71	-4,09; -5,78	⊗	4,1
World	-2,4	-1,96	-2,39	-1,97	-3,96	-3,77	-3,17	-2,80	0,83	-1,96; -3,96	⊗	26,1
Percent of total grain production from rice: 62,67											⊗	**Overall:** ⊗
Senegal	-3,07	-2,5	-2,72	-2,2	-3,15	-3,79	-3,76	-3,03	0,60	-2,2; -3,79		

Table 4.5 shows projected climate change yield impacts until 2020 for Senegal's key trading partners for rice imports, according to seven different SRES scenarios. Described changes in the SRES scenario rice yields are calculated based on an average baseline yield over the years from 1970 to 2000. The average column is the computed mean value of these seven scenarios; standard deviation column was computed for the scenario as an indicator for the conformity between scenarios, summarizing the variation between the SRES model data; and the scenario range column represents the lowest and highest climate scenario impacts. The rating based on traffic lights categorizes the key producing countries according to their range of projected direct climate change yield impacts as high, medium or low. The import share [%] states the five year trade average share of the respective producing country; the rating of these shares is combined to the overall assessment of the climate sensitivity of rice imports for the case study country.

The result to rank Senegal's rice imports as highly sensitive to climate change impacts is not obviously visible through the rating of the producing countries in Table 4.5.
Reasons for ranking Senegal as highly sensitive are that producing countries which are projected to suffer high direct climate impacts (India, Pakistan and World) account for 46,4% of imports. India was further accounting for 64,8% of rice imports alone in 2012 (Table 4.1) after relaxing the export ban of low quality rice from 2007 to 2011 (FAO 2011b). This indicates that India is the first choice producer country and Indian rice production is projected to significantly decrease under future climate conditions.

Senegal is aiming for self-sufficiency in rice production which will be significantly more difficult to achieve with climate change impacts on national production (last row in Table 4.5).
Rice production in Thailand and Vietnam is not expected to considerably suffer under climate change impacts, in the time span up to 2020. They account for 53,7% of Senegal's imports and hence reduce the sensitivity of this country. However, the scenarios are not considering sea level rise which will have major climate related impacts on Vietnam in the long run (e.g. 2050). Please refer to the discussion section 5.6 for a detailed reflection on producing countries yield impacts under different scenarios.

Furthermore, it needs to be considered that reduced global yields (see World, Table 4.5) will increase global food prices where Senegal is not considered as 'competitive' as a poor country. Accordingly it can be expected that future trading relations are shifting so that rice producers prioritize exports to wealthy countries which can pay a higher price. Hence the overall rating for Senegalese rice imports is high.

Table 4.6 – *Climate sensitivity of South Korean rice imports based on yield impacts on key trading partners.*

S. Korea	Scenario Data from Iglesias and Rosenzweig 2010								Standard		Rating	Import share [%]
	A1F	*A2a*	*A2b*	*A2c*	*B1a*	*B2a*	*B2b*	Average	Deviation	Range		
Producer	*% in rice yield change by 2020*											
China	-0,92	-1,18	-0,24	-1,31	-0,67	-1,68	-1,78	-1,11	0,55	-0,24; -1,78	!	48,1
Thailand	0,75	1,54	0,57	1,46	-0,4	0,78	0,22	0,70	0,68	1,54; -0,4	✓	17,6
USA	2,08	2,63	0,25	1,47	-0,95	-0,54	-0,14	0,69	1,38	2,63; -0,95	✓	27,7
Vietnam	-0,7	0,09	0,11	0,04	-0,78	-1,43	-1,12	-0,54	0,63	0,11; -1,43	!	3,8
World	-2,4	-1,96	-2,39	-1,97	-3,96	-3,77	-3,17	-2,80	0,83	-1,96; -3,96	✗	2,8
Percent of total grain production from rice: 98,85											✓	**Overall:** !
S. Korea	0,84	1,84	1,6	1,79	0,73	0,15	0,11	1,01	0,74	1,84; -0,11		

Based on the current trading partners, South Korea is rated with a medium (M) sensitivity. The majority of rice imports (54,7%) originates from countries which are rated M (China and Vietnam), while other sources are either H (World) or Low directly climate change impacted countries (Thailand and USA).

Table 4.7 – *Climate sensitivity of UAE's rice imports based on yield impacts on key trading partners.*

UAE	Scenario Data from Iglesias and Rosenzweig 2010								Standard		Rating	Import share [%]
	A1F	*A2a*	*A2b*	*A2c*	*B1a*	*B2a*	*B2b*	Average	Deviation	Range		
Producer	*% in rice yield change by 2020*											
India	-6,1	-4,23	-3,78	-4,8	-3,68	-6,62	-4,93	-4,88	1,13	-3,68; -6,62	✗	65,7
Thailand	0,75	1,54	0,57	1,46	-0,4	0,78	0,22	0,70	0,68	1,54; -0,4	✓	5,4
Pakistan	-5,78	-4,39	-4,68	-5,85	-4,09	-5,62	-5,33	-5,11	0,71	-4,09; -5,78	✗	27,2
World	-2,4	-1,96	-2,39	-1,97	-3,96	-3,77	-3,17	-2,80	0,83	-1,96; -3,96	✗	1,7
Percent of total grain production from rice: 0											**Overall:** ✗	

The UAE's imports are highly climate change sensitive. India and Pakistan account for 92,9% of total imports over the recent 5 years (2007 – 2011) and both are expected to experience high rice yield reductions.

Table 4.8 – *Climate sensitivity of UK's rice imports based on yield impacts on key trading partners.*

UK	Scenario Data from Iglesias and Rosenzweig 2010								Standard		Rating	Import share [%]
	A1F	*A2a*	*A2b*	*A2c*	*B1a*	*B2a*	*B2b*	Average	Deviation	Range		
Producer	*% in rice yield change by 2020*											
India	-6,1	-4,23	-3,78	-4,8	-3,68	-6,62	-4,93	-4,88	1,13	-3,68; -6,62	✗	22,7
Thailand	0,75	1,54	0,57	1,46	-0,4	0,78	0,22	0,70	0,68	1,54; -0,4	✓	9,5
Pakistan	-5,78	-4,39	-4,68	-5,85	-4,09	-5,62	-5,33	-5,11	0,71	-4,09; -5,78	✗	10,8
USA	2,08	2,63	0,25	1,47	-0,95	-0,54	-0,14	0,69	1,38	2,63; -0,95	✓	8,7
World*	-2,4	-1,96	-2,39	-1,97	-3,96	-3,77	-3,17	-2,80	0,83	-1,96; -3,96	✗	48,3
Percent of total grain production from rice: 0											**Overall:** ✗	

**EU missing because of unknown production percentage; percentage is included in World*

The UK imports are highly climate change sensitive. This rating involves a higher uncertainty since nearly half of the UK's imports are assumed to originate from the rest of the World (rated as high yield reductions). The EU trading percentages are included in the World since EU countries are mainly acting as trade intermediaries and re-export instead of produce (please

refer to the Appendices, Figure 7.4 for more detailed information). This re-exported rice is likely to originate from the same key producing countries (i.e. India, Pakistan, Thailand, etc.).
Under the assumption of EU countries are acting as trade intermediaries, over 80% of the UK's rice originates from areas highly sensitive to climate change, hence the overall rating of High sensitivity. Changes in world yields will have significant indirect climate change impacts on the intermediaries and the UK through the trade pathways.

4.2 STEP 3 - Magnitude of climate change impacts on rice imports

The magnitude of indirect climate impacts on imported rice will be mediated by the importing countries ability to pay (GNI per capita) for rice at higher prices, or for substitutes, which may be more expensive. South Korea (22,670$), the UAE (35,770$) and the UK (38,670$) have a high GNI per capita, while Senegal ($1,030 is ranked as a low-income country by the World Bank.

Domestic rice consumption indicates the reliance of peoples' diets on rice. The change in domestic rice consumption over the recent years shows different dependency on rice as a staple food across the consuming countries (Figure 4.2). Figure 4.2 shows trends in domestic rice consumption since 1961 in all countries; a high and/or increasing dependency on rice indicates a higher magnitude of risk from climate related changes in the rice price; a low and/or reducing dependency indicates lower magnitude.

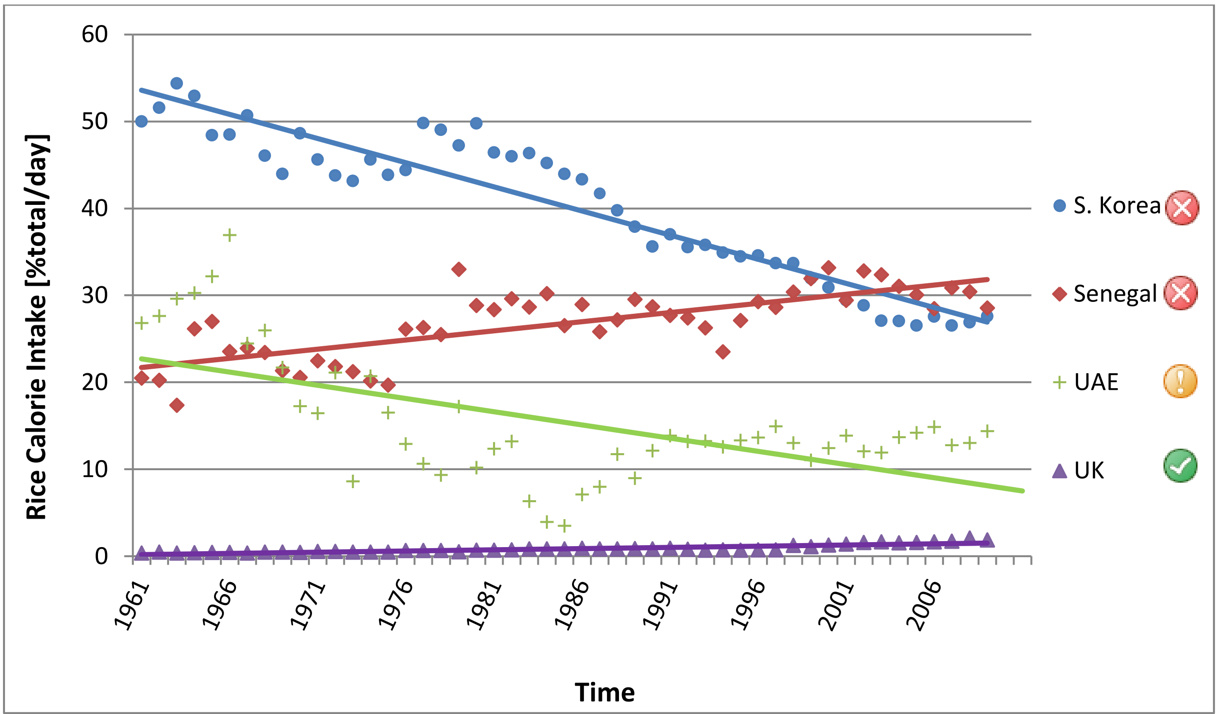


Figure 4.2 – *Consumption trends from 1961 – 2009 in each consuming country. Data collected from IRRI, 2014.*

Present consumption and consumption trends over the last decades reveal different dependencies on rice as a staple food. Senegal is highly dependent on rice (~29,7% rice calorie intake over last 5 year average, ↑ consumption trend) and the trend is steadily increasing over the available time.
South Korea is also highly dependent on rice (~27% rice calorie intake over last 5 year average, ↓ consumption trend) but the trend is decreasing over time.

The UAE can be categorized as being medium dependent (~13,8% rice calorie intake over last 5 year average, ↔ consumption trend) on rice as a staple food and the overall trend of consumption is declining. However, since 1991, the consumption trend is stable.
The UK is not depending on rice as a calorie source as it only provides ~1,8% over the last 5 years, but the overall consumption trend is steadily increasing (↑) over time, potentially as the result of demographic change and immigration patterns, as well as diversification of diets and preferences away from traditional staples. Nevertheless, the low level of consumption indicates a low magnitude from trade-related risks to rice.

The self-sufficiency ratio (SSR) indicates to which extent domestic rice production is sufficient to cover rice consumption and how much rice needs to be imported by the country. The SSR calculated based on rice trade data from the USDA database showed the following results: Senegalese rice production covers nearly one-third of domestic rice consumption (29%;), South Korean production accounts for over 90% (92%;), while the UAE and the UK both do not produce any rice (0%) and are consequently highly import dependent to satisfy domestic demand.

4.3 Climate risk profile

The rating for both the Likelihood and the Magnitude is obtained by combining the score of each of their three individual risk indicators. The resulting score for the Likelihood and Magnitude will then be rated as ✓ if it is 0 or 1, as ! if it is 2, 3 or 4 and as ✗ if it is 5 or 6 (section 3.4).

Table 4.9 – *Likelihood of indirect climate change impacts on rice imports.*

A) Likelihood		Senegal	S. Korea	UAE	UK
Climate sensitivity of imports *i*	**World level** *(Sensitivity)*	✗	✗	✗	✗
Climate sensitivity of imports *ii*	**Current trade profile** *(Sensitivity)*	✗	!	✗	✗
iii	**Concentration** *(HHI)*	! *(0,208)*	✗ *(0,341)*	✗ *(0,509)*	✓ *(0,119)*
	Rating	✗	✗	✗	!

Table 4.10 - *Magnitude of indirect climate change impacts on rice imports.*

B) Magnitude	Senegal	S. Korea	UAE	UK
Income (GNI*) *(The World Bank, 2014)*	✗ *(1,030$)*	✓ *(22,670$)*	✓ *(35,770$)*	✓ *(38,670$)*
Dependency on rice *(%calorie intake, trend)*	✗ *(~30%, ↔)*	✗ *(~28%, ↓)*	! *(~14%, ↔)*	✓ *(~2%, ↑)*
SSR *(USDA, 2014)*	! *(29%)*	✓ *(92%)*	✗ *(0%)*	✗ *(0%)*
Rating	✗	!	!	!

Senegal has a combined score of 5 (2+2+1) risk indicators in both the Likelihood and the Magnitude. South Korea's score in the Likelihood is 5 (2+1+2) and 2 (0+2+0) in the Magnitude. The UAE's Likelihood amounts 6 and the Magnitude is 3, while the UK's Likelihood is 4 and the Magnitude 2. These scores can be illustrated in the following way (Figure 4.3).

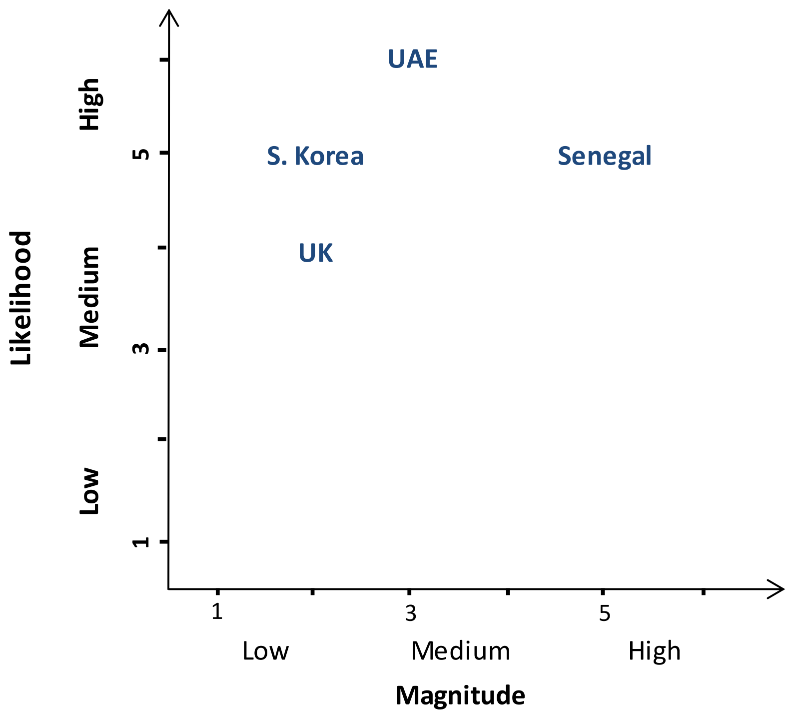


Figure 4.3 – *Illustration of the individual risk indicator scores for the likelihood and Magnitude for the importing countries.*

The Likelihood and Magnitude ratings are combined using a 3x3 risk matrix to establish the climate risk profile:

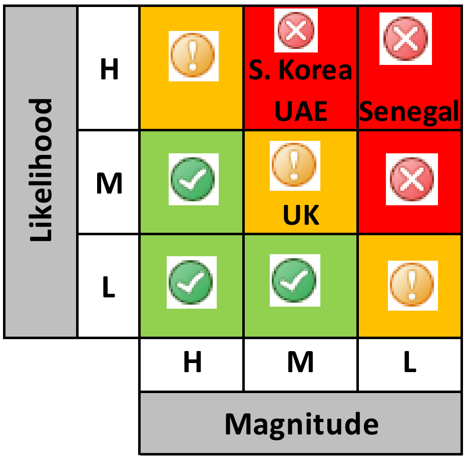


Table 4.11 - *Climate risk profile.*

A + B = C) Climate Change Risk Profile	Senegal	S. Korea	UAE	UK
A) Likelihood	⊗	⊗	⊗	!
B) Magnitude	⊗	!	!	!
C) Rating	⊗	⊗	⊗	!

