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Climate Vulnerability of the Supply-Chain: Literature and Methodological review

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Abstract

The increasing complexity of the present economic system and the strong interdependencies existing between production activities taking place in different world areas make modern societies vulnerable to crisis. The global supply-chain is a paradigmatic example of economic structures on which the impacts of unexpected events propagate rapidly through the system. Climate change, which affects societies all over the world, is one of the most important factors influencing the efficiency of the present economic networks. During the last decades a large set of studies have been oriented to investigate the direct impacts generated on specific geographical areas or productions. However, a smaller number of analyses have been oriented to quantify the cascading economic effects generated all over the world. The great complexity of the global economic system, coupled with methodological and data gaps makes it difficult to estimate the domino effects of unexpected events. A clear understanding of the possible consequences generated all over the world is, however, a fundamental step to build socio-economic resilience and to plan effective adaptation strategies. Within this context, the main objective of the present report is to provide an overview of the main studies, methodologies and databases used to investigate the climate vulnerability of the global supply chain. This information can be useful to i) support further studies, ii) to build consistent quantification methodologies, and iii) to fill the possible data gap.

Climate Vulnerability of the Supply-Chain: Literature and Methodological review

Summary

The increasing complexity of the present economic system and the strong interdependencies existing between production activities taking place in different world areas make modern societies vulnerable to crisis. The global supply-chain is a paradigmatic example of economic structures on which the impacts of unexpected events propagate rapidly through the system. Climate change, which affects societies all over the world, is one of the most important factors influencing the efficiency of the present economic networks. During the last decades a large set of studies have been oriented to investigate the direct impacts generated on specific geographical areas or productions. However, a smaller number of analyses have been oriented to quantify the cascading economic effects generated all over the world. The great complexity of the global economic system, coupled with methodological and data gaps makes it difficult to estimate the domino effects of unexpected events. A clear understanding of the possible consequences generated all over the world is, however, a fundamental step to build socio-economic resilience and to plan effective adaptation strategies. Within this context, the main objective of the present report is to provide an overview of the main studies, methodologies and databases used to investigate the climate vulnerability of the global supply chain. This information can be useful to *i)* support further studies, *ii)* to build consistent quantification methodologies, and *iii)* to fill the possible data gap.

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1 Setting the scene

The increasing complexity and interconnectivity that characterize the present economic system makes modern societies largely vulnerable to any kind of disturbance. The global supply-chain and the just-in-time production are paradigmatic example of networks on which disruption propagate rapidly through the system (Albrow, 1996; Castells, 1996).

Supply-chain can be defined as a coordinated networks and entities connected by the physical flows of materials and products (Mentzer et al., 2001). The globalized system of production characterized by low costs of transports, economies of scale and comparative advantages make it possible to connect consumers and producers localized all over the world. During the last decade, however, an increasing number of events, as terroristic attacks, local conflicts, earthquakes or climate change related disasters, generated disruptions along the chain, with domino effects on the global supply (Barker and Santos, 2010a; Krausmann, 2004; Regmi, 2001; Yamano et al., 2007).

The climate change related events, affecting societies all over the world, are one of the most important factors influencing the efficiency of the present economic networks. According to data provided by the Center for Research on the Epidemiology of Disasters (CRED, 2007) the frequency of climate change related events increased from about 195 per year between 1987 and 1998 to an average of 365 per year between 2000 and 2006. The largest parts of impacts are taking place in developing countries where the large vulnerability of infrastructures and society make the economic and human costs particularly high[1]. In the near future climate change is expected to generate increasing and extensive disasters with severe consequences in terms of safety, stability, food security, environmental degradation and economic costs (UNEP, 2007).

[1] 98% of the 262 million people affected annually by the climate disasters that took place between 2000 and 2004 lived in developing countries (CRED, 2007).

The hurricane Katrina in 2005, the severe heat wave that affected Russia in 2010, the frequency of heavy precipitation and the magnitude of storms are just some examples of the huge destructions that short-term unexpected events and long-term climate variations could generate both in developed and in developing countries.

In order to quantify the possible consequences generated by climate change, a large number of studies have been oriented to investigate the direct impacts generated on economy and societies. Sea level rise (Sanchez-Arcilla et al., 1996), vulnerability of coastal areas and marine ecosystem (Hanak and Moreno, 2012), heavy precipitation and tropical storms (IPCC, 2012) are just some examples of the different areas of analysis.