The final climate risk profile ranks Senegal, South Korea and the UAE with a high risk of indirect climate change impacts on rice imports, while the UK is rated as medium.

4.4 Adaptation policy analysis

This section presents the results found during the review of a range of relevant adaptation documents and other relevant non-adaptation documents. It is tested to which extent and how possible indirect climate change impacts are reflected in the national policies.
The ODI (2010) framework distinguishes between the preventing of climate change impacts to occur, reducing the magnitude of impacts in case they have occurred and the protection of consumers from higher food prices. These separate strategy approaches are distinguished regarding the existing or planned adaptation measures.

4.4.1 Senegal

1. Awareness

Senegal's most recent National Adaptation Programmes of Action (NAPA) was published in 2006 under the UNFCCC framework and is available in French (Republique du Senegal 2006).
This strategy focuses exclusively on direct climate change impacts. It addresses direct climate impacts on rice yields and food production within the country. Stated climate change impacts on the agricultural sector are influenced by climate parameters such as floods, coastal erosion, salinization of soil and water (in irrigated areas and deltas), drying winds as well as weaker and irregular rainfall (Republique du Senegal 2006). These climate change impacts may reduce rice production through irrigation problems, limitations in the availability of agricultural land and desertification (Republique du Senegal 2006).
There is a need to better understand climate change to develop adaptation measures for poor people in rural areas (Republique du Senegal 2006). The predominantly rural population (more than 60% are farmers) is highly dependent on natural resources. Resource availability is altered by climate change, causing scarcity and degradation, and exacerbating impoverishment and vulnerability (Republique du Senegal 2006).

Beside the NAPA from 2006, there is an assistance strategy prepared by the African Development Bank for Senegal asserted to the ambition of Senegal becoming an emerging economy. This country strategy covers indirect climate change risks, by stating at multiple occasions (e.g. pp. iv, 2, 3, 11 and 20) that Senegal suffers from a substantial vulnerability to external factors such as world market foodstuff price fluctuations and foreign capital inflows (development aid, foreign direct investment, migrant remittances, etc.). In the past, particularly the agricultural sector has suffered from international crisis like the food, energy (petroleum products) and financial crisis (Republic of Senegal 2010).

2. Measures

Preventing

The NAPA from 2006 describes two activities to tackle direct climate impacts. One activity is to fight salinization of rice land by building protective infrastructure (like dams and anti-salt dikes) and through introducing halophile rice varieties to farmers (Republique du Senegal 2006). The African Development Bank will finance the construction of rural water harnessing infrastructures and develop small-scale irrigation schemes to enable the reclamation of degraded lands and facilitate irrigated rice cultivation on marshland (Republic of Senegal 2010).
The second NAPA activity is to enhance the climate change resilience of agricultural products by promoting access to improved rice seeds, offering training sessions and raising awareness on technical issues (Republique du Senegal 2006). Additionally, the African Rice Center is developing and distributing higher yielding NERICA rice seedlings to the Southern and northern

rain-fed and irrigated regions of Senegal (Colen et al. 2013). A diversification of domestic agricultural production was a response to the recent crisis as traditional staple production like cassava increased in 2007/8 but was reduced to pre-crisis levels in 2009 (John 2014, unpublished).

The Senegalese government applied a productivist strategy to deal with externally caused price fluctuations. In 2008, as a response to the food crisis, the Senegalese President Abdoulaye Wade launched the Great Agricultural Offensive for Food and Abundance (GOANA) (Demont & Rizzotto 2012). GOANA and the subsequent National Rice Self-Sufficiency Programme (PNAR) aim to cover rice consumption through domestic production by 2015 through large investments ($792 million) in subsidized fertilisers, seeds and pesticides for farmers in the Senegal River Valley (SRV) (Aker et al. 2011; Demont & Rizzotto 2012).

Regional level adaptation was initiated by the African Rice Center through the Rice Emergency Initiative (ERI) in 2008 and aimed to boost domestic rice production (Africa Rice Center 2011). The program lasted for two years; rice farmers were supported with subsidized inputs like fertilizers and seeds and also trained with management practices (Africa Rice Center 2011). After the crisis in 2009, regional West African players like the African Rice Center and the Economic Community of West African States (ECOWAS) considered the viability of creating a West African grain reserve. The option of forming a rice import cartel where the region imports rice as a single entity, was also discussed to enhance bargaining power (Africa Rice Center 2011). West Africa embodies around one-third of global rice imports (Africa Rice Center 2011).

Initiatives have emerged in the private sector triggered by the volatility of international rice prices. Senegalese rice importers launched a joint venture with producers and processors under the name SPCRS (Société de Promotion et de Commercialisation du Riz Sénégalais) (Diagne et al. 2013). SPCRS consists of contracts between companies purchasing local paddy rice in the SRV from milling factories and farmers and market it to urban Senegalese consumers while governing quality along the value chain (Mohapatra 2011).
The private company Vital invested massively in high-quality milling infrastructure to supply quality SRV rice to urban markets in Senegal (Diagne et al. 2013).

Besides national adaptation measures, there are also international efforts to support Senegalese rice self-sufficiency.
The Japan International Co-operation Agency (JICA) has launched initiatives since 2004 to develop the rice industry and improve the production capacity of the full range of SRV rice stakeholders in Senegal (JICA 2006). The Belgian investor Durabilis contracts with SRV farmers and millers to market quality SRV rice in Dakar (Diagne et al. 2013).
The R4 Rural Resilience Initiative is a strategic collaboration between the World Food Programme and Oxfam America (NGO) and is supported by the United States Agency for International Development and Swiss Re (global reinsurer) (Agrifeeds 2013). The project aims to strengthen food and income security of poor Senegalese farmers "*through a four-part approach – improving natural resource management (community risk reduction), accessing microcredit ("prudent" risk-taking), gaining insurance coverage (risk transfer), and increasing savings (risk reserves)* (Agrifeeds 2013)."

In 2006, Oxfam (NGO) launched the PINORD (Plateforme d'appui aux initiatives du Nord) platform with the mission to "*to contribute to the food security of the Senegalese people by improving their living conditions in a sustainable way through the promotion of local rice* (Demont

& Rizzotto 2012)". PINORD's strategy to reinforce the organisational capacity of rural micro-enterprises involved in the SRV rice sector is fourfold: "*improving quality and packaging, improving transport, increasing market share and points of sale in urban markets (especially in Dakar), and multi-medium publicity of a quality rice brand* (Demont & Rizzotto 2012)".
These international projects try to achieve an enhanced and upgrade the rice value chain to achieve self-sufficiency within the country. Critical points seem to be to increase resilience towards direct climate change impacts of small-scale farmers and the marketing in urban markets.

Reducing / Protecting
During the price spike in 1972/3, Senegal subsidized imported rice which resulted in a 60% lower domestic rice price compared to the world prices in the respective time (Aker et al. 2011).

As a response to the price increase during the crisis in 2007/8 and to stabilize domestic rice prices, Senegal applied trade policy measures such as releasing rice stocks at subsidized rates, suspending value added taxes on rice and restricting private trade (Republic of Senegal 2010; Demeke et al. 2011).
These attempts to reduce or protect Senegalese consumers were insufficient as domestic rice prices continued to increase, albeit at a slower rate than international prices (John 2014, unpublished).
The government failed to isolate domestic prices from international price fluctuations like in the 1972/3 (Gajigo & Denning 2010).

4.4.2 South Korea

1. Awareness

South Korea has no NAPA in a European language in place. There is a website hosted by the KACCC (Korea Adaptation Center for Climate Change) but the information available is elementary and unspecific (KACCC 2014).

A web search found presentations from the Department of Environmental Cooperation (Department of Environmental Cooperation n.d.), and a Country Paper concerning the Climate Change and Adaptation Strategies in the Republic of Korea's Agricultural Sector (Kim n.d.). These two presentations provide general information on climate change impacts on agriculture (rice is occasionally mentioned).

A study from the Korea Rural Economic Institute conducted by Kim et al. (2010) recognises the indirect risks of climate change on rice imports. In this report, it is stated that "*climate change has negative impacts on the agricultural production of developing countries, due to the fact they weak adaptability to climate change, and this in turn will affect the international crop market* (Kim et al. 2010)". Furthermore, "*a decrease in national and or regional crop production due to intense global warming will act as a factor that will raise the international grain price* (Kim et al. 2010)". Global food production will be altered by changing climatic parameters and mid/long-term models would be a useful tool to estimate domestic food demand and supply (Kim et al. 2010).

It needs to be questioned to what extent this report represents the decision maker's opinion as the report was commissioned by the Rural Economic Institute and the results are not mentioned on the KACCC homepage or in an official climate change strategy.

There is only limited formal national adaptation planning and indirect climate change impacts have so far not featured in the national planning of adaptation within the government. The issue of indirect impacts has not featured in South Korea's national adaptation thinking to date, according to personal communications with a key official within the Ministry of Environment (Republic of Korea 2014).

2. Measures

Preventing

In the absence of a NAPA, source found suggest that the overall objective is to achieve a self-sufficient rice production (Kim et al. 2010). South Korea already has a rice SSR of ~90% which is further supported by an action plan from the Ministry for Food, Agriculture, Forestry and Fisheries (MIFAFF) (Kim n.d.). Efforts of the MIFAFF are mainly dedicated to maintain 2011 production level and productivity in agriculture industry in the future despite negative climate change impacts (Kim n.d.). These plans shall be achieved through enhanced research and development investments (increase investment to 130 billion KRW per year, compared to 28 billion KRW in 2011), introducing new climate tolerant breeds, and strengthening weather information ability and providing climate change manuals (Kim n.d.).

Further adaptation measures stated by Kim et al. (2010) include the development of high-temperature resistant varieties, inhibition or induction measures to produce the proper number of grains, cultivation density controls, and improved fertilizer application. Improved crop cultivation can significantly mitigate climate change impacts by adjusting the cultivation period (sowing season) to changing temperatures, and through amounts of nitrogenous fertilizers and irrigation applied (Kim et al. 2010).

Despite the high SSR in rice production, South Korea is heavily food import dependent (60% of their food from abroad) (GRAIN 2008). In 2008, the Korean government announced the formulation of a national plan to facilitate land acquisitions for food production (GRAIN 2008)

Reducing / Protecting

South Korea is engaging in the storage of emergency food reserves to protect consumers against temporary production shocks due to calamities (Briones et al. 2012). Storage is an obvious preparation for crop losses and public stocks can not only substitute private stocks but can also help to dispel fear and panic in periods of crisis (Briones et al. 2012).

The Association of Southeast Asian Nations Plus Three Emergency Rice Reserve (APTERR) consists of 787,000 tons of rice stocks that have been donated or earmarked by the ASEAN Plus Three countries (Southeast Asian Nations plus China, Japan and South Korea) (Briones et al. 2012). The earmarked stocks are typically part of the country's national food security reserve, South Korea pledged at present a major share (250,000 tons) of the APTERR (Briones et al. 2012). The APTERR council deploys the stocks while the earmarking country maintains the control but also has the responsibility for the storage of their stocks (Briones et al. 2012). The APTERR council is a prearranged scheme involving a forward contract between a supplying country and a recipient. The contract between participants prescribes that the supplying country agrees to deliver a specific quantity of rice of a specific grade out of its earmark to the recipient country within 30 days (including shipping time) in an emergency situation (Briones et al. 2012).

In the working paper, Briones et al. (2012) evaluated the effectiveness of APTERR and concluded that an increase of the size of earmarked reserves (from currently 787,000 tons, 250,000 tons from South Korea) of about 1.2 million tons would largely enhance the storage capacity to offset calamity damages. Additional policy options like social safety nets (e.g. targeted food transfers), insurance, and hedging tools such as future contracts may be beneficial to address the price risk attributed to calamity (Briones et al. 2012).

Kim et al. (2010) also recommends the incorporation of financial management schemes (like crop insurance) for individual farm households to avoid the risk of income reduction, engage participation in the income stabilization program, enable the diversification of revenues for farm households through crop diversification and participation in the future's market of agricultural crops.

4.4.3 United Arab Emirates

1. Awareness

The two most recent NAPAs from the UAE are from 2010 and 2012 (UAE 2010; UAE 2012). Further, there is a report from the Economist Intelligence Unit which is sponsored by the Qatar Financial Centre Authority (QFCA 2010).
The food crisis in 2008 has had strong policy reverberations for the UAE, ensuring the availability of food imports at an affordable price is a key strategic priority (QFCA 2010).
The lack of arable land, intense heat, and limited water supplies are the main obstacles for the UAE and resulting in a substantial reliance on food imports (90% in 2007) (UAE 2012). As food supply depends on imports, changing precipitation patterns and diminishing crop yields in many supplier countries may have significant climate change related impacts on food price and supplies (UAE 2012). The UAE explicitly states in the most recent adaptation strategy under the UNFCCC, that climate change is leading to reduced crop productivity in food-exporting countries, which is resulting in a steady increases in food prices, and increased food insecurity around the world (UAE 2012). A country that is heavily dependent on food imports is particularly vulnerable (UAE 2012).

Furthermore, "*an integrated adaptation assessment that accounts for climate change impacts on agriculture, international food trade, and economic livelihoods can help to identify potential options to increase long-term food security under climate change* (UAE 2012)".

2. Measures

Preventing

The shortage of desalinated water and lack of arable land prevents domestic production as an option to meet domestic food needs. A current strategy to pursue food supply security is to buy or long-term lease farming land abroad, mainly in Africa (QFCA 2010). The objective of these deals to acquire farmland is to have the guaranteed access to farmland and to be able to export the produced food back to the UAE (GRAIN 2008).
The acquisition of land abroad is described as a measure in the official adaptation strategy. It is stated that the "*policy is well underway with a total of 2.9 million hectares already under agreement, and another 300,000 hectares in process (see Table 1-2), with North Africa and Asia accounting for 97% of the total land area between them (82% and 15%, respectively)* (UAE 2012)". The table (1-2) referred to in the citation can be found below (Table 4.12).

Table 4.12 – *UAE agricultural land acquisitions abroad* (GRAIN 2008).

Table 1-2: UAE food outsourcing to other countries (GRAIN, 2012)

Region	Country	Size (hectares)	Production	Status
North Africa	Algeria	31.000	Milk. olive oil. potatoes	Complete
	Egypt	68,500	Dill, maize, potatoes, wheat, fodder	Complete
	Morocco	700,000	Citrus and olives	Complete
	Sudan	1,799,100	Barley, cotton, hay, maize, sugar cane, sunflowers, wheat, peanuts, sorghum, alfalfa	1,643,100 ha done; 156,000 ha in process
Sub-Saharan Africa	Ghana	10,000	Maize	Complete
	Namibia	200	Date Palm	Complete
	Tanzania	50,000	Rice	In process
Asia	Pakistan	369,100	Rice, crops, dairy, alfalfa, livestock	334,100 ha done; 35,000 in process
	Indonesia	100,000	Fruit, palm oil, rice, sugar cane	In process
Europe	Romania	50,000	Cereals	In process
	Spain	5,050	alfalfa	Complete

This approach to pursue food security is controversial, for the investing countries as well as for the hosting countries. Key concerns raised by the Qatar Financial Centre Authority (QFCA) are "*ensuring a transparent land valuation and transfer process, ensuring a broader range of stakeholders than just governments, providing clear and visible benefits for local communities, and respecting the country's trade rules, export regulations and obligations to international trade regulations* (QFCA 2010)".

Another struggle described by the QFCA are that investments abroad will be tailored to the dietary requirements of the Gulf Cooperation Council (GCC) countries (i.e. UAE) but that private firms and wealth funds may focus on investments to maximize profits instead. In times of serious food shortages, some contracts may be terminated by the host country's when GCC investors try to export all of the farmed products (QFCA 2010).
The strategy to invest abroad neglects political instability and food insecurity in most host countries which are likely to make agreements untenable in the longer term (Sowers & Weinthal 2010).

Despite this acknowledgement of many of the risks associated with foreign land investments, the potential impacts of climate change on agricultural production in those countries where the UAE has invested has not been assessed, according to currently available information.

Reducing / Protecting
Before and during the global food crisis in 2007/8, the UAE used food subsidies, price controls, or wage bonuses to reduce the effects of food price spikes (UAE 2012).