In recent times, an increasing attention has also been devoted to analyze the overall vulnerability of the supply chain and to identify the cascading effects generated all over the world. Just to provide some examples, after the Tohoky-Pacific earthquake of 2011 The Economic Times reported that *"Japan's Toyota Motor will cut production at its Indian subsidiary by up to 70% between April 25 and June 4 due to disruption of supplies"*. On the same event, The New York Times reported that *"auto production in Japan is at only half the normal level for Honda. That is mainly because many of the 20,000 to 30,000 parts that go into a Japanese car come from the earthquake-stricken region in northeast Japan, where numerous suppliers were knocked off line".* Other examples can also be provided by the increase in the international price of coffee generated by a fungus disease that affected Brazil in the '90s or by the global wheat price variation linked to the heat wave that affected Russia in 2010 (Andreoni and Duriavig 2013).

If in normal times the present globalized system has proven to be more cost effective than local production, during crises or disasters, the ripple effects on production and consumption can be a serious element of cost. Since industrial societies are largely dependent from primary resources, as agricultural products, mining, metal commodities or fuel, the climate change related events constitute a relevant risk for the present system of production and supply (Halegatte et al., 2007).

International literature, business administration and global governance largely recognized the importance of the possible cascading effects. However, until now, very few studies have been able to investigate the main transmission mechanisms and to quantify the total costs generated along the chain. The large uncertainty on the magnitude of the short and long term effects, together with the large complexity of the global economic connections and the limited understanding of the transmission networks makes it difficult to define clear methodologies for impacts quantification. The various assessments performed until now, being based on different approaches, generally reached quite different results (Arto et al, 2014).

In addition, a lack of clarity also exits in the multiplicity of words used to identify the impacts of climate change related event. Direct and indirect costs, output losses, capital or asset damages, welfare reduction, market and non-market costs, are just some examples of the multitude of words used on literature to identify the costs generate by disasters. In the present context of lexicographical and methodological uncertainty is then difficult to compare different methods or estimations (Hallegatte and Przyluski, 2010).

The same definition of *disaster* is not clearly defined on literature and several terms, such as hazard, unscheduled event or catastrophe have been used interchangeably. According to the Intergovernmental Panel on Climate Change (IPCC) disaster is defined as ‘a severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effect that require immediate emergency response to satisfy critical human needs and that may require external support for recovery’ (IPCC, 2012). A similar definition is provided by the United Nations Department of Humanitarian Affairs (UNDHA) that define disaster ‘expected losses (of lives, person injured, property damaged and economic activity disrupted) due to a particular hazard for a given area and reference period’ (1992). From an economic perspective, disaster refer to unexpected event that causes a short-term negative shock in the considered economic system and eventually, a long term perturbation in the local or global context (Arto et al., 2014)

In order to analyze the vulnerability of the global supply chain, the identification of the main areas of vulnerability[2] and the most important transmission mechanisms need to be considered. In particular, 3 main macro areas of impacts[3] can be identified (Advisen Ltd, 2013):

Impact to suppliers: includes the economic costs (or benefits) and disruptions generated to the economic unit that produce the basic or intermediate components of every product.

Impact to infrastructures: includes all the disruptions affecting the trader companies or the infrastructures used for transport or for electricity and water supply.

Impact to consumers: includes all the direct and indirect costs (or benefits) generated on final consumers.

Events affecting one or more entities could generate impacts on the other parts of the network. For this reason, the main vulnerabilities of every one of them need to be analyzed. However, since a multitude of different supply chain systems exist, the magnitude of the damage and the transmission mechanisms can be different based on specific supply chain characteristics (Mentzer et al., 2001; Manuj and Mentzer, 2008). In particular, some of the most important factors determining climate change vulnerability of different supply chains can be identified as (Advisen Ltd, 2013):

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[2] According to the Intergovernmental Panel on Climate Change (IPCC) vulnerability is defined as 'the extent to which climate change may damage or harm a system' (Watson et al., 1996: 26).

Vulnerability to climate change does not manifest due to climate alone but it is generated by a combination of multiple factors, as for example the socio-political environment, the economic structure or the institutional and political characteristics (Diaz and Ortega, 2011)

A large set of different definitions of vulnerability have been provided on literature. Tinnerman (1981) defines vulnerability as the degree to which a system reacts adversely to the occurrence of an event. Liverman (1990) consider vulnerability based on socio-economic, political and geographical conditions. IPCC (2014) use a definition that is much more similar to the concept of resilience "vulnerability is defines as the measure of a system's capacity to absorb and recover from the occurrence of a hazardous event". In general terms, however, it largely agreed that vulnerability is a function of sensitivity of the different elements composing the system and the existing connectivity between them.

[3] Impacts are here defined as the positive or negative consequences generated by events (Nakano, 2011).

Complexity and dimension of stages and networks: when the supply chain is constituted by a large quantity of suppliers, the possibility to suffer negative impacts generated by disruptions is larger than in the case of small and local supply-production systems.

Concentration of suppliers: the possibility to have different suppliers for the same commodity is an important element to increase the flexibility of the supply chain and to reduce the costs and the time of recovery after an unexpected event.

The magnitude of the impact: it is dependent by: i) how and how much the commodity is susceptible to the effects generated by climate change. Resilience and adaptability or substitution between resources are important element to determine the magnitude of the impacts; ii) how able is the supplying area to cope with unexpected events. This is based on elements as governance, recovery and risk management strategies.

Other elements need also to be considered to identify possible factors of vulnerability. Between them, some of the most important are:

Sensitivity: identifies the degree to which a system is affected by climate change related events (Smith et al., 2000).

Hazardous events: refer to the natural, socio-natural or anthropogenic events that are responsible for severe alterations in the normal functioning of a system (Lavell, 1996; Wisner et al., 2004).

Exposure or Element of risks: refers to the different system components that can be affected by events, as for example population, buildings, civil engineering works, economic activities, public services and infrastructure that are exposed to hazards (UNISDR, 2004; Downing and Patwardhan 2003).

Resilience: refers to the short-medium term ability to recover after an unexpected event. Resilience is mainly influenced by flexibility and it is largely determined by the socio-economic and political structure (Gunderson and Holling, 2000; Folke et al., 2002; Hallegatte, 2014a).

Adaptive capacity: refers to the long term or planned strategies including all the structural changes that have to be adopted to overcome adversities caused by climate change. Long-term strategies involve changes in all the elements of the supply system. Crop substitution, land allocation, inventories, substitution possibilities, transport and infrastructure resilience or flexible managements are just some examples of changes that need to be implemented in order to minimize the direct and indirect economic impacts generated by climate change (Reidsma et al., 2010; Smith and Olesen, 2010).

Having defined these important elements influencing vulnerability and costs, a set of challenges also exist in the quantification of the impacts that climate change related events can generate on the supply chain. In particular, the main elements that need to be considered are:

1. The costs of the climate change related events need to be calculated by comparing the climate change related scenario with a counterfactual baseline. The definition of the baseline can be difficult, particularly when long-term analysis need to be performed and when complex and globally integrated economic systems are considered. Different scenarios can be proposed and different costs estimated (Yohe et al., 2007).

2. Since different economic agents could have different economic priorities, the types of costs considered and the perspective adopted, can largely influence the magnitude of estimations (Yohe et al., 2007).

3. The spatial scale and the time period considered are other important factors influencing the magnitude of the impacts. Some studies, for example, found that adopting a long term perspective the benefits generated on economy can be larger than the costs (Hallegatte and Ghil, 2008; West and Lenze, 1994).

4. The same definition of impact can also be difficult. Pelling et al., (2002); Lindell and Prater (2003) and Rose (2004), among others, provide and discuss different types and definitions of impact. In general terms, however literature identify two main categories of impact, namely (Rose, 2004; Hallegatte, 2008):

   Direct impacts are defined as the immediate and short-term consequences of a climate change related event. They are generally classified as "market" and "nonmarket" costs (or benefits[4]):

   a. **Market costs** include all the elements that have a price in a market system, as for example damage on capital and build environment, equipment, factories or transport infrastructures.

   b. **Non-market costs** refer to health, to lives damages or to natural asset and ecosystem losses for which price estimation is not directly determined by market. Various ethical issues have to be taken into account when prices have to be attributed to non-market factors.

   Indirect impacts include all the costs (and benefits) that are not directly generated by the disaster itself[5]. The impact generated on the supply chain by a reduction of the productive or transport capacities are included in this category, as well as all the possible economic benefits generated by increasing demand for recovery and reconstruction. In a context of supply chain, the indirect impacts can also be disaggregated between upstream and downstream effects (Arto et al., 2014; Hallegatte, 2008):

   a. **Upstream effects** are defined as the impacts generated on the sectors that provide input to the affected activity.

[4] Since, in the short run, costs of disaster are much more relevant than benefits, we will just refer to costs.

[5] Some authors, as for example Rose (2004) suggested to use "higher-order effects" instead of indirect effects, because of the conflict with the terminology used in IO model.

b. **Downstream effects** are defined as the effects generated on the sectors that use the goods and services provided by the affected activity.

The direct impacts generally refer to the short time period following the climate change related event. On the contrary, the indirect consequences can be quantified both for the short and for the long term.