4.4.4 United Kingdom

1. Awareness

The most recent NAPAs from the UK are from 2010, 2012 and 2013 (Defra 2010; Defra 2012a; Defra 2012b; Defra 2013; PwC 2013). The Met Office Hadley Centre and the Foresight were employed by the Government Office for Science and supported by the Department for Environment, Food and Rural Affairs (Defra) to compliment the NAPAs (Lewis et al. 2010; Met Office 2011; Foresight 2011a; Foresight 2011b).
The UK demonstrates a high awareness of international climate change implications. In the Foresight (2011a) report it is concluded "*that the impacts of climate change overseas could be as important as the direct impacts within UK shores over the next decades*".

The UK is heavily dependent on imports and exports, and hence particularly sensitive to climate change impacts abroad which are interrelated with global food and water security, macroeconomic and geopolitical risks (Defra 2012b). Climate change challenges the security of supply and price of essential commodities imported by the UK (Lewis et al. 2010; Defra 2012a).

In the short-term (to 2020s), "*climate change is highly likely to exacerbate volatility of import prices and cause disruptions of supply* (Defra 2013)". Magnifying impacts of climate change in the longer term (2050s to 2080s) "*could lead to more pervasive changes systemic changes to trade in food and other physical commodities* (Defra 2013)". Protectionist measures may be the response of nations facing short supply and rising prices of key commodities in response to short-term crises or as more enduring measures (Foresight 2011a). Climate change "*may disrupt the UK economy through impacts on traded goods, supply chains, migration and international relations* (Defra 2012b)". Increasing volatility of commodity prices in the future is expected as a response to climate change (Defra 2012a).

The most recent report by the Defra (2013) states "*that the UK is unlikely to experience food scarcity in the short term but supply disruption in a major food producing country may lead to sharp rises in prices or temporary shortages of particular foodstuffs*".
Global production and as a consequence UK imports of certain foodstuffs are concentrated in a few countries (e.g. rice), thus supply shocks have a disproportionately larger feedback on the price (PwC 2013). An assessment commissioned by the Met Office highlights the particular sensitivity of rice production compared to more temperate crops like wheat or barley (Foresight 2011a). Southeast Asian regions which are currently very suitable for rice production because of warm and wet climate conditions may not be so in the future, while other areas could become more favourable (Foresight 2011a). Climate change related variability may cause fluctuations in agricultural commodity prices, leading to sharp fluctuations in food production resulting in food price volatility (Foresight 2011a). This price volatility can be exacerbated by countries implementing protectionist measures and focussing on more immediate national concerns (Foresight 2011a). In the long run, it may be required to switch to more resilient trading partners for certain commodities (Defra 2013).

"*As a mature, low-risk and stable economy, the UK is comparatively less vulnerable to global food price shocks; however there are still cost implications to the UK and particularly the poor in the UK* (PwC 2013)". Periods of food price volatility of global agricultural commodities alters the security of supply and price of imported products while also increasing the need for UK aid and assistance in LICs (Foresight 2011a). LICs and poor communities in all countries are disproportionately affected by price spikes resulting in hunger, causing conflicts and imperil stability in weakly governed countries (Foresight 2011a; Defra 2013).

2. *Measures*

Preventing

The interconnectedness of the global food system has advantages and disadvantages. Supply shocks can be compensated by producers in other regions while economic disruption is quickly transmitted between regions (Foresight 2011b). A global food system is superior because global efficiency is improved by allowing bread-basket regions to export food to less favoured regions (Foresight 2011b).

The Foresight (2011b) report rejects food self-sufficiency as a viable option to contribute to global food security. Global "*food security is best served by fair and fully functioning markets and*

not by policies to promote self-sufficiency (Foresight 2011b)". Export bans and trade restrictions are the major obstacle that need to be prevented in times of crisis (Foresight 2011b). International institutions like the G20 will have to play an important role in the short-term and mechanisms need to be introduced to strengthen the confidence of governments in the global trade system and to resist imposing export restrictions (Foresight 2011b). Virtual and actual grain reserves to dampen price fluctuations on global markets have been considered but have not found sufficient priority (Foresight 2011b).
The strategy from other countries (like the UAE) to invest in land to 'sequester' supply overseas is regarded critically by the UK as it "*may signal a lack of confidence in international markets and multilateral trade, and this in turn risks legitimising protectionist practices elsewhere* (Defra 2010)".

The following strategies are described by the UK to prevent or mitigate indirect climate change impacts on production.
Defra along with other UK funders engage through the Global Food Security Programme to coordinate research (approx. £400 million).
Investment and associated productivity growth in developing countries will enhance overall global food supply (Defra 2010). The UK engages in several initiatives such as the EU Joint programming Initiative on Food, Agriculture and Climate change (JPI-FACCE), the EuraNet Susfood programme and the Global Research Alliance (Defra 2013).
The government's new Agri-Tech Strategy aims to increase climate resilience of the agricultural sector through modern genetics, breeding techniques and effective knowledge transfer to intensify agriculture and pursue global food security (Defra 2013).
Climate change impacts on agricultural yields and commodity prices can be reduced in businesses "*by diversifying supply chains and providing additional storage capacity to carry higher inventories of input products and raw materials* (Defra 2012a)".

Defra (2010) states that "*the principal food security challenge for the UK is a global one*" and further that "*global food security is important for the UK because, ultimately, global stability depends on there being enough food in the world to feed everyone and for it to be distributed in a way that is fair to all*".
Governments and regional systems of support (such as the EU) are responsible for improving education and awareness of risk management options and have to particularly support most vulnerable countries (Foresight 2011b). Targeted emergency food reserves and financing facility for the World Food Programme help LICs when facing sudden food price spikes (Foresight 2011b). Safety nets and specific assistance for the poorest producers to obtain insurance against risk and volatility are needed to prevent the worst effects (Foresight 2011b). Most severe effects often occur among the rural poor who rely on subsistent farming, hence international bodies such as the World Food Programme or major NGO's with public support are important to provide the safety net of emergency food resources (Foresight 2011b).

It can be concluded that "*the main threat is fluctuating and volatile prices as a result of disruptions in the production, transportation and distribution of imported foodstuffs, exacerbated by political and policy interventions such as protectionist measures. Stakeholder consultation suggests that UK businesses are responsive to and can manage fluctuations in supply chains to a certain threshold* (PwC 2013)".

5 Discussion

This study began with an introduction of methodologies used to inform adaptation decision making. The paper can be framed as a bottom-up assessment which started by exploring the vulnerability of a selected rice trading network consisting of four rice import depending countries and their six key trading partners.
The vulnerability of the four case study countries was assessed by creating a country specific climate risk profile based on the likelihood (Step 1 & 2) and magnitude (Step 3) of climate change impacts on rice imports. A range of relevant adaptation documents and other relevant non-adaptation documents were reviewed to investigate how well they address indirect climate risks (Step 4).

This discussion section summarizes the important findings of the analytical steps 1 to 4 and compares the identified climate risks with current adaptation and non-adaptation documents. For clarity reasons, the discussion will be divided into four sections, one for each of the case studies. Each case study section will start by presenting the results concerning the likelihood (Step 1 & 2) of climate change impacts on rice imports. This likelihood is then tested against the policy measures identified through relevant documents in Step 4, categorized using the ODI (2010) framework.

5.1 Senegal

Senegal is rated as being at **high risk** and expected to both suffer under a high likelihood as well as high magnitude of climate change impacts on rice imports.

Senegal is highly dependent on a small number of producing countries (Thailand 37,3%, Vietnam 16,4%, India 16,2% and Pakistan 4,1% average share of imports over the last five years). Particularly the substantial share of Indian rice imports in 2012 (accounting for 64,8% alone) is problematic considering past trading experiences; India was the first country to ban low quality rice exports during the food crisis in 2007 and re-entered the market four years later in 2011 (FAO 2011b). The strong drivers for India to maintain domestic stability in rice via such export restrictions mean that the chances of such measures being implemented again in future is significant.

During the time when rice exports from India were restricted, Senegalese total rice imports declined from 1000 (1000 MT) in 2008 to 700 (1000 MT) in 2010 and afterwards recovering to the original 2008 level only by 2012 (Table 4.1). Senegal did not manage to substitute for the import losses with other producing countries because of decreased rice export availability on the global market, as well as the major rise in prices. This observation signifies the dependence on rice imports from India. A study from Dorosh & Rashid (2013) confirms that India is no longer perceived as a reliable supplier due to experiences during the crisis in 2007/8.

Senegalese key trading partners are projected to experience yield declines, India in particular (Table 4.5). The projected decline of global rice yields (see World, Table 4.5) and more frequent damages due to extreme events (Mall et al. 2006; Bruce & Haites 2008) further increase the likelihood of price volatility and market shocks. Additionally, Senegalese domestic rice production will experience adverse climate change impacts in the future (Table 4.5). This is particularly relevant because Senegal's main policy response to the 2007/8 crisis has been to intensify rice production with the aim of achieving self-sufficiency (Demont & Rizzotto 2012).

Senegal's concentration ratio of imports is rated as medium, according to the methodology employed in this study. This overall rating, however, may be too optimistic as it is computed from trade data and neglects the central role India plays as a trading partner. During the 2007/8 crisis, without rice imports from India, the amount of rice that Senegal was able to import decreased substantially, which is not reflected well in the data used to calculate concentration ratio. This weakness of the methodology will be discussed in more detail in the subsequent section 5.5.

The projected decline in global rice yields (see World, Table 4.5) will lead to increased prices which affect Senegal disproportionately as an 'uncompetitive' poor country that is less able to react to market shocks by stock piling rice at high prices, as demonstrated during the 2007/8 crisis. Accordingly, we might expect to see trade relationships shifting in the future whereby rice producers are able to command higher contract prices, thereby aligning with wealthier importing countries that can afford to pay a premium for rice imports. The UK as a wealthy country for example, expresses the ability to switch key trading partners and transform supply chains to reduce the dependence and absorb price spikes (Defra 2013; PwC 2013). India's export ban also supports this argument as only low quality rice was banned from export (FAO 2011b) while the money making cash crop (basmati rice) remained unrestricted (FAO 2011b)[4].

Senegal's adaptation response to reduce this high likelihood is mainly based on the GOANA and the subsequent National Rice Self-Sufficiency Programme (PNAR) as well as other national and international ambitions, which aim to achieve rice self-sufficiency. The targets formulated in GOANA and PNAR are very ambitious considering the average self-sufficiency ratio (SSR) from 2009 to 2013 was 29%; meaning that more than 70% of rice was imported. Self-sufficiency targets are meant to be achieved mainly through extensive investments ($792 million) in existing and new rice perimeter in the Senegal River Valley (SRV) (Aker et al. 2011; Demont & Rizzotto 2012). So far these investments have not been linked to Senegal's national climate adaptation plans.

Despite these planned investments, Senegal does not possess a competitive advantage in the production of rice; production of white rice is more expensive and of lower quality compared with Asian producers (Wilson n.d.; World Bank 2011). There are constraints concerning the supply of inputs (failure, delay distribution problem), facilities and obsolete irrigation equipment (Wilson n.d.), as well as "*market imperfections such as breakdown of fertilizer supply and weaknesses of the credit system* (Diagne et al. 2013)". The NAPA further states a number of already present direct climate change impacts on agricultural production leading to irrigation problems, limitations in the availability of agricultural land and desertification (Republique du Senegal 2006). Achieving a higher level of self-sufficiency will become more difficult in future due to projected increasing climate change impacts leading to reduced rice yields in Senegal (Table 4.5).
These problems and constraints manifest themselves at present and lead to insufficient supply of paddy rice in the Senegal River Valley (SRV), implying that further investment in productivity is needed to enhance operations that are running below their optimal level (Diagne et al. 2013).

[4] Senegal has developed a high demand for imported 'broken' rice that is considered 'low quality' according to global classifications.

Demont & Rizzotto (2012) question that even if the ambitious GOANA target is met, "how will domestic rice reach urban markets, where consumers generally prefer imported rice for its superior grain quality". SRV rice is of inferior quality and notorious for its heterogeneous grain-size composition and impurity (Seck et al. 2010), consisting of a mix of varieties and grain sizes along with impurities (like stones, dirt and husks) (Demont et al. 2013). Senegalese consumers prefer 100% broken rice which is considered to be of inferior quality on international markets and therefore cheaper than whole-grain rice (Brüntrup et al. 2006).
In order to enhance domestic rice production, Demont & Rizzotto (2012) recommend a "*three stage policy sequence: (i) investment in post-harvest product-quality infrastructure, (ii) scaling-up of quality produce by investment in productivity, aggregation and storage infrastructure, and (iii) adoption of sector-wide marketing strategies that enhance the chain competitiveness of domestic relative to imported rice.*"

In their study, Diagne et al. (2013) investigated the self-sufficiency policy and concluded that the exacerbation of biological and institutional constraints in Senegal prevent intensification and thereby jeopardizing the national objective of self-sufficiency. Further the study states that "*Senegal's high dependence on rice imports exposes the country to international market shocks with concomitant serious risks for food security* (Diagne et al. 2013)". This conclusion is in strong agreement with the findings of this study.

Senegal has a low consumer GNI and a high dependence on rice imports as a major staple food along with a medium self-sufficiency in rice production: overall this leads to a **high magnitude** rating. The limitations deriving from a low GNI per capita can be seen in Table 4.1 which shows that import losses from India where not substituted for by other producing countries like the 'World'.
Vincent (2007) compared the adaptive capacity of African countries and found Senegal ranked relatively high amongst other low income countries, indicating that Senegal is certainly not the worst off among least developed countries. These results by Vincent (2007) might be opposing with the GNI per capita results, but could also be in agreement since the study only considers African countries, while Senegal could still be rated low in a global context. Experiences during the 2007/8 crisis confirm a low adaptive capacity, as the effects of the crisis (most notably the Indian export ban) persisted until the end of 2011: i.e. for four years. Between 2007 and 2008, the increase in domestic rice prices were highest in Senegal compared to all of West Africa (Prakash 2011). The world price for Thai 25 (rice type most imported by Senegal) almost tripled in half a year during the crisis (FAO 2009b). Consequently, the amount of rice imported significantly declined.

Growing consumption (Figure 4.2) and low substitutability underlines the importance of rice as the major cereal consumed in Senegal (Wilson n.d.), which adds to the magnitude of current and future risks and creates greater urgency for adaptation measures. Growing urbanization leads to changes in diets – chiefly from other cereals or root crops to rice - and is a major driver for rice demand in West Asia, South America and Sub Saharan Africa (Hossain 2007). Other studies state that "*with such high dependence on imports, Senegal is exposed to international market shocks, sometimes with grave consequences for its food security and political stability, as attested by the violent riots during the 2008 food crisis* ((Diagne et al. 2013), see also (Moseley et al. 2010; Seck et al. 2010; Diagne et al. 2013))".

Following the ODI (2010) policy analysis framework (Figure 3.2), measures to reduce the magnitude of indirect climate change impacts on rice imports are to "*prevent or dampen impacts* *on trade*” and to “*protect consumers from higher food prices*”. In the 1972/3 crises, the Senegalese government successfully subsidized imported rice which resulted in a 60% lower domestic rice price compared to the world prices in the respective time (Aker et al. 2011).

During the 2007/8 food crisis, the government aimed to stabilize domestic rice prices by applying trade policy measures such as releasing rice stocks at subsidized rates, suspending value added taxes on rice and restricting private trade (Republic of Senegal 2010; Demeke et al. 2011). This time, the government failed to isolate the domestic prices from international price fluctuation as domestic prices continued to increase, albeit at a slower rate than international prices (Gajigo & Denning 2010).

Factors that increased Senegal’s vulnerability to previous shocks include the level of its import dependence, its not existing strategical response to the rice crisis and its low ability to afford mass rice purchases when prices increased to such high levels. Senegal as a low-income country (LIC) has small stocks, low tariffs on imported food, low taxes on staples, and little administrative capacity to intervene in food markets which limits the scope for influencing rice trade (ODI 2010). The low Senegalese GNI per capita therefore means that trade-related climate risks may have a high magnitude of impact for Senegalese consumers. Most measures to counter price spikes are costly and administratively demanding making them unsuitable for many LICs (ODI 2010).
On the other hand, LICs have the highest share of vulnerable population (ODI 2010). Protecting these vulnerable consumers from higher food prices is complicated, since the measures presented are all costly or infeasible for LICs. Current options to increase the bargaining power of West African nations by forming a rice cartel may help to enhance the trade-links, if they ever materialise (Africa Rice Center 2011).

Senegal does not consider the indirect impacts of climate change on rice imports in its NAPA (Republique du Senegal 2006). The vulnerability of food security to external factors is addressed in the African Development Bank development assistance strategy for Senegal (Republic of Senegal 2010) but it neglects the climate change context.