Table 1 summarizes some of the main direct and indirect impacts that a climate change and/or an unexpected events could generate on economy

Table 1. Examples of direct and indirect impacts

Direct Impacts	Indirect Impacts
Primary direct impacts	***Primary indirect impacts***
Physical damage to buildings and infrastructure	Loss of production due to direct damages
Physical damage to production equipment	Loss of production due to infrastructure disruptions
Physical damage to agricultural land	Loss of production due to supply-chain disruption
Physical damage to raw materials	
Physical damage to products in stock	
Physical damage to semi-finished products	
Secondary direct impacts	***Secondary indirect impacts***
Costs for recovery and reconstruction	Market disturbances (e.g. price variations of complementary and substitute products or raw materials)
Costs for remediation and emergency measures	Damage to company's image
	Decreased competitiveness, in the short term
	Increasing productivity and technological development, in the medium long term
	Economic growth for reconstruction
	Increasing poverty and inequalities

A set of different elements need to be considered as factors influencing the magnitude of the impacts, namely:

1) Destruction in crucial intermediate sectors as water, electricity, gas and transportation (McCarty and Smith, 2005; Tierney, 1997).

2) Local conditions such as hazard, exposure and vulnerability. They are generally considered as fundamental elements to determine disaster risks and magnitude (IPCC, 2007).

3) Resilience of the supply chain: is defined as the ability to recover quickly from disruptions. It is a key element in the definition of the overall costs generated by climate change related events. The capability to respond quickly and effectively is in fact one of the main elements influencing the magnitude of the direct and indirect costs. According to Craighead et al., 2007 three main supply chain characteristics (namely: density, complexity, and node criticality) and two mitigation capabilities (namely: recovery and warning) exist. The combination between them can be used to investigate the responses to unexpected events.

4) Effective disaster supply chain responses: the timely delivery of critical goods after a crisis is a fundamental element influencing both the magnitude of costs and the propagation of the negative effects. Several elements need to be considered in order to have effective responses in case of crisis (Editorial IJPE, 2010):

    a. **Planning:** unexpected events are difficult to predict. However, in the case of climate change scientific knowledge and research can be useful to identify sensitive geographical areas and to forecast certain types of events.

    b. **Preparation:** both individual organizations and the societies at large need to be prepared to the short and long term impacts generated by climate change. Culture of awareness, international support and adaptation strategies are fundamental elements to increase resilience and to reduce the costs (Weick and Sutcliffe, 2001; Hallegatte, 2014a).

c. **Leadership, agreement and collaboration:** to reduce the magnitude and costs of climate change related events, leadership, international agreement and collaboration are needed. Leadership is a fundamental element on crisis and disasters. It refers to the power and ability to take timely decisions and effective strategies for recoveries and costs mitigations. International agreement and collaboration refers to the urgent necessity to implement strategies oriented to avoid and reduce the negative impacts generated by climate change.

5) Stimulus effect of disasters: the increase in demand for reconstruction can generate an economic growth effect in the medium-long term (Hallegatte and Ghil, 2008; West and Lenze, 1994).

6) Productivity effect (or Shumpeterian creative destruction effect): when a disaster occurs, destructions can foster a more rapid turnover of capital and a more rapid embodiment of new technologies (Albala-Bertrand 1993; Steward and Fitzgerald, 2001; Benson and Clay, 2004). However, some studies, as for example Cuaresma et al. (2008) found that only countries with higher level of income per capita can benefit from technological improvements after a disaster.