Senegal fails to acknowledge the insufficiency of existing adaptation strategies and may be missing an opportunity to lay out in its national adaptation plans the need for investments that will reduce its vulnerability to external climate shocks. This is important because nationally determined adaptation plans – such as the NAPAs and forthcoming National Adaptation Plans under the UNFCCC – form on of the main bases for appeals to international finance mechanisms for adaptation finance investments in developing countries such as Senegal.

Based on the information described in this section, it seems highly unlikely that Senegal will reach its self-sufficiency target by 2015 or even 2018. Only with massive investments and new measures, can Senegal achieve this target in the longer term, given its high risk starting position, coupled with the negative direct impacts of climate change on domestic rice production. The policy options applied in the past crises are not sufficient to protect the domestic market from international price fluctuations as a consequence of increasing climate change impacts on rice imports.

The results of the climate risk profile of Senegal’s imports in this study suggest a bigger emphasis on strategic rice storage, regional cooperation and international efforts to reduce the

volatility of rice markets (e.g. via reducing the scope for export restrictions in key producer countries) are needed in order for Senegal to adapt.
Further, Senegal will not be able – at least in the short term – to cope with indirect climate change impacts independently. International support will be required to invest in adaptation measures that build adaptive capacity, particularly to protect the most vulnerable consumers. To address this issue early and most likely most efficiently, international institutions should intensify the engagement in preventing or mitigating direct climate change impacts on production in key rice exporting countries, as well as supporting import dependent countries like Senegal directly. Increasing climate change resilience of production systems, promoting national agriculture for higher rice production and establishing or expanding international or regional rice reserves (Gilbert 2012) seem the most sustainable and suitable measures.

5.2 South Korea

There are some similarities between South Korea and Senegal in the way they address the climate change risk, though the two importing countries differ significantly in many ways. South Korea's likelihood of indirect climate change impacts on rice imports is rated as high, while the magnitude is rated as medium.

South Korea seems to be better-adapted to climate change impacts on rice trade than Senegal, mainly because of the high self-sufficiency in production (around 90% over the last 5 years). In the possible case that it achieves self-sufficiency within the coming years, indirect climate change impacts through rice imports would cease to be a threat.
Favourable climatic conditions as predicted in Table 4.2 would be beneficial for the national agricultural productivity even though the MIFAFF assumes negative climate change impacts. However, the model results applied in this analysis are positively biased, suggesting there may be some gains for domestic production.
Additionally, the current trade profile is rated as medium which is the best rating of partner countries in all four case studies. This rating is mainly determined by low climate rice yield impact projections on Thailand and the USA and medium for China, which account for a large share of South Korean rice imports.

South Korea's stated adaptation strategies intent to reduce the likelihood through preventing or mitigating direct climate change impacts on domestic production and thereby enhance self-sufficient production. South Korea aims to increase climate change resilience and promote agricultural production through a number of measures such as enhancing research and development investments, introducing high-temperature resistant varieties and improved fertilizer application.

The intense rice farming takes place at the expense of the production of other food, 90% of food is imported from abroad if rice is excluded (GRAIN 2008). To overcome limitations in the availability of farmland, Korea implemented a national plan to facilitate land acquisitions by the private sector for food production abroad (GRAIN 2008). According to GRAIN (2012), 1,2 million hectares are already under agreement or in the negotiation process.

Rice is the major food staple in South Korea and constitutes nearly 30% of daily calorie intake, revealing the high dependency on rice. Otherwise, the magnitude of indirect climate change impacts on rice imports is reduced through a high consumer GNI and a very high rice SSR. The rice crisis in 2007/8 does not seem to have had any influence on trade data presented in Table

4.6, which indicates a lower vulnerability. The flip side of this is that a low perception of import-related risks may lead to the risk being neglected and inaction on indirect climate change impacts.

In order to reduce the magnitude of indirect climate change impacts, South Korea is engaging in the storage of emergency food reserves to guarantee rice availability for vulnerable (i.e. low income) consumers and to maintain the option to release stocks for counter trading during market shocks. The spike of rice imports in 2011 (Table 4.2) could be related to the 'ASEAN plus three' storage engagement where Korea pledges a major share of 250,000 tons.
South Korea could also implement financial management schemes (like crop insurance) as recommended by Kim et al. (2010) to protect consumers and producers from climate change related impacts on rice.
Further measures related to prevent or dampen the climate related impacts on trade seem to be possible, based on South Korea's high ability to pay (GNI per capita).

Since there is no South Korean NAPA, the assessment of adaptation is severely limited due to a missing overview of 'official' strategies, making it impossible to identify clearly the focus of adaptation policy makers in South Korea.
There is only limited formal national adaptation planning and indirect climate change impacts have so far not featured in the national planning of adaptation within the government[5] , however, South Korea demonstrated a certain awareness of the risks associated with climate change impacts on rice imports through relevant non-adaptation documents (e.g. Kim et al. 2010). It needs to be questioned to which extent these documents reflect decision-makers opinion since the risk is not stated in a climate change adaption strategy.

Even though, the overall climate profile indicates a high risk and the adaptation strategies are poorly articulated, South Korea is in a significantly better position compared to Senegal and other countries in terms of indirect climate impacts on rice imports. Both countries are rated in the climate risk profile as high which can be mostly attributed to methodological limitations (facilitation). The methodology under-represents the significance of South Korea's near self-sufficiency in rice (SSR=92% average from 2009 to 2013) and therefore the risks associated with its imports are proportionally less relevant.

Nevertheless, it needs to be mentioned that South Korea is a highly food import dependent country. Total grain (Maize, Rice and Wheat) production is still small and highly dependent on imports (Lyddon 2012). Consequently, South Korea is highly food import dependent and indirect climate impacts may be substantial for other food commodities. Being highly food import dependent causes similar trade pathway risks which need to be considered and addressed. The market for other food commodities like wheat and maize are more diverse and robust, but current IPCC results show that climate change impacts on these production systems will be worse for wheat and maize compared to rice in the future (IPCC 2014a).

[5] The issue of indirect impacts has not featured in South Korea's national adaptation thinking to date, according to personal communications with a key official within the Ministry of Environment (Republic of Korea 2014).

5.3 United Arab Emirates

As a country that depends heavily on food imports, the UAE shows an awareness of indirect climate change impacts on rice imports. The UAE is rated as **high** in the climate change risk profile, resulting from a high likelihood and a medium magnitude.

The current trade profile reveals a very high likelihood of indirect climate change impacts because of the poor diversification of trade partners (two countries account for 92,9% of total imports) and India solely accounts for two-thirds of imports. During the 2007/8 crises, India did not restrict the trade of high quality basmati rice to the UAE. This indicates that the trade relation between the two is more resilient since the UAE as a wealthy country can afford to pay price premiums for rice. India is highly interested to maintain such profitable rice trade agreements, while it is capable of protecting domestic markets and food security with lower quality and hence less valuable rice.
However, adverse climate change impacts on India and Pakistan are likely to reduce rice yields which increase the likelihood of indirect impacts on rice imports for the UAE (Table 4.7). As a response, the UAE are attempting to diversify its rice imports, for example via enhanced negotiations with Pakistan, Cambodia and Vietnam (Oryza 2014b).

Self-sufficient rice production in the UAE is not a viable option due to the lack of arable land and desalinated water. One measure to prevent or mitigate indirect climate change impacts on rice imports employed by the UAE is to buy or long-term lease farming land abroad, mainly in Africa, but also in South Asia. Such measures guarantee the import security of rice and other food commodities produced in these areas. Regarding this measure in a global context, the acquisition of land may in some cases increase vulnerability. According to GRAIN (2012), 3,2 million hectares are already under agreement or in process.

However, the acquisition of land abroad is unlikely to guarantee food security in times of global shortages.Most food-insecure people are located in South Asia (IPCC 2014a), where rice is the major food commodity and a major part of the land is acquired (Defra 2010). Political instability and food insecurity in most host countries are likely to make agreements untenable in the longer term and contracts may be terminated, particularly in times of a (food) crisis (Sowers & Weinthal 2010; QFCA 2010).

The UAE is the world's largest rice re-exporter, approx. one-third of the rice imports were re-exported over the last years; hence its name is the 'queen of rice'. Accordingly, climate change impacts on rice trade has also implications for the country's economy with a rice trading value of $2 billion and exports to 80 countries in 2011 (mainly to Iran) (Oryza 2014b). The UAE is pursuing to boost its role as regional rice trading hub further, e.g. by building mill to increase the processing capacity (Oryza 2014b).
Additionally, rice has a certain importance as a food staple, providing around 14% of daily calorie intake. Instead of focussing exclusively on supply-side adaptation, a diversification of diets would reduce the risk magnitude by decreasing rice dependency (Sowers & Weinthal 2010).

The rice crisis in 2007/8 had no significant repercussions on the rice trade profile of the UAE (Table 4.3). Accordingly, the high GNI per capita enabled the UAE and its consumers to absorb higher prices and maintain imports at similar levels. Consumers were supported through food subsidies, price controls, or wage bonuses during the crisis in 2007/8 (UAE 2012). In the future, a diversification of trading partners and switching to more resilient producers might be possible adaptation measures.

Sowers & Weinthal (2010) suggest different adaptation measures for the UAE and other Gulf Cooperation Council countries such as the cooperation in regional infrastructures for strategic food reserves, creation of a virtual international fund for counter trading and the coordination of agricultural investments overseas. Agricultural investments in the food value chain of producing LICs could be beneficial for both countries by improving production and the entire rice value chain while the gains could be shared. This could be achieved by both or either direct, bilateral investments (i.e. official development assistance) or contributions to multilateral funds, including global climate/ adaptation mechanisms, such as the Green Climate Fund[6]. These investments would help to increase global food security and are appealing for countries seeking reduction of US and EU agro-subsidies in international trade negotiations (Sowers & Weinthal 2010).

Using the ODI (2010) framework, applicable measures to reduce the magnitude of price shocks could be the creation of rice reserves, market interventions like reduced food taxes or subsidies, and long-term trade agreements with a larger number of trade partners. As a rice trading hub, as well as a significant importer, UAE has a double interest in maintaining global rice trade during climate shocks and avoiding a situation of increased protectionism in rice producing countries. It therefore may see an interest in maintaining or building trade openness via the World Trade Organization, where the scope for preventing export restrictions is currently rather weak.
In order to secure vulnerable consumer groups, a diversion of food grains and the implementation of insurance and safety nets could be a suitable policy option.

The UAE demonstrates a high awareness of the risk associated with indirect climate change impacts on rice imports. The adaptation strategies however are not sufficient as they more or less exclusively consist of investments in agricultural land abroad, which, depending on its effects and the perspective taken, may constitute 'mal-adaptation' if they end up 'relocating' food insecurity and compounding the vulnerability of low income households in host countries.

5.4 United Kingdom

Like the UAE, the UK is heavily dependent on imports but in a better overall position due to a higher diversity of trade partners and a lower dependence on rice as a staple food. Both, the likelihood and the magnitude in the risk assessment were rated to be **medium**. The key issue for the UK may be that climate-related shocks that cause spikes in the price of rice could create a social justice challenge for low income, rice dependent consumers.

The UK does not produce rice domestically, which makes it import dependent and heightens the likelihood of indirect climate change impacts. However, compared to the other case study countries and particularly to the UAE, the UKs concentration of trading partners is more resilient because it is diverse. However, the concentration indicator has to be regarded critically as it considers a number of (EU) countries which act as trade intermediaries but do not produce rice (e.g. Belgium and Netherlands). Accordingly, the dependence on producing countries is veiled and the dependence on a smaller number of partners might be higher (i.e. because the UK

[6] The Green Climate Fund is hosted by the UNFCCC; please find more information on the homepage: http://www.gcfund.org/home.html

receives rice from only a small number of 'original' producer countries, some of which is imported via intermediaries).

The UK acknowledges the principal food security challenge as a global one and further states that global stability depends on food security, i.e. that "*there being enough food in the world to feed everyone and for it to be distributed in a way that is fair to all* (Defra 2010)." The Defra (2010) report emphasizes the importance of global food security for an open, trading economy like the UK since security influences long-term availability and prices. Global food security needs to be addressed through governments and regional systems of support (such as the EU) which need to improve education and awareness of risk management options and have to particularly support most vulnerable countries. Further described assistance measures are food reserves and financing facility to help LICs when facing sudden food price spikes, as well as safety nets and specific assistance for the poorest consumer groups to obtain insurance against risk and volatility are needed to prevent the worst effects.

On the other hand, the UK identifies its ability to switch key trading partners and transform supply chains (Defra 2013; PwC 2013), which enhances its ability to adapt to changing risks in rice production. This strategy seems feasible considering the high average income of consumers allowing them (in theory) to pay price premiums, and the central and powerful position of the UK in international trading relations. Switching to more resilient production partners may, however, deliver only marginal improvements in supply chain resilience given that global rice production is projected to decrease overall, according to the modelled projections reviewed in this study, and the number of shocks to increase.
This strategy of switching to more resilient trading partners is opposing to global food security targets, as it may increase the risk likelihood for other (lower-income) countries since they will be left to depend on vulnerable producers and unstable supply chains (e.g. Senegal and India). The UK might in return be affected indirectly by higher need for aid and assistance in LICs and poor communities.

The Foresight (2011b) report rejects food self-sufficiency as a viable option to contribute to global food security. Further, the strategy of other wealthy countries (like the UAE) to acquire land abroad is a growing concern to the UK because it alters the confidence in the market and multilateral trade.
Nevertheless, an investigation in the GRAIN (2012) report reveals significant overseas land investments by the UK. Compared to South Korea (1,2 million hectares) and the UAE (3,2 million hectares), the UK has most land accumulated abroad with 4,9 million hectares under agreement or in process, according to GRAIN (2012).
The robustness and adequacy of the data from GRAIN (2012) needs to be regarded critically as there is no officially agreed classification for 'landgrabbing' meaning that the classification can be challenged and might be relatively subjective, for example if it includes investment by private firms as opposed to state backed companies. Further, it needs to be considered that land investments may be beneficial and conducted with the aim to support ~~the domestic market of~~ the host country.

A very low dependency on rice (2% calorie intake) reduces the magnitude of indirect climate change impacts by allowing substitution and hence preventing food scarcity. Indirect climate change impacts are unlikely to endanger food security but may have significant cost implications for the UK and particularly for the poor in the UK (PwC 2013). Within the last decades, rice consumption in the UK has steadily increased; one important driver is immigration. In the

middle of the 1980s, 90% of foreign foods (i.e. rice) were consumed by minority ethnic groups but over time indigenous population started to integrate ethnic foods into their cooking (Panayi 2002; Jamal 2003; Crang & Cook 2003). It is expected that minority ethnic groups still consume a higher share of daily calories through rice compared to the indigenous population and also that there are income inequalities between these two groups.
Climate risks associated with rice imports therefore present the UK with an adaptation challenge in terms of social justice and social cohesion, rather than a food security risk. Lower income groups in the UK may be disproportionately affected through a higher dependence on rice in case of climate-related price spikes for foodstuffs such as rice.
Also, LICs and poor communities overseas are disproportionately affected by climate change impacts on rice imports which increases the need UK aid and assistance (Foresight 2011a).

National adaptation measures aim to enhance global food security which means sufficient and fairly distributed food in all countries. The UK engages in regional systems such as the EU to implement measures which enhance the resilience of the rice market to systemic indirect climate change risks of rice imports globally. Measures to increase the rice market resilience are to restrict food price betting, avoid a 'prisoner's dilemma', and to increase traded rice volumes on the market by e.g. by shifting cultivation areas in more favourable climatic regions, increasing multilateral trade and through storing rice.

The PwC (2013) report states that developing countries are generally expected to experience a greater size of stress from indirect climate change impacts due to the dependence on resource imports from developing countries which are particularly vulnerable to climate impacts. Based on the information presented in this study, this statement is contradicted as the countries with a high GNI (UAE and UK) have the ability to absorb increasing prices, while Senegal suffered under the repercussions of the 2007/8 crises.
The UK is less vulnerable to global price shocks as a mature and stable economy but there are cost implications of price shocks which are particularly serious for the poor in the UK. However, the UK fails to address this vulnerability of (ethnic) consumer groups within the UK specifically, as adaptation strategies focus on the 'Business, Industry and Services Sector' (Defra 2012a). Vulnerable consumer groups could be protected from higher food prices by compensating transfers, insurance and safety nets, and through subsidies and wage bonuses. In this case, adapting to import-related risks to rice is more a case of social policies to protect low income groups.

5.5 Evaluation of the methodology

The aim of this study is to develop and test a method of analysis; strengths and weaknesses of this method are discussed in this section based on experiences made throughout the progress. The wide range of different data sources used in this study leads to significant variations in terms of data quality and detail level between the risk indicators. A simplifying method ('traffic-lights') was necessary to combine these different data sources and generate the climate risk profile. This simplified method was aligned with the lowest quality data (e.g. GNI per capita and SSR) which causes that higher quality data (e.g. trade data, rice consumption data) is not represented in full detail.
The 'traffic-light' methodology could be adjusted to higher quality data by increasing the number of categories, e.g. applying five categories instead of the three (high, medium, and low). The method does not restrict the number of categories and hence the level of detail of the method can be adjusted to the data quality.