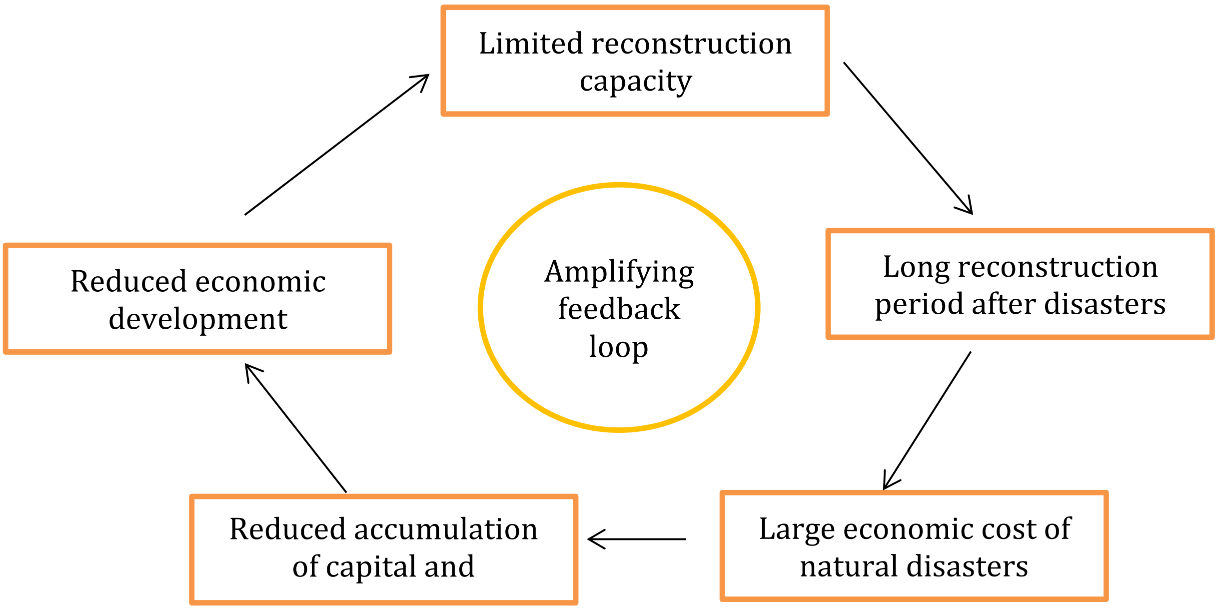
7) Pre-existing economic situation: some studies suggested that the overall cost of unexpected events might depend on the pre-existing economic situation. The World Bank (1999), for example, estimated that the strong economic recession that affected Turkey at the end of the '90s largely contributed to keep at a relatively low level the production loss generated by the Marmara earthquake in 1999. Similar results have also been obtained in a modelling exercise proposed by Hallegatte et al. in 2008. By using a Non-Equilibrium Dynamic Model (NEDyM) the interaction between economic fluctuations and natural disasters has been investigated. The main results showed a sort of "vulnerability paradox": when disasters occur in a period of economic recession

the total cost seems to be lower than the cost generated by disasters during high-growth period. The main explanation is provided by the fact that the increasing demand for reconstruction is able to activate unused resources and to drive economic recovery. On the contrary, during period of economic growth the total costs of disaster can increase by two main elements. The first one is the risk of inflation: since during economic expansion unemployment rate is very low, the increasing labour demand for reconstruction can induce wage inflation. The second one is the lack of financial resources. Since during economic growth the investment rate is very high it is difficult to find additional resources for reconstruction.

8) Socio-economic dynamics and socio-political stability: that includes a large variety of factors ranging from international aids, compassionate behaviour and community support.

9) Socio-economic distribution of effects and poverty traps: natural disasters and climate change related events can increase poverty and inequality. When natural and man-made assets are destroyed in regions with limited capacity of saving, as for example developing countries, the low level of capital accumulation can be a real limit for reconstruction and a determining factor for poverty perpetuation. Estimations provided by Hallegatte et al., 2007 show how reconstruction capacity is a fundamental element to determine the overall impact of natural disasters. When reconstruction capacity is large enough the average GDP impact can be close to zero. On the contrary, when reconstruction capacity is limited the GDP impact can be very large. Rodriguez-Oreggia et al., 2009, used the World Bank's Human Development Index to analys the impacts generated by natural disasters in Mexico. They found that municipalities affected by unexpected events see an increase in poverty by 1.5% to 3.6%. In figure 1 some of the main feedback mechanisms existing between disasters and poverty are reported.

Figure 1: Amplifying feedback loop that illustrates how natural disasters could become responsible for macro-level poverty traps



Source: Hallegatte and Przyluski, 2010

From a theoretical perspective, disaster theory supports the idea that economic growth and development are important variables in the management of disaster and in the recovery and adaptation strategies. Empirical evidences also suggest a negative relation between development and disaster. The lower is the level of development the higher is the magnitude of costs (Albala-Bertrand, 1993; Anbarci et al,. 2005; Kahn, 2005). Based on that, development strategies are considered as an important element to reduce losses and damages for less development countries (Okonski, 2004).

However, if from one side economic development seems to be able to increase the ability to respond to unexpected events, on the other side, the increasing complexity of the supply chain can rise the indirect costs generated on the overall system (Lester; 2008). Some studies support the idea that, form an economic point of view, the most venerable economies are not the underdeveloped, but the most developed ones. The complexity and the large interdependency across sectors and activities can increase the magnitude of the effects generated on the overall economic system. A “U” shape curve is generally used on literature to summarize the trend between economic development and costs generated by disasters (Kellenberg and Mobarak, 2008). Some simulation studies based on business cycle models also found that economies with low growth rate and production factors left unused appear to be less vulnerable than economies with a high growth (Hallegatte and Ghill, 2008).

11. Market value of assets: the possibility to be affected by a natural disaster largely influences the value of local assets. Hallstrom and Smith (2005) for example, quantified the impact of hurricane risk perception on housing value in Florida and they find that hurricane risks reduce property values by 19%.