Another consequence of varying data quality was the consideration of different timeframes; the GNI and SSR are based on the recent year data (from 2012), the concentration (HHI) and current trade profile used the five year average data, and the dependency on rice was based on consumption trends over the past ~50 years. Instead, the five year average of all these risk indicators could have been used to improve the data conformity between the indicators. Furthermore, most risk indicators are considered in terms of their recent values and thereby neglecting that they are subjects to uncertainty and change in the future. All three magnitude indicators (GNI, rice consumption, and SSR), as well as the trade partner concentration, might shift in the future and hence significantly influence the results of the climate risk profile. In this study, only the future climate change impacts on rice yields and their effect on the current trade profiles are examined in detail. This was based on purpose of the study to develop a method and test the possibility to combine different data sets in order to explore new dimensions.

It can be argued that the time spend on compiling the 'current trade profile' data is not reflected in the simplified 'traffic light' assessment. However, the value of the trade data compilation by far exceeds the information of the single risk indicator; this data provides insights to explore the rice trade system and determine trade dependencies which enabled the identification of the effects of the 2007/8 crises and further revealed the systemic nature of risk to the rice market. Additionally, the trade data was used for the trade partner concentration indicator.
Generally, the data availability restricted the choice of indicators (section 3) and thereby limited a more efficient progress e.g. through reducing or adjusting the level of data detail applied.

The methodology could be improved through weighing between the risk indicators. In the method applied, each indicator has the same influence (1/6) on the climate risk result. However, this equal influence is not adequate since some indicators determine the vulnerability to indirect climate impacts more significantly than others. Indicators like the SSR or the rice consumption are of superior importance for the risk climate related trade impacts compared to other indicators like the HHI. However, the determination of weights for indicators appears subjective and complex to establish due to significant feedbacks on the risk evaluation of different countries.

The analysis of this study focuses on climate scenario data while climate extremes could not be evaluated due to a lack of applicable data. Climate change impacts are likely to reduce rice yields and lead to higher prices due to general shortage but do not directly cause market shocks. Increasing general shortage is likely to be of importance long-term – depending on on-farm adaptation, in context of changing demands on agricultural land for fuel and food. Additionally, shortages are likely to feature short-term shocks and price volatility because countries are more inclined to implement protectionist measures and start hoarding.
This study considers market shocks since they are key determinants for crises where consumers suffer more than 'necessary' given the sometimes moderate changes in actual production. During the financial crises in 2007/8, rice was never 'short' but countries' actions led to a tripling of the market price (Dawe & Slayton 2011). The assessment of these systemic risks is more valuable as an indicator of food security compared to solely regarding the 'increasing price' effects. Further, yield declines amplify the risk of market shocks to occur.

Studies at the global level on climate change and food production are generalized and contain many important assumptions – which frequently result in positively biased results – that it is difficult to undertake this kind of study. This is especially the case regarding extreme weather events which is a general weakness of research on climate change impacts.

This is a major point for using a bottom-up approach to not be fully constrained by climate scenario data, but to explore the system's current vulnerability (i.e. including its vulnerability to shocks and extreme events) and then to investigate this vulnerability alongside data available on potential future trends and events. The bottom-up approach therefore enables an assessment of the country's risk to future market shocks even though quantitative data on future extreme events is lacking.

Trade networks are complex systems of market influences which are represented in this study trough simplified indicators. The study does not try to assess the trade system itself, but how each case study interacts with this complex system. In this case, the diversity (or concentration) of rice supply chains; and the likely climate impacts in current trade partners are regarded to establish the risk profile of countries that rely on this system to different extents. Accordingly, the method necessarily simplifies the complexity of trade by investigating the specific aspects of the interaction between our decision making unit (the importing country) and the complex system (i.e. rice markets).

The case study selection of South Korea is questionable in the retrospective. South Korea was selected as a case study because of its expected high rice consumption and as a rapidly transforming country representing an 'intermediate' development state to the other case studies. The high rice self-sufficiency is an important factor to reduce the risk to indirect climate change impacts on rice imports (underrepresented through methodology) and therefore South Korea might not be a suitable case study. However, South Korea is still importing ~350 1000 MT of rice per year which is less than the other case study countries but still a substantial amount and it qualifies therefore as a rice import dependent country. Additionally, the case study countries were selected for varying vulnerabilities to indirect climate change impacts.
The South Korea case study shows the need to implement a weighing between risk indicators, but also shows the general ability of the methodology to deal with different case study characteristics. The high South Korean SSR is not sufficiently valued by the methodology since the country is rated to be at high risk.

The study begins to explore new dimensions of climate vulnerability that are currently not explored in climate change literature and it trials a new way of looking at climate risk. The risk indicators provide a structure of analysis of trade-related risk which contributes to increased clarity in understanding the risks of indirect climate change impacts that import dependent countries face.
By taking a systems approach and combining data on multiple countries from both trade and climate impacts literature, the study begins to explore the ways in which climate change may create systemic risks. Drawing attention to these systemic risks in the global markets, and the need for globally coordinated adaptation are contributions of this study to future climate change adaptation planning.

5.6 Study limitations

There are various limitations with the methods applied in this study and so results should be treated with caution and seen as indicative of potential risk profiles for each of the countries considered.

The lack of studies with a similar methodology and objective complicates an objective selection of risk indicators. The indicators were selected using expert judgement comprising a small panel of expert researchers. These included an adaptation expert, a rice systems expert and the thesis author. Time did not allow for a more robust indicator selection process, for example a consultation or survey method for indicator selection. It has to be stated that the selection and composition of the risk indicators naturally influence the final climate change risk profile for each consuming country. Changes in indicator selection would therefore alter the overall results and potentially the balance of results between different countries. The results are valuable though because the same methodology has been applied to all countries, allowing for some insightful comparison.

Limitations of the online databases and the positive bias of the climate change scenarios show that there are imperfections in the data applied in the analysis. Further the limited availability of national adaptation documents for some countries reduced the comparability.
To reduce these flaws and strengthen the objectivity, sources of information were as consistent as possible for each case study country involving the same database, climate scenarios and same methods to search and analyse adaptation and non-adaptation documents. This way of conducting the study also has advantages or disadvantages for each country. For example, the results for South Korea would have been significantly better in a study design which places more emphasize on self-sufficiency as this is a very powerful way to mitigate the examined indirect climate change impacts via trade. However, the approach applied in this study is for example confirmed by Foresight (2011b) rejecting self-sufficiency as a viable option to contribute to global food security which shall be exemplified through the four case study countries.

Equilibrium-based models, which were used for the climate change scenarios that underpin part of the assessment of likelihood in Step 2, are susceptible to a range of limitations and often tend to underestimate the size of climate risks (Benzie et al. 2014). Particularly the climate change data from Iglesias & Rosenzweig (2010) was shown to be positively biased because of the consideration of positive effects such as CO_2 fertilization and possible adaptation measures, while neglecting a number of negative climate change impacts on yield like sea-level rise, increased pest and diseases and tropospheric ozone formation (section 3.2.2). The IPCC (2014a) states that many studies disregard CO_2 fertilization in order to simulate worst case scenarios or to avoid a bias by omitting positive CO_2 effects but not considering negative effects like elevated O_3 and increased weed and pest damage.

On the other hand, there is the possibility that rice cultivation might shift to other regions with more favourable climatic conditions in the future (section 2.3.1). Increasing pressure on production areas through meteorological variables such as temperature increases and changing precipitation patterns, as well as sea-level rise might feature this trend e.g. in China, Thailand and Vietnam. Cultivation areas threatened by sea-level rise are the most productive area (Mainuddin et al. 2011); a shift to other areas might therefore be difficult to offset the losses of highly productive regions.
The shift of cultivation areas might have a significant effect on the global rice system, however the IPCC mainly focuses on on-farm adaptation measures (IPCC 2014a). This trend is further limited by irrigation infrastructures, the availability of agricultural land in other regions of the country.

Therefore, the overall impacts of climate change on rice yields are likely to be more negative than indicated by the study results from Iglesias & Rosenzweig (2010), and hence the results described in the current trade profile (Table 4.5 to Table 4.8). Conservative study results from

Masutomi et al. (2009)[7] are in agreement with this and project even more pessimistic yield declines in 2020 (Table 5.1).

Table 5.1 – *Climate change impacts on rice production for 2020, 2050 and 2080 in key producing countries modified from Masutomi et al. (2009).*

	1990s - 2020s			1990s - 2050s			1990s - 2080s		
Country	A1B	A2	B1	A1B	A2	B1	A1B	A2	B1
China	-5.8	-7.1	-3.4	-5.2	-3.8	-2.1	-10.0	-13.1	-5.7
India	-4.2	-4.5	-3.4	-0.5	-0.1	0.8	-3.0	-4.9	0.6
S Korea	0.8	-1.0	2.3	5.7	6.0	2.7	2.5	-6.0	8.2
Pakistan	1.2	0.7	2.3	7.9	9.0	5.8	7.7	6.8	8.1
Thailand	-2.5	-2.6	-1.7	-0.2	-2.3	1.2	-8.2	-16.2	-0.4
Vietnam	-3.7	-2.2	-2.2	2.3	0.6	0.4	-11.7	-20.7	-1.0

Gray shading indicates large decreases of at least 10%.

Based on Masutomi et al. (2009) data, all producing countries are ranked as highly climate sensitive, except Pakistan which is rated low and the USA where no data is available. These changes in climate sensitivity in the producing countries are affecting the case study countries in the following way: The tables below (Tables 5.2 to 5.5) show an alternative to Table 5.1 and include the Masutomi et al. (2009) data which are combined with the data from Iglesias & Rosenzweig (2010) in a similar way as in Step 2 (section 4.1.2).

Table 5.2 – *Current trade profile indicating the climate change sensitivity of imports for Senegal based on combined data from Masutomi et al. (2009) and Iglesias & Rosenzweig (2010).*

Senegal	Scenario data								Standard		Rating	Import share [%]
	A1F	*A2a*	*A2b*	*A2c*	*B1a*	*B2a*	*B2b*	Average	Deviation	Range		
Producer	*% in rice yield change by 2020*											
India	-6,1	-4,23	-3,78	-4,8	-3,68	-6,62	-4,93	-4,88	1,13	-3,68; -6,62	✗	16,2
		A1B	-4,2	***A2***	-4,5	***B1***	-3,4	-4,03	0,57	-3,4; -4,5	✗	
Thailand	0,75	1,54	0,57	1,46	-0,4	0,78	0,22	0,70	0,68	1,54; -0,4	✓	37,3
		A1B	-2,5	***A2***	-2,6	***B1***	-1,7	-2,27	0,49	-1,7; -2,6	✗	
Vietnam	-0,7	0,09	0,11	0,04	-0,78	-1,43	-1,12	-0,54	0,63	0,11; -1,43	!	16,4
		A1B	-3,7	***A2***	-2,2	***B1***	-2,2	-2,70	0,87	-2,2; -3,7	✗	
Pakistan	-5,78	-4,39	-4,68	-5,85	-4,09	-5,62	-5,33	-5,11	0,71	-4,09; -5,78	✗	4,1
		A1B	1,2	***A2***	0,7	***B1***	2,3	1,40	0,82	0,7; 2,3	✓	
World	-2,4	-1,96	-2,39	-1,97	-3,96	-3,77	-3,17	-2,80	0,83	-1,96; -3,96	✗	26,1
Percent of total grain production from rice: 62,67											✗	**Overall:** ✗
Senegal	-3,07	-2,5	-2,72	-2,2	-3,15	-3,79	-3,76	-3,03	0,60	-2,2; -3,79		

White Area presents scenario data (A1F, A2a, A2b, A2c, B1a, B2a & B2b) from Iglesias and Rosenzweig 201

Grey Area presents scenario data (A1B, A2 & B1) from Matsutomi et al. 2009

[7] The Masutomi et al. (2009) study was not used as the basis for Step 2 because it did not cover 100% of the six producer countries selected for this study.

Table 5.3 – *Current trade profile indicating the climate change sensitivity of imports for South Korea based on combined data from Masutomi et al. (2009) and Iglesias & Rosenzweig (2010).*

S. Korea	Scenario data								Standard		Rating	Import
	A1F	*A2a*	*A2b*	*A2c*	*B1a*	*B2a*	*B2b*	Average	Deviation	Range		share [%]
Producer	*% in rice yield change by 2020*											
China	-0,92	-1,18	-0,24	-1,31	-0,67	-1,68	-1,78	-1,11	0,55	-0,24; -1,78	!	48,1
		A1B	-5,8	***A2***	-7,1	***B1***	-3,4	-5,43	1,88	-3,4; -7,1	✗	
Thailand	0,75	1,54	0,57	1,46	-0,4	0,78	0,22	0,70	0,68	1,54; -0,4	✓	17,6
		A1B	-2,5	***A2***	-2,6	***B1***	-1,7	-2,27	0,49	-1,7; -2,6	✗	
USA	2,08	2,63	0,25	1,47	-0,95	-0,54	-0,14	0,69	1,38	2,63; -0,95	✓	27,7
Vietnam	-0,7	0,09	0,11	0,04	-0,78	-1,43	-1,12	-0,54	0,63	0,11; -1,43	!	3,8
		A1B	-3,7	***A2***	-2,2	***B1***	-2,2	-2,70	0,87	-2,2; -3,7	✗	
World	-2,4	-1,96	-2,39	-1,97	-3,96	-3,77	-3,17	-2,80	0,83	-1,96; -3,96	✗	2,8
Percent of total grain production from rice: 62,67											✗	**Overall:** ✗
S. Korea	0,84	1,84	1,6	1,79	0,73	0,15	0,11	1,01	0,74	1,84; -0,11		

White Area presents scenario data (A1F, A2a, A2b, A2c, B1a, B2a & B2b) from Iglesias and Rosenzweig 201
Grey Area presents scenario data (A1B, A2 & B1) from Matsutomi et al. 2009

Table 5.4 – *Current trade profile indicating the climate change sensitivity of imports for the UAE based on combined data from Masutomi et al. (2009) and Iglesias & Rosenzweig (2010).*

UAE	Scenario data								Standard		Rating	Import
	A1F	*A2a*	*A2b*	*A2c*	*B1a*	*B2a*	*B2b*	Average	Deviation	Range		share [%]
Producer	*% in rice yield change by 2020*											
India	-6,1	-4,23	-3,78	-4,8	-3,68	-6,62	-4,93	-4,88	1,13	-3,68; -6,62	✗	65,7
		A1B	-4,2	***A2***	-4,5	***B1***	-3,4	-4,03	0,57	-3,4; -4,5	✗	
Thailand	0,75	1,54	0,57	1,46	-0,4	0,78	0,22	0,70	0,68	1,54; -0,4	✓	5,4
		A1B	-2,5	***A2***	-2,6	***B1***	-1,7	-2,27	0,49	-1,7; -2,6	✗	
Pakistan	-5,78	-4,39	-4,68	-5,85	-4,09	-5,62	-5,33	-5,11	0,71	-4,09; -5,78	✗	27,2
		A1B	1,2	***A2***	0,7	***B1***	2,3	1,40	0,82	0,7; 2,3	✓	
World	-2,4	-1,96	-2,39	-1,97	-3,96	-3,77	-3,17	-2,80	0,83	-1,96; -3,96	✗	1,7
Percent of total grain production from rice: 0											**Overall:** ✗	

White Area presents scenario data (A1F, A2a, A2b, A2c, B1a, B2a & B2b) from Iglesias and Rosenzweig 2010
Grey Area presents scenario data (A1B, A2 & B1) from Matsutomi et al. 2009

Table 5.5 – *Current trade profile indicating the climate change sensitivity of imports for the UK based on combined data from Masutomi et al. (2009) and Iglesias & Rosenzweig (2010).*

UK	Scenario data								Standard		Rating	Import
	A1F	*A2a*	*A2b*	*A2c*	*B1a*	*B2a*	*B2b*	Average	Deviation	Range		share [%]
Producer	*% in rice yield change by 2020*											
India	-6,1	-4,23	-3,78	-4,8	-3,68	-6,62	-4,93	-4,88	1,13	-3,68; -6,62	✗	22,7
		A1B	-4,2	***A2***	-4,5	***B1***	-3,4	-4,03	0,57	-3,4; -4,5	✗	
Thailand	0,75	1,54	0,57	1,46	-0,4	0,78	0,22	0,70	0,68	1,54; -0,4	✓	9,5
		A1B	-2,5	***A2***	-2,6	***B1***	-1,7	-2,27	0,49	-1,7; -2,6	✗	
Pakistan	-5,78	-4,39	-4,68	-5,85	-4,09	-5,62	-5,33	-5,11	0,71	-4,09; -5,78	✗	10,8
		A1B	1,2	***A2***	0,7	***B1***	2,3	1,40	0,82	0,7; 2,3	✓	
USA	2,08	2,63	0,25	1,47	-0,95	-0,54	-0,14	0,69	1,38	2,63; -0,95	✓	8,7
World	-2,4	-1,96	-2,39	-1,97	-3,96	-3,77	-3,17	-2,80	0,83	-1,96; -3,96	✗	48,3
Percent of total grain production from rice: 0											**Overall:** ✗	

White Area presents scenario data (A1F, A2a, A2b, A2c, B1a, B2a & B2b) from Iglesias and Rosenzweig 2010
Grey Area presents scenario data (A1B, A2 & B1) from Matsutomi et al. 2009

The less optimistic – possibly more accurate - results from the Tables 5.2 to 5.5 show a high climate sensitivity ranking for all four case studies. In the analysis for the climate risk profile (based on Iglesias & Rosenzweig 2010), South Korea was ranked as medium.