Until now, the analysis of the economic impacts generated by climate change related events have been focused in two main areas. The first one is the estimation of the short-term effects generated by unexpected events in a specific region. The second one is the quantification of the long-term economic variations generated by disasters or adaptation strategies. In both cases, negative economic effect normally occur through losses in primary production factors, as human resources, physical capital, infrastructure, land endowments and productivity. In the case of long terms analysis, however, some positive correlations have been found between economic growth, damages and adaptation (Hallegatte and Ghil, 2008; West and Lenze, 1994). Results obtained by Skidmonre and Toya (2002), for example, indicate that climatic disasters may provide an opportunity to update capital stock, to adapt new technologies or to increase total factor productivity. In a similar way, Okuyama (2011) estimated that after the initial negative impact, the Kobe earthquake generated positive economic gains resulted from changes in the economic structure of Kobe and from increasing demand for recovery and reconstruction.

However, both in the short and in the long term analysis, the main impacts generated on the supply chain have been largely ignored by literature. Even the assessments provided by the Intergovernmental Panel on Climate Change and the main discussion around adaptation, still ignore the domino effects on the global markets (Levermann, 2014). Climate change related events in general, and natural disasters in particular, have multiple impacts. Beyond the costs in terms human life and infrastructure, they also affect the functioning of the economic system leading to domino effects on the entire global system (Peeling et al., 2002; Lindell and Prater, 2003; Rose, 2004; Hallegatte and Przylusky, 2010; Hallegatte, 2014). Economic costs related to reduction of the value added of production can be directly due to the destruction of capital and infrastructure or to the indirect effects generated on the system of supply and demand. Interruption of water, electricity, communication and transports together with damage on production structures are some of the main elements determining a temporary collapse in the economic system of the affected area (Kroll et al., 1991; Tierney, 1997; Gordon et al., 1998; Tsuchiya et al., 2007). This production shock and the consequent bottlenecks generated on the supply chains is the responsible for the economic effects generated in other world areas (Henriet et al., 2012). Evidence from disasters show that domino effects can represent a significant share to the total cost (Kroll et al., 1991; Tierney, 1997; Gordon et al., 1998; Haimes et al., 2005; Rose et al., 2005). Their quantification, together with modelling exercises oriented to forecasts the cascading effects along the supply chain, is fundamental for risk management design (Haimes, 2004; 2012).

International consensus exists on idea that a good understanding of the global supply chain and a reliable identification of the most vulnerable entities is essential to reduce and mitigate the economic costs generated by climate change. To do that, a combination between climate modelling and data, together with analysis on the intra-regional and intra-sectorial links between activities is urgently needed. At the present stage, however, the lack of up-to-date international databases able to capture the trade relationships between countries and sectors, and the consequent limited use of inter-regional models make it difficult to estimate the cascade and domino effects resulting from disruptions in the international supply chain (Arto et al., 2014). In addition, the large data gap existing for developing countries and small island developing states, where climate change related events are expected to generate large catastrophic impacts, make even more difficult to estimate the global economic costs. In a context of low information and large uncertainty the identification of costs is extremely difficult. However a clear understanding of the possible consequences is a fundamental element in the planning of effective adaptation and risk management strategies (Mirza, 2003).

The present report provides an overview of the main studies, methodologies and databases used to investigate the climate vulnerability of the supply chain. The report is structured as follow: section 2 reviews the main international literature on climate vulnerability of the supply chain. Agriculture and fisheries, food production, industrial sector, infrastructure and overall economic system are the main sectors considered in this report. Section 3 summarizes the main indexes and indicators used to identify the costs and vulnerabilities of the supply chain. Sections 4 and 5 present the main methodologies and databases that can be used to estimate the direct and indirect effects generated by climate change related events. In section 6, some possible future developments are reported together with conclusions.

2 Review of the literature and experiences

The largest parts of analysis oriented to quantify the direct and indirect effects generated by climate change related events have been focused on developed countries and a minor number of analysis have been oriented to identify the costs and the cascading effects on developing ones. The main reasons can be explained by a combination of different factors, namely (Accenture, 2013; World Bank, 2010):

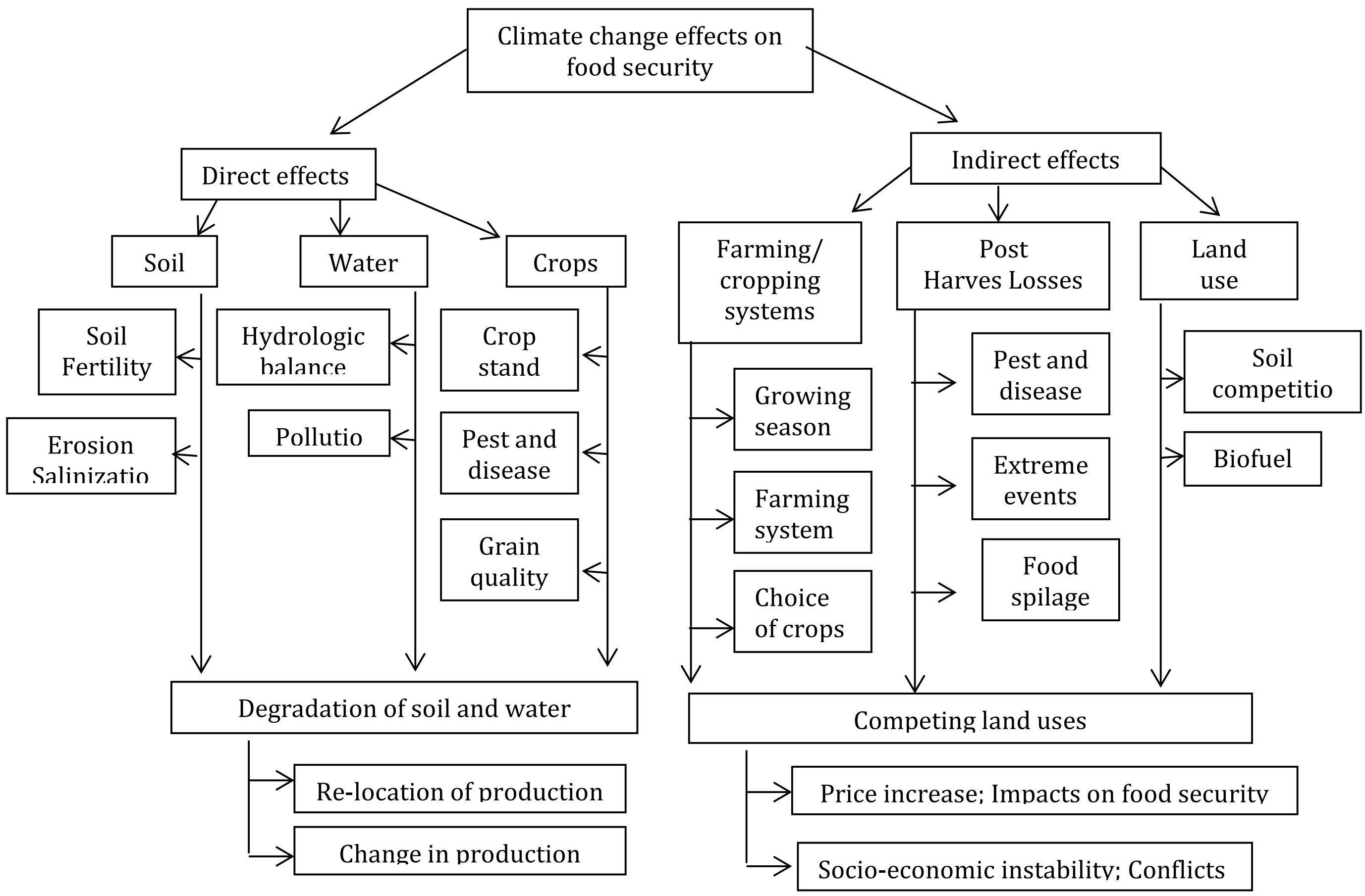
1) In-availability of reliable data on capital losses, magnitude of economic activities, and relationships between industries and sectors;
2) Lack of policy maker's interest;
3) Difficulty to model the long-term economic structure, particularly when macroeconomic conditions are largely dependent from other variables as for example political (in) stability or debt burden.

In this section the main studies oriented to investigate the impacts on the supply chain are reported. However, since climate change related events can affect different stage of the supply chain the impacts generated on different economic sectors will be considered. In particular, the attention is focused on a) agriculture and fisheries; b) food production; c) industrial sector; and d) infrastructure. An overview of the studies that investigated the impacts on the overall economic system is also provided.

2.1 Agriculture and fisheries:

Weather and climate conditions play a major role in agricultural productivity. Despite the technological improvements achieved in the last century agriculture remains one of the most vulnerable sectors to climate change. Food and natural resources availability are fundamental elements for development and stability, influencing peace, livelihood security, human health and economic growth (FAO, 2009; FAO, 2009a). Climate change related events can affect agricultural productivity and generate impacts on food security, economic costs and social instability. Price variations, relocation of productions and increasing uncertainty on productivity could have important impacts in terms of poverty and conflicts, particularly in developing countries. In Figure 2 some of the main direct and indirect effects generated by climate change related events are reported (Lal, 2013).