6 Conclusion & Recommendation

Climate change factors pose a serious threat to rice production and hence to global food security. This study uses a unique methodology to establish a country specific risk profile and compare this risk profile with recent adaptation strategies aiming to explore the risks of future climate change to import dependent countries; draw attention to indirect climate change impacts for import dependent countries; and broaden perspectives on what constitutes 'climate change adaptation' and how climate vulnerabilities are shared between producer and consumer countries.

Based on the results, the two research questions pursued in this study: '***How vulnerable are rice importing countries to climate induced trade disturbances?'*** and '***To what extent and how do these import-dependent countries consider trade-related risks in their climate change adaptation plans?'*** can be answered.

All four case studies countries are sensitive to indirect climate change impacts on rice imports and were ranked accordingly in the climate risk profile: Senegal is at high risk based on a high likelihood and a high magnitude; South Korea and the UAE both are at high risk based on a high likelihood and medium magnitude; while the UK has a medium risk due to a medium likelihood and magnitude. Generally, it can be concluded that wealthier developed countries have the ability to absorb price volatility and market shocks.

Senegal highlights the precarious situation of many LICs. It is highly dependent on rice as a staple and also highly vulnerable to shocks as experienced during the 2007/8 crisis. Senegal's adaptive awareness and responses are rudimentary and limited by monetary constraints leaving no space for manoeuvring. Therefore, Senegal and many other countries are dependent on international cooperation and support to increase the rice market stability.

South Korea is a rice import depending country (approximately 350 1000 MT rice imported), even though a large share of consumed rice is produced self-sufficiently. The limited national adaptation planning does not feature indirect climate impacts for rice or for overall food security, while non-adaptation documents demonstrate a certain awareness (e.g. Kim et al. 2010). However, present South Korean adaptation efforts are insufficiently addressing national food security in the context of indirect climate impacts, which could particularly become an issue for other food staples such as wheat and maize which are imported to 90%.

The UAE is aware of the risk associated to indirect climate change impacts and uses its wealth to invest in land overseas as a key adaptation measure. This can be effective adaptation for the UAE unilaterally; however, political instability and food insecurity in host countries may terminate agreements, particularly in times of a (food) crisis.
Further, land acquisitions raise major concern since they may constitute 'mal-adaptation' in an international context by relocating food insecurity in some cases to more vulnerable low income consumers in host countries.

The UK addresses indirect climate change impacts in a global adaptation context through regional systems of support (such as the EU) which aim to raise awareness and implement measures to protect particularly the most vulnerable countries and the poorest consumer

groups. Resilience of the rice market shall be enhanced through a higher confidence in the market and increasing multilateral trade.
Opposing to the global food security target, the UK also identifies its ability to switch to resilient producers and further is most heavily involved, of all case studies, in the acquisitions of land oversea. These investments may in some cases increase the host countries food insecurity but may also be beneficial for the country in other cases.

The risk analysis in this study (4 importers, 6 producers) is useful because it sheds light on the **systemic nature of trade related climate risks**. The trade pathway of indirect climate change impacts is not just about changing flows between two discreet countries ('a producer' and 'a consumer'); risks are magnified when multiple importers are exposed to the same risks, especially when triggered by individual countries behaviour in a thin market like rice, and compound those risks via their own adaptations, e.g. stockpiling or panic buying rice or via land investments with the sole intent of importing the produced foodstuff from the host country.

Rice trade is somewhat disconnected with markets for other cereals. To address food security holistically, similar studies on other staple foods like wheat and maize would be supplementary. The markets for wheat and maize have different characteristics as they comprise a larger number of producers with a more equal distribution of power. However, the Russian export ban of wheat subsequent to a drought in 2010 contributed to a doubling of global wheat prices by the end of the year (Nelson et al. 2010; IPCC 2014a). This substantial effect of the export ban of one producing country indicates a serious volatility of the global wheat market.

The unit of analysis in this study is the country level, since rice trade is defined by governments. This level of detail neglects societal complexity by fails to identify and address vulnerable consumer groups. A scaling-down of the study to sub-national levels would further help to define the complex adaptive capacity of consumer groups which is a very important factor in the assessment of a countries' vulnerability.

Climate change data from Rosenzweig & Iglesias (2010) and the less optimistic – possibly more accurate - results from the Tables 5.2 to 5.5 both project high climate change impacts on rice yields in the key producing countries.
Projections on the likelihood of extreme events at either the global or producer-country scale are directly relevant as they trigger climate-driven shocks. The unavailability of accurate data limited the results of this study as model results do not consider extreme events or shocks, which induced past and current crises (e.g. crisis 1972/3, Russia 2010 and California 2014). Present IPCC reports (IPCC 2007a; IPCC 2013; IPCC 2014a) project increased frequency and intensity of future weather extremes as a consequence of climate change.

These amplifying indirect climate change impacts indicate a high climate sensitivity of rice imports for all four case studies, and even the whole rice market, and reduce the space for adaptation. A lower availability of rice globally intensifies the competition between import dependent countries and thereby increases the scope for the 'powerful' or rich countries to outcompete the poorer ones. Shifting cultivation areas are presently not a widespread measure to adapt to increasing climate change driven pressure on global rice production systems.

The systemic nature of risk to the rice market raises the importance of coordinated adaptation between countries to the international dimension of the risk. Strategies exclusively focussing on country level adaptation such as land acquisition, protectionism through trade restrictions, accepting high prices during shocks and absorbing them with their high GNI per capita, panic buying or even higher value contracts between 'resilient' producers and rich importers – all of these 'adaptations' could potentially increase the vulnerability of other import-dependent countries and of the whole rice market system.

Global coordinated adaptation is therefore needed to ensure that the systemic risks via trade are identified and reduced in a coordinated fashion to the benefit of the system as a whole. Actions to reduce climate related risks should aim to enhance climate change resilience of key producing countries by investing in and improving supply chains. Global adaptation measures would be to enhance trade openness (via WTO or EU); reducing the volatility of markets especially from food price speculation and biofuel mandates; create rice reserves to release stocks in times of market shocks and enhance the 'trust' in the robustness of the market; and establish financial support and safety nets for the vulnerable consumer groups in times of price shocks.
In order to avoid these protectionist measures, coordinated global action to guarantee trade openness can help to reduce the individual rational response of a country. Thereby, other (producing) countries could compensate for supply shortages in one country instead of that every country is restricting their exports ('prisoner's dilemma').

The financial crises in 2007/8 demonstrated that market shocks can be triggered by a range of factors where climate change impacts is only one amongst many. This study focuses on climate related impacts as a driver for shocks, while other factors are equally important for the rice market and possibly more complex to address by individual countries (e.g. the effects of biofuel mandates).

The identification of the systemic nature of the risks to the rice market in this study pose interesting questions for adaptation planning and governance, for example:

- Do these globally coordinated measures regarding indirect impacts of climate change represent and extension of what national 'adaptation' is about?
- Could climate finance be used more effectively if it was invested in measures that reduce systemic risks globally? Is this a legitimate use of international climate finance?
- How can adaptation plans evolve to take account of indirect climate change impacts, such as those highlighted in this study relating to trade in climate-sensitive food commodities like rice?

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7 Appendices

7.1 Glossary of terms

Adaptation – "*Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory, autonomous and planned adaptation* (IPCC 2007b)".

> **Maladaptation** – "*could mean either:*
> *– any changes in natural or human systems which inadvertently increase vulnerability to the hazards of climate change;*
> *– an adaptation that does not succeed in reducing vulnerability but increases it instead;*
> *– spending a disproportionate amount of effort and investment on adaptation beyond what is required.* (Defra 2013)"

Adaptive Capacity - "*The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences the available adaptation options and their characteristics* (IPCC 2007b)".

C_3 plants – "*Plants that produce a three-carbon compound during photosynthesis, including most trees and agricultural crops such as rice, wheat, soybeans, potatoes and vegetables* (IPCC 2007b)".

C_4 plants – "*Plants, mainly of tropical origin, that produce a four-carbon compound during photosynthesis, including many grasses and the agriculturally important crops maize, sugar cane, millet and sorghum* (IPCC 2007b)".

Carbon dioxide (CO_2) – "*A naturally occurring gas, also a by-product of burning fossil fuels from fossil carbon deposits, such as oil, gas and coal, of burning biomass, of land use changes and of industrial processes (e.g., cement production). It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured and therefore has a Global Warming Potential of 1* (IPCC 2013)."

Carbon dioxide (CO_2) fertilization – "*The enhancement of the growth of plants as a result of increased atmospheric carbon dioxide (CO_2) concentration* (IPCC 2013)".

Climate – "*Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system* (IPCC 2013)"

Climate change – "*Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the* *atmosphere or in land use. Note that the Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes* (IPCC 2013)".

Climate prediction – "*A climate prediction or climate forecast is the result of an attempt to produce (starting from a particular state of the climate system) an estimate of the actual evolution of the climate in the future, for example, at seasonal, interannual or decadal time scales. Because the future evolution of the climate system may be highly sensitive to initial conditions, such predictions are usually probabilistic in nature* (IPCC 2013)"

Climate projection – "*A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative forcing scenario used, which is in turn based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized* (IPCC 2013)".

Climate scenario – "*A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as the observed current climate. A climate change scenario is the difference between a climate scenario and the current climate* (IPCC 2013)".

Drought – "*The phenomenon that exists when precipitation is significantly below normal recorded levels, causing serious hydrological imbalances that often adversely affect land resources and production systems* (IPCC 2007b)".

Evapotranspiration – "*The combined process of evaporation from the Earth's surface and transpiration from vegetation* (IPCC 2013)".

Extreme weather event – "*An extreme weather event is an event that is rare at a particular place and time of year. Definitions of rare vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season)* (IPCC 2013)"

General Circulation Model (GCM) – "*General circulation models: A mathematical model that simulates changes in climate as a result of slow changes in some boundary conditions or physical parameters, such as the greenhouse gas concentration. General circulation models and global climate models are widely applied for weather forecasting, understanding the climate, and projecting climate change. These computationally intensive numerical models are based on the* *integration of a variety of fluid dynamical, chemical and, sometimes, biological equations* (Foresight 2011b)".

Global trade – "*The exchange of capital, goods and services across international borders* (Foresight 2011b)".

Greenhouse effect – "*The infrared radiative effect of all infrared-absorbing constituents in the atmosphere. Greenhouse gases, clouds, and (to a small extent) aerosols absorb terrestrial radiation emitted by the Earth's surface and elsewhere in the atmosphere. These substances emit infrared radiation in all directions, but, everything else being equal, the net amount emitted to space is normally less than would have been emitted in the absence of these absorbers because of the decline of temperature with altitude in the troposphere and the consequent weakening of emission. An increase in the concentration of greenhouse gases increases the magnitude of this effect; the difference is sometimes called the enhanced greenhouse effect. The change in a greenhouse gas concentration because of anthropogenic emissions contributes to an instantaneous radiative forcing. Surface temperature and troposphere warm in response to this forcing, gradually restoring the radiative balance at the top of the atmosphere* (IPCC 2013)".

Greenhouse gas (GHG) – "*Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine- and brominecontaining substances, dealt with under the Montreal Protocol. Beside CO_2, N_2O and CH_4, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride (SF6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs)* (IPCC 2013)".

Globalisation – "*The growing integration and interdependence of countries worldwide through the increasing volume and variety of crossborder transactions in goods and services, free international capital flows, and the more rapid and widespread diffusion of technology, information and culture* (IPCC 2007b)".

(climate change) Impacts – "*The effects of climate change on natural and human systems. Depending on the consideration of adaptation, one can distinguish between potential impacts and residual impacts* (IPCC 2007b):

> ***Potential impacts****: all impacts that may occur given a projected change in climate, without considering adaptation.*
> ***Residual impacts****: the impacts of climate change that would occur after adaptation*. "

Impact – "*An effect of climate change on the socio-bio-physical system (e.g. flooding, rails buckling)* (Defra 2012a)".

Modelling – "*A theoretical method that represents (economic) processes by a set of variables and a set of quantitative relationships between them. The model is a simplified framework designed to illustrate complex processes* (Foresight 2011b)".

Monsoon – "*A monsoon is a tropical and subtropical seasonal reversal in both the surface winds and associated precipitation, caused by differential heating between a continental-scale land mass and the adjacent ocean. Monsoon rains occur mainly over land in summer* (IPCC 2013)".

Ozone – "*The triatomic form of oxygen (O_3), is a gaseous atmospheric constituent. In the troposphere, it is created both naturally and by photochemical reactions involving gases resulting from human activities (smog). Tropospheric ozone acts as a greenhouse gas. In the stratosphere, it is created by the interaction between solar ultraviolet radiation and molecular oxygen (O_2). Stratospheric ozone plays a dominant role in the stratospheric radiative balance. Its concentration is highest in the ozone layer* (IPCC 2013)".

Projection – "*A projection is a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Unlike predictions, projections are conditional on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized* (IPCC 2013)".

Region – "*A region is a territory characterized by specific geographical and climatological features. The climate of a region is affected by regional and local scale features like topography, land use characteristics and lakes, as well as remote influences from other regions* (IPCC 2013)".

Resilience – "*The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change* (IPCC 2007b)".

Safety net programme – "*Non-contributory transfer programmes seeking to prevent the poor or those vulnerable to shocks and poverty from falling below a certain poverty level. Safety net programs can be provided by the private or the public sector* (Foresight 2011b)".

Sea-level rise – "*An increase in the mean level of the ocean. Eustatic sea-level rise is a change in global average sea level brought about by an increase in the volume of the world ocean. Relative sea-level rise occurs where there is a local increase in the level of the ocean relative to the land, which might be due to ocean rise and/or land level subsidence. In areas subject to rapid land-level uplift, relative sea level can fall* (IPCC 2007b)".

Sensitivity– "*in this context, the degree to which a system is affected, either adversely or beneficially, by climate variability or change* (Defra 2013)".

SRES – "*The storylines and associated population, GDP and emissions scenarios associated with the Special Report on Emissions Scenarios (SRES), and the resulting climate change and sea-level rise scenarios. Four families of socio-economic scenario (A1, A2, B1 and B2) represent different world futures in two distinct dimensions: a focus on economic versus environmental concerns, and global versus regional development patterns* (IPCC 2007b)".

Supply chain – "*A system of organisations, people, technology, activities, information and resources that begins with the sourcing of raw material and extends through the delivery of end items to the final customer* (Foresight 2011b)".

Vulnerability – "*the degree to which an individual or a system is susceptible to adverse effects. In this context, the adverse effects of climate change, including extreme events. Vulnerability is* *influenced by the system's sensitivity and its adaptive capacity, as well as the magnitude of the change* (Defra 2013)".

Volatility (price volatility) – "*The wide and frequent variation in average price over a period of measurement* (Foresight 2011b)".

Uncertainty – "*A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures (e.g., a probability density function) or by qualitative statements (e.g., reflecting the judgment of a team of experts)* (IPCC 2013)".

Urbanisation – "*The rapid physical growth and migration to urban areas. Urbanisation is also defined by the United Nations as movement of people from rural to urban areas with population growth equating to urban migration* (Foresight 2011b)".

Water-use efficiency – "*Carbon gain in photosynthesis per unit water lost in evapotranspiration. It can be expressed on a short-term basis as the ratio of photosynthetic carbon gain per unit transpirational water loss, or on a seasonal basis as the ratio of net primary production or agricultural yield to the amount of available water* (IPCC 2007b)".