Figure 2: Food security – direct and indirect climate change related effects



The largest part of climate change literature agrees on estimating that low-latitude and developing countries are expected to be more adversely affected by natural disasters, agricultural disease and productivity reduction. High-latitude countries, on the contrary, could obtain some benefits in terms of crop production increase. If these scenarios will result to be true, the consequences for rural communities in developing countries, where agriculture is the main sector contributing to employment and GDP and where the largest share of family income is already spent on food, could be devastating (IPCC, 2012; Miraglia et al., 2009).

Being aware of that, an increasing number of studies have been oriented to investigate the possible consequences generated by climate-change related events on food security, prices and socio-economic stability. In order to do that, two main interrelated research areas need to be developed:

1) The first one is the quantification of the possible impacts that climate change related events generate on agricultural production.
2) The second one is a clear understanding of (i) the complex and interrelated relationships existing between agricultural sector and other economic activities; (ii) the links between different world regions.

Integrated analysis need to be performed across the two research areas. Starting form a quantification of the possible impacts generated in a specific region and production, an estimation of the cascading effects on the other economic sectors and regions can be performed. In order to do that, both partial and general equilibrium models have been used.

The partial equilibrium models used to identify the agricultural impacts of climate change can be grouped in three main categories, namely:

- Crop simulation models: are oriented to investigate crop performances under different climatic conditions and different level of CO_2. Since they are performed in specific fields or laboratories, they are not able to include and simulate the farmer adaptation strategies. For this reasons, the crop simulation models generally tend to overestimate the consequences generated by climate change (Mendelsohn and Dinar, 1999).

- Agro-economic zone (AEZ) models: investigate changes in crop production by combining crop simulation models with land management decision analysis. Staring from a classification of the existing lands based on different agro-ecological zones, AEZ investigates performance by considering variations on temperature, precipitation and soil characteristics. To take into account the consequences of adaptation, different levels of inputs and management conditions are also considered (Cline, 2007).

- Ricardian models: are cross-sectional approaches that investigate the relationships between productivity and climate variables based on statistical data from farm survey or country/regional data. Ricardian models can include climate change adaptations but are unable to account for price variations or for other economic influences (Cline, 1996).

Estimating the variations taking place on crop production, partial equilibrium models are generally used as a starting point to quantify the impacts that climate change related events can generate in a specific region/market/sector/activity. However, by ignoring the links with other socio-economic sectors, they are unable, by themselves, to quantify the consequences generated along the supply chain. General equilibrium modes can be used for that. By considering the relationships between different regions/markets/sectors/activities they are oriented to investigate the impacts that a specific variation generates on the overall economy (Nunes and Ding, 2009). To assess the consequences of climate change on agriculture, two main CGE approaches have been used:

- Integrated assessment modes: they combine CGE model with a partial agricultural land use equilibrium model.
- Improve the modelling of land use and land productivity within the CGE framework.

Both of them generally use different elasticity of substitution to investigate the socio-economic consequences of the allocation of lands for different uses. Palatnik and Roson (2009), for example, used a dynamic multi-regional CGE model to investigate land productivity variations in eight world regions between 2001 and 2050. India and China result to be largely affected by productivity decrease.

The combination of general equilibrium models and geographic information system (GIS) is also used to analyse the impacts that variations on regional productivities generate on prices, both at local and at global level. Darwin et al. (1995), for example, used a future agriculture resource model to evaluate the impacts on agricultural production and prices. By considering eight different world regions and by disaggregating land into six categories based on the length of the growing season, the author highlight that costs and benefits of climate change vary across area. In particular, high-latitude regions and some mid-latitude, as Japan and some Asian regions, are expected to increase productivity, on the contrary, tropical regions are expected to be largely affected by climate change variations.

Other examples of modelling approaches include the Kleines Land Use Model (KLUM) proposed by Ronneberger et al. (2008) that combine a CGE model and a partial agricultural land use model. Based in an optimization function on which farmers maximize profits for each unit of land, the model investigates the impacts of climate change on global cropland allocation. Main findings show that yield losses in China, United States and South America would be compensated by price increases.

Different sets of global and regional climate models (CGM and RCM) have also been used to quantify the impacts on agricultural sector (Olesen et al., 2007; Christensen et al., 2007).

To estimate the possible socio-economic consequences generated by climate change related events on primary production, "bottom up" or "starting point" approaches have also been used. The main objective is to identify the processes and conditions that determine the exposure and the coping capacity of a considered system (Downing, 2003; Polsky et al., 2003). Pittman et al. (2011), for example investigated rural community vulnerability to various types of climatic conditions. The case study focused on the Canadian region of Saskatchewan, characterized by an agricultural-based economy. The objective was to investigate how adaptation strategies could reduce the negative impacts generated by climate change. Main