7.2 Biophysical climate change impacts

Climate change impacts on agriculture occur through meteorological variables such as rising mean air temperature, changing precipitation patterns and increased atmospheric carbon dioxide (CO_2) concentration leading to carbon dioxide (CO_2) fertilization (Parry et al. 2004; Soora et al. 2013). The biophysical response of agricultural production towards these impacts can be either positive or negative depending on farming systems and regions, and can also vary through time (Parry et al. 2004).
Figure 7.1 presents a schematic overview over the range of interconnected primary and secondary effects on rice production caused by climate change.

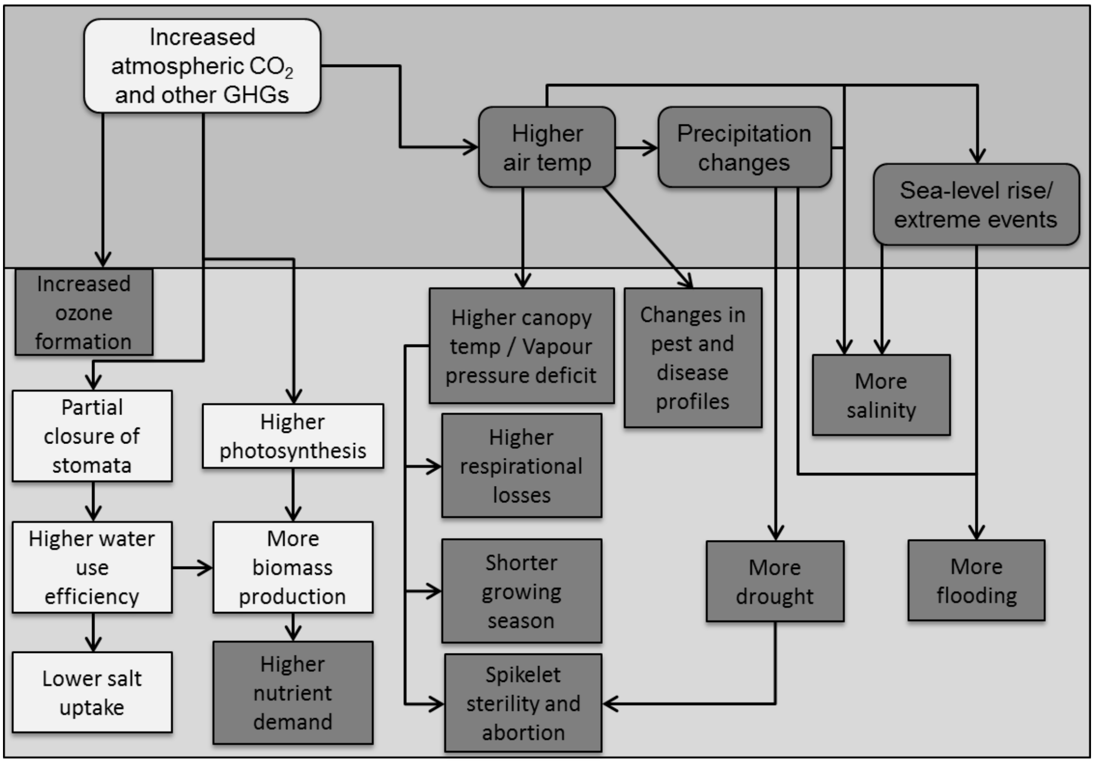

Figure 7.1 - *Schematic presentation of potential climate change impacts on rice production (modified from Wassmann et al. 2010). Effects described in dark-grey boxes specify effects leading to a total yield decline and lower quality rice grain; light-grey boxes indicate positive or neutral rice yield effects.*

Primary climate change effects are induced by the emission of greenhouse gases (GHGs) which are accumulating in the atmosphere. Crops like rice are directly affected by higher atmospheric CO_2 levels through '**CO_2 fertilization**' (Krishnan et al. 2007; Iizumi et al. 2011; Jalota et al. 2012). CO_2 fertilization means that higher atmospheric carbon dioxide concentrations stimulate rice production through enhanced photosynthesis rates and higher water use efficiency, and thereby increases yields.
A study by Parry et al. (2004) demonstrates a nearly linear correlation between yield change and elevated atmospheric CO_2 level (Figure 7.2). Some crops (C_3 plants like rice, wheat and soya) benefit physiologically from higher concentrations of CO_2 in the atmosphere compared to C4 plants like maize (Long et al. 2004).

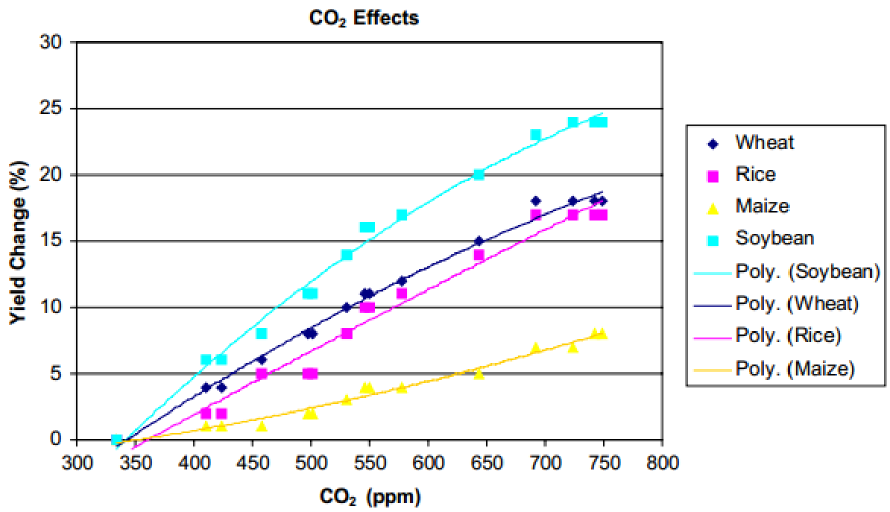

Figure 7.2 – *Potential increase of yield under elevated levels of atmospheric CO_2* (Parry et al. 2004).

In contrast, Foresight (2011b) states that the positive impact of CO_2 fertilization is highly uncertain and that benefits for C_3 plants will only occur if it is not limited by other factors (such as e.g. water and nutrient availability). Peng et al. (1997) states that global warming is likely to negate any potential benefit from CO_2 fertilization. Lal et al. (1998) observed an increase in yield of 28 % for a doubling of CO_2 concentration, but this benefit was offset by a 2 °C warming. Yield reductions predicted by cereal simulation models largely offset any benefit from CO_2 fertilization (Auffhammer et al. 2012).

Ambient concentrations O_3 and CO_2 are connected and have counteractive effects on C_3 plants which may compensate each other (Taub et al. 2008; Ainsworth et al. 2008; Gillespie et al. 2012). High temperatures combined with O_3 are likely to exceed the effect of CO_2 fertilization (Long 2012). Therefore, many studies disregard CO_2 fertilization in order to simulate worst case scenarios or to avoid a bias by omitting positive CO_2 effects but not considering negative effects like elevated O_3 and increased weed and pest damage (IPCC 2014a).

The IPCC (2014) observed warming trends and more frequent **temperature** extremes across most Asian regions with growing numbers of warm days and decreasing numbers of cold days. A mean average annual warming between 1.0 and 1.4 °C by 2020 and between 2.23 and 2.87 °C by 2050 is projected for South Asia (Defra 2005; IPCC 2007b).
Higher global temperature impacts can both be positive or negative based on the geographical region. Rice is a tropical crop and hence well adapted to high temperatures with an optimal temperature range of 25 to 30 C (Wassmann et al. 2010). Temperatures above or below these optima decrease growth and productivity rapidly (Saseendran et al. 2000; Mohammed & Tarpley 2009; Wassmann et al. 2010; Tian et al. 2010) and may sometimes be lethal for the crops (Schlenker & Roberts 2009).

In regions where the temperature is lower than these optima, an increase can extend the growing season and allow or enhance production through reaching the temperature optima (Lioubimtseva & Henebry 2009). As a consequence, rice cultivation areas are expected to shift with climate change throughout Asia (IPCC 2014a). Rice production may on the other hand decline in temperate regions where heat per se may not be a limiting factor as a consequence of higher crop water demand and a concomitant reduced water availability (Wassmann et al. 2010).

Overall, increasing temperatures are projected to reduce yields in many tropical and subtropical regions (Mall et al. 2006). Wassmann et al. (2009; 2010) found that the following parts of Asia are approaching critical temperature levels during susceptible stages of rice plants: Pakistan/North India (October), South India (April, August), East India (March-June), Thailand (March-June), Vietnam (April/August) and China (July/August) (excluding other producing countries not considered in this study).
Excessive heat (>35°C) is particularly harmful during the spikelet anthesis (flowering) as it causes spikelet sterility or abortion through heat injury during the particle emergence (Peng et al. 1997; Prasad et al. 2006; Jagadish et al. 2007; Wassmann et al. 2009). Experiments have shown that spikelet fertility declines from 90 % to 20 % after only 2 h exposure to 38 °C and is reduced to 0% after less than1 h exposure to 41 °C (Yoshida 1981). Slingo et al. (2005) found that temperatures greater 35 °C for more than 1 h impair pollen sterility, as well as temperatures below 20 °C (Wassmann et al. 2010). Furthermore, excessive heat shortens the grain filling duration which leads to reduced grain size and therefore grain yield (Wassmann et al. 2010; Soora et al. 2013).
Warming night temperatures decrease rice yields (Peng et al. 2004; Wassmann et al. 2009; Welch et al. 2010; Auffhammer et al. 2012) and quality (Okada; et al. 2009), especially at the end of the growing season. According to Auffhammer et al. (2012), night time warming had a greater impact on rice yield in India from 1966 – 2002 than changes in monsoon characteristics.

A higher temperature causes sea level rise due to thermal expansion of sea water and rapid melting of glaciers and ice caps, exposing highly productive but sensitive coastal and deltaic rice cultivation areas to inundation and salinity intrusion (Wassmann et al. 2010). Sea-level rise threatens especially coastal and deltaic rice production areas in Asia; about 7% of Vietnam's agriculture land may be inundated (Dasgupta et al. 2009; Wassmann et al. 2010; IPCC 2014a). Asian megadeltas are considered most vulnerable to observed and projected climate change trends and impacts such as sea level rise, increasing frequency and intensity of storm surge and accompanied flooding and salinity stress (Adger et al. 2007; Wassmann et al. 2010). Sea level has risen for 10-25 cm over the last 100 years (IPCC 2007b) and will rise between 13 – 94 cm (central estimate 49 cm) based on model employed until 2100 (IPCC 2001).
In many coastal and deltaic regions, rice is the only crop that can be grown because of unstable water levels and high salinity (Wassmann et al. 2010). South, East, and Southeast Asian coastlines comprise among others nine megadeltas which are larger than 1 million ha each (IPCC 2007b). Rice production in these deltas forms the economic backbone in many Asian countries by contributing a large share of internationally marketed and even a small decrease in productivity will drastically threaten food security (Wassmann et al. 2010), as well as social stability in producer regions.

South Asia will experience a more frequent occurrence of heavy **rainfall** events while the number of rainy days will decrease (Lal et al. 2000) and the monsoon will continue to weaken (Kripalani et al. 2007). The IPCC (2007) projects that the mean rainfall is not expected to change by 2010. However, variability will increase by up to 10 % during the kharif (summer) and rabi (winter) crop season until 2070 (Wassmann et al. 2010). Current climate change scenarios predict that the area subjected to 'increasing water' stress will be more than double the area with 'decreasing water' stress by 2050s (Bates et al. 2008).
Increasing water stress results from increasing precipitation variability leading to shifts in water supply, water quality and flood risks. An increase in the frequency of heavy rainfalls in combination with poor or non-existent drainage can create water logging and eventually

complete submergence, or prolonged stagnant floods (Wassmann et al. 2010). More heavy rainfall events lead to altered runoff and drainage patterns, reducing the water availability for the plants (Challinor et al. 2004).
In other areas, a decrease in rainfall reduces the availability of irrigation supplies and hence leading to droughts. Droughts not only reduce water supplies but also amplify the amount of water needed for plant transpiration (Wassmann et al. 2010). The global area affected by drought is likely to increase in the future, as well as the frequency of heavy rainfall events (Mall et al. 2006; Pachauri & Reisinger 2007).

Changes in temperature as well as in precipitation patterns and amounts will influence soil conditions (like soil water content, run-off and erosion, salinization, biodiversity, and organic carbon and nitrogen content) and evapotranspiration (Mall et al. 2006).
Further potential effects on production that are altered by climate change are snow melt, change in pest and disease profiles and availability of energy (Aggarwal 2003; Mall et al. 2006; IPCC 2014a). Negative impacts include increased moisture stress in many areas, increased losses from pests, more difficult crop planning due to increased climatic variability (with wrong choices resulting in crop losses) and increased crop damage from extreme weather events (e.g. heat waves, hail, floods, drought) (Mall et al. 2006; Bruce & Haites 2008).

The impacts of extreme weather events on crops are difficult to model, however extremes have sizable impacts that are apparent immediately or soon after the event (IPCC 2014a). Extreme weather events in major producing countries can cause significant fluctuations and trends in food and trigger price spikes (IPCC 2014a). The frequency and intensity of future weather extremes is very likely to increase as a consequence of climate change (IPCC 2007a; IPCC 2013; IPCC 2014a). Expected climate change and weather extremes are likely to degrade the quality of rice and thereby the market value (Lee et al. 2013).

The total climate change impacts on future rice yield are very difficult and complex to assess as they appear as locally variable impacts (Wassmann et al. 2010). Weather and yield relationships are hard to establish since they are often crop and region specific and may depend on baseline climate, management and soil, as well as the duration and timing of crop exposure to various conditions (IPCC 2014a). A case study in China for example showed positive responses to increasing temperature in some regions while responding negatively in others (Zhang et al. 2010). Statistical studies show positive depending on whether the rice yields are limited by low or high temperatures (IPCC 2014a). Other studies provide evidence that high temperatures will reduce yield in cool environments as well (Semenov et al. 2012; Teixeira et al. 2013).
'Confounders' such as cultivar improvements and increased use of fertilizers, herbicides, and irrigation (IPCC 2014a) further aggravate the detection and attribution of climate change impacts (Stone et al. 2013). The impact of these confounders is hard to measure across space and time and therefore difficulty to quantify or model (IPCC 2014a).
Further complexity arises from spatial variation and uncertainties in crop responses to combinations of CO_2, weather, soils, and management factors (farmers' behaviour), as well as uncertainties in the evolution of global social, political, and land-use systems (Peng et al. 1997; Mainuddin et al. 2012).

It can be concluded that potential climate change impacts on rice production (Figure 7.1) are most likely to be overall negative for current rice producing areas. These potential impacts are likely to be enhanced in the immediate future (2016 – 2035), and very likely to virtually certain in the late 21st century (2081 - 2100) (IPCC 2014a).

7.3 Trade Data

Table 7.1 – Original *trade data for **Senegal** and key producing partners, extracted from UNcomtrade (2014). Import % is computed based on partner country NetWeight (kg) and total imports World.*

Period	Trade Flow	Partner	Trade Value [$]	NetWeight (kg)	Import %
2005	Import	India	52820644	181688297	14,52
2006	Import	India	18165835	61887067	8,77
2007	Import	India	101599011	305128682	28,88
2008	Import	India	8539787	16411560	1,62
2009	Import	India	100931	250000	0,03
2010	Import	India	N/A	0	0,00
2011	Import	India	4531877	9715300	1,20
2012	Import	India	272976515	674586404	64,81
2005	Import	Thailand	146976280	495932036	39,63
2006	Import	Thailand	98555220	332170558	47,06
2007	Import	Thailand	197513902	555774255	52,61
2008	Import	Thailand	394889096	617975716	61,01
2009	Import	Thailand	189716404	400789136	51,93
2010	Import	Thailand	120899979	258387280	37,05
2011	Import	Thailand	126335540	253303219	31,35
2012	Import	Thailand	56378209	86961743	8,35
2005	Import	Viet Nam	72134661	243710197	19,47
2006	Import	Viet Nam	24558197	83973777	11,90
2007	Import	Viet Nam	10389411	30766586	2,91
2008	Import	Viet Nam	63194315	102144432	10,08
2009	Import	Viet Nam	67912742	188250383	24,39
2010	Import	Viet Nam	46809696	119255680	17,10
2011	Import	Viet Nam	113568552	247441595	30,63
2012	Import	Viet Nam	20935748	51349110	4,93
2005	Import	Pakistan	1299599	3698924	0,30
2006	Import	Pakistan	1114151	3425000	0,49
2007	Import	Pakistan	1296703	3626450	0,34
2008	Import	Pakistan	24203813	35736685	3,53
2009	Import	Pakistan	8418310	24654146	3,19
2010	Import	Pakistan	15029365	43538294	6,24
2011	Import	Pakistan	10125773	25511298	3,16
2012	Import	Pakistan	19062766	45974389	4,42
2005	Import	World	368594778	1251539873	
2006	Import	World	209269732	705887782	
2007	Import	World	363903952	1056431575	
2008	Import	World	646209183	1012887427	
2009	Import	World	326904813	771762364	
2010	Import	World	289491763	697308807	
2011	Import	World	376440020	807887813	
2012	Import	World	449579589	1040856256	

Table 7.2 – Original *trade data for **South Korea** and key producing partners, extracted from UNcomtrade (2014). Import % is computed based on partner country NetWeight (kg) and total imports World.*

Period	Trade Flow	Partner	Trade Value [$]	NetWeight (kg)	Import %
2005	Import	India	396	115	0,00
2006	Import	India	438	110	0,00
2007	Import	India	266	123	0,00
2008	Import	India	4683	1008	0,00
2009	Import	India	16842	3511	0,00
2010	Import	India	31546	6322	0,00
2011	Import	India	40205	6813	0,00
2012	Import	India	6389349	12942967	5,28
2005	Import	Thailand	3755050	13000000	9,74
2006	Import	Thailand	13552134	42721550	16,75
2007	Import	Thailand	11445149	35142503	13,27
2008	Import	Thailand	40316032	63162438	20,46
2009	Import	Thailand	15001170	28261507	10,57
2010	Import	Thailand	31287418	64417428	18,67
2011	Import	Thailand	60751725	115683032	20,19
2012	Import	Thailand	20539355	35075099	14,30
2005	Import	Viet Nam	N/A	0	N/A
2006	Import	Viet Nam	N/A	0	N/A
2007	Import	Viet Nam	N/A	0	N/A
2008	Import	Viet Nam	182	33	0,00
2009	Import	Viet Nam	321	113	0,00
2010	Import	Viet Nam	184	50	0,00
2011	Import	Viet Nam	7196473	15000143	2,62
2012	Import	Viet Nam	21759838	51441163	20,97
2005	Import	Pakistan	9	1	0,00
2006	Import	Pakistan	N/A	0	N/A
2007	Import	Pakistan	N/A	0	N/A
2008	Import	Pakistan	N/A	0	N/A
2009	Import	Pakistan	22	2	0,00
2010	Import	Pakistan	3353716	6133246	1,78
2011	Import	Pakistan	5078527	8262908	1,44
2012	Import	Pakistan	265	70	0,00
2008	Import	USA	58336224	83806581	27,15
2009	Import	USA	79223799	75591740	28,28
2010	Import	USA	78412619	102684741	29,76
2011	Import	USA	125429298	155158908	27,08
2012	Import	USA	47702940	64220449	26,18
2008	Import	China	96262644	161721124	52,39
2009	Import	China	159230900	163421112	61,14
2010	Import	China	136181388	171657113	49,76
2011	Import	China	230489725	263806084	46,05
2012	Import	China	70643693	76606276	31,23
2005	Import	World	51369167	133485920	
2006	Import	World	118465590	255027652	
2007	Import	World	136541945	264739332	
2008	Import	World	194920225	308691271	
2009	Import	World	253475159	267278845	
2010	Import	World	249457129	344994936	
2011	Import	World	436426232	572928709	
2012	Import	World	168826963	245318822	

Table 7.3 – Original *trade data for the **UAE** and key producing partners, extracted from UNcomtrade (2014). Import % is computed based on partner country NetWeight (kg) and total imports World.*

Period	Trade Flow	Partner	Trade Value [$]	NetWeight (kg)	Import %
2005	Import	India	90621430	205700053	28,69
2006	Import	India	118112634	260471818	33,83
2007	Import	India	349676349	500863393	48,16
2008	Import	India	967838234	743462443	57,43
2009	Import	India	896396401	793768906	71,85
2010	Import	India	908464350	895043724	67,91
2011	Import	India	831134724	826801578	62,60
2012	Import	India	N/A	N/A	#WERT!
2005	Import	Thailand	20292839	47919420	6,68
2006	Import	Thailand	24030774	54629753	7,10
2007	Import	Thailand	42250887	83425344	8,02
2008	Import	Thailand	103036269	132623393	10,25
2009	Import	Thailand	68707325	98143959	5,51
2010	Import	Thailand	57889296	80921161	4,33
2011	Import	Thailand	55929627	76551894	5,80
2012	Import	Thailand	N/A	N/A	#WERT!
2005	Import	Viet Nam	1490480	5362065	0,75
2006	Import	Viet Nam	659476	2279203	0,30
2007	Import	Viet Nam	1510767	4101041	0,39
2008	Import	Viet Nam	5517252	8218806	0,63
2009	Import	Viet Nam	2450400	4500850	0,20
2010	Import	Viet Nam	1808223	4043163	0,14
2011	Import	Viet Nam	929520	1449178	0,11
2012	Import	Viet Nam	N/A	N/A	#WERT!
2005	Import	Pakistan	238687805	419464417	58,51
2006	Import	Pakistan	228597971	433281149	56,28
2007	Import	Pakistan	278706266	427446993	41,10
2008	Import	Pakistan	423393852	389461535	30,09
2009	Import	Pakistan	257722956	319030274	20,66
2010	Import	Pakistan	354868673	460537640	26,53
2011	Import	Pakistan	322976771	397268275	30,08
2012	Import	Pakistan	N/A	N/A	#WERT!
2008	Import	Egypt	5603647	9047492	0,37
2009	Import	Egypt	5576025	6461932	0,45
2010	Import	Egypt	3706775	5524826	0,28
2011	Import	Egypt	2451885	2379867	0,20
2012	Import	Egypt	N/A	N/A	#WERT!
2005	Import	World	366272227	716870702	
2006	Import	World	380432968	769900814	
2007	Import	World	684660837	1040081813	
2008	Import	World	1517458984	1294463937	
2009	Import	World	1247581299	N/A	
2010	Import	World	1337672336	N/A	
2011	Import	World	1230047921	1320795842	
2012	Import	World	N/A	N/A	

Table 7.4 – Original *trade data for the **UK** and key producing partners, extracted from UNcomtrade (2014). Import % is computed based on partner country NetWeight (kg) and total imports World.*

Period	Trade Flow	Partner	Trade Value [$]	NetWeight (kg)	Import %
2005	Import	India	113178192	177089377	25,18
2006	Import	India	122196434	190963267	27,56
2007	Import	India	160499394	207523160	29,47
2008	Import	India	205857943	146704015	20,62
2009	Import	India	183779008	135994058	19,72
2010	Import	India	162547473	152652595	21,13
2011	Import	India	157372065	146565799	20,58
2012	Import	India	177545619	211229204	32,21
2005	Import	Thailand	13582923	25088604	3,57
2006	Import	Thailand	17993924	32746314	4,73
2007	Import	Thailand	37649921	67942601	9,65
2008	Import	Thailand	57173533	71938588	10,11
2009	Import	Thailand	55654464	76666169	11,12
2010	Import	Thailand	63208747	75055760	10,39
2011	Import	Thailand	67155766	80175079	11,26
2012	Import	Thailand	32379226	28423848	4,33
2005	Import	Viet Nam	403417	545160	0,08
2006	Import	Viet Nam	654480	816739	0,12
2007	Import	Viet Nam	994296	1307996	0,19
2008	Import	Viet Nam	1179219	1735700	0,24
2009	Import	Viet Nam	821961	1875758	0,27
2010	Import	Viet Nam	91884	96676	0,01
2011	Import	Viet Nam	107005	113066	0,02
2012	Import	Viet Nam	335678	393417	0,06
2005	Import	Pakistan	29050287	43787726	6,23
2006	Import	Pakistan	25599457	40900734	5,90
2007	Import	Pakistan	28943758	35945952	5,10
2008	Import	Pakistan	94361147	77158636	10,85
2009	Import	Pakistan	54529648	67618745	9,80
2010	Import	Pakistan	77469483	92155025	12,75
2011	Import	Pakistan	91915734	99485865	13,97
2012	Import	Pakistan	32542117	39037986	5,95
2008	Import	Belgium	8549608	6823134	0,96
2009	Import	Belgium	13308469	11521232	1,67
2010	Import	Belgium	13678166	17507133	2,42
2011	Import	Belgium	16686115	21405403	3,01
2012	Import	Belgium	13831919	12972091	1,98
2008	Import	France	36893137	28776851	4,05
2009	Import	France	33161897	24688560	3,58
2010	Import	France	29192291	23149312	3,20
2011	Import	France	29489491	22755799	3,20
2012	Import	France	22264880	19844164	3,03
2008	Import	Italy	92383824	89742236	12,62
2009	Import	Italy	104260014	85475792	12,39
2010	Import	Italy	67049707	69787330	9,66
2011	Import	Italy	66201450	57908102	8,13
2012	Import	Italy	65928205	65610875	10,00

Table 7.4 – *Continued.*

2008	Import	Netherlands	50753838	46604877	6,55
2009	Import	Netherlands	37711033	44038942	6,39
2010	Import	Netherlands	24011297	28370062	3,93
2011	Import	Netherlands	25858517	28661418	4,03
2012	Import	Netherlands	28310426	23722574	3,62
2008	Import	Spain	59668504	84626897	11,90
2009	Import	Spain	43199573	69316247	10,05
2010	Import	Spain	63726731	103255178	14,29
2011	Import	Spain	69043994	95289463	13,38
2012	Import	Spain	75438410	108000722	16,47
2008	Import	USA	61427285	78947149	11,10
2009	Import	USA	47198925	67750782	9,82
2010	Import	USA	42148824	65085337	9,01
2011	Import	USA	36157807	56684094	7,96
2012	Import	USA	24286430	35964990	5,48
2005	Import	World	379657800	703394322	
2006	Import	World	398597594	692839517	
2007	Import	World	480903919	704226279	
2008	Import	World	719935851	711317089	
2009	Import	World	630303610	689671996	
2010	Import	World	589396156	722564776	
2011	Import	World	623906023	712026599	
2012	Import	World	537482008	655823771	

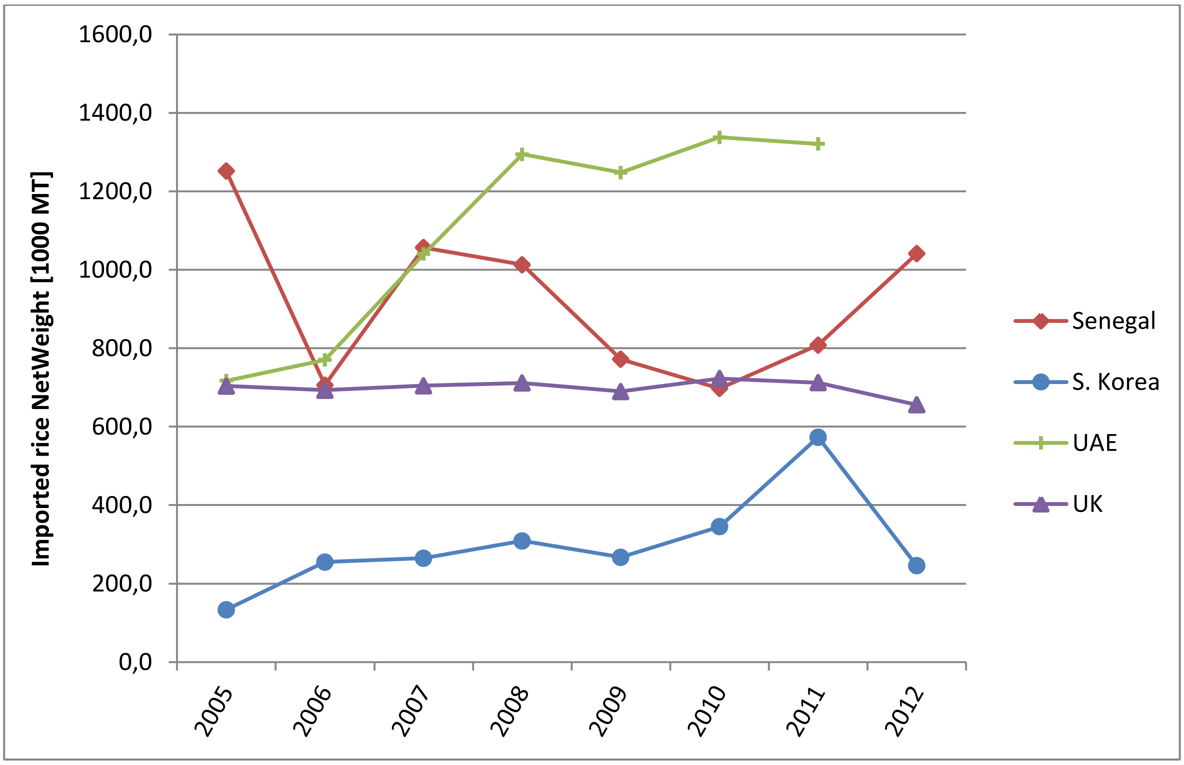

Figure 7.3 - *Overview of total imports from 2005 to 2012 for all four case study countries. Data collected from UNcomtrade (2014).*

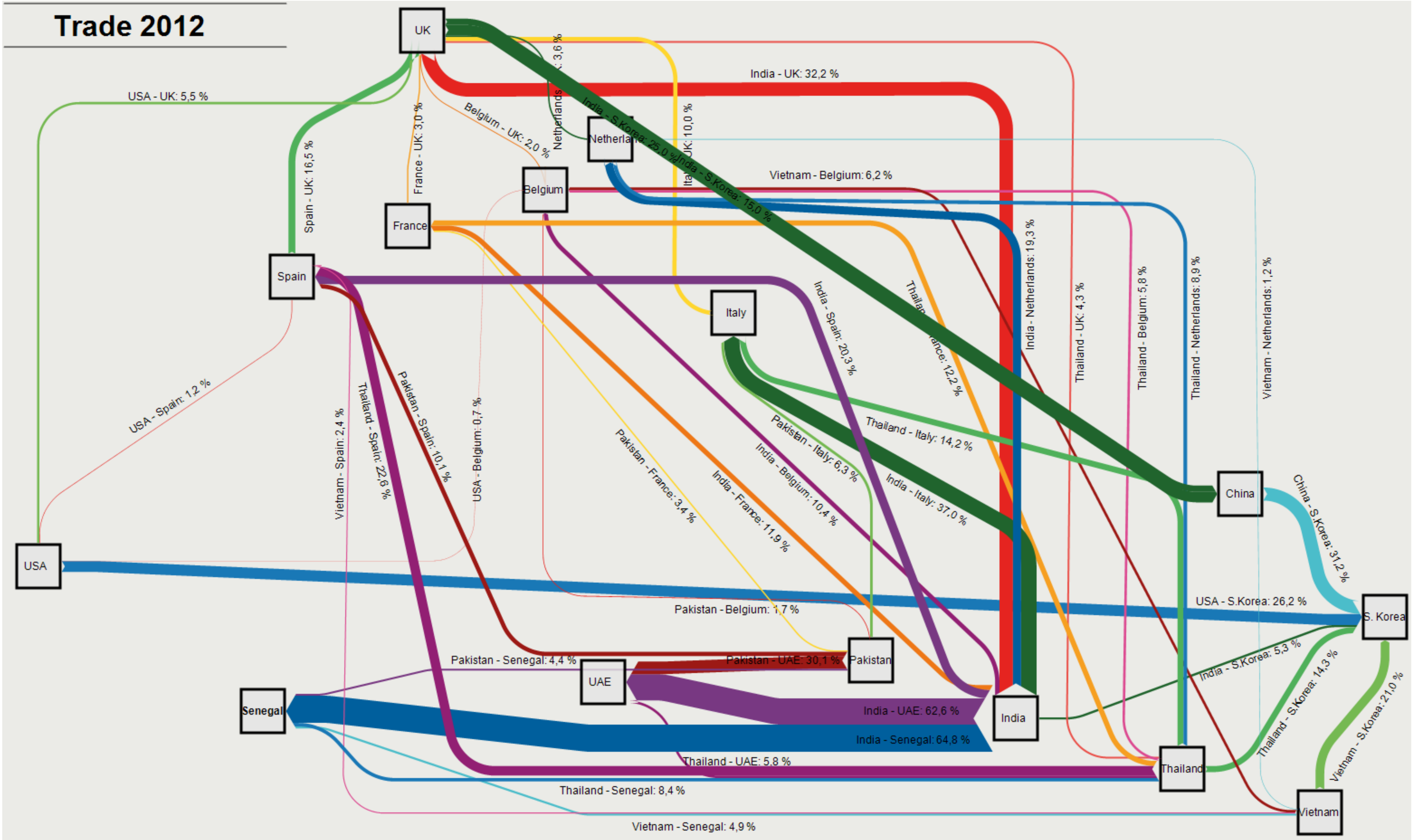

Figure 7.4 – *Trade network between the four case study countries and six key producing countries. Trade flows are based on 2012 trade data from UNcomtrade (2014). Including European countries as trade intermediaries.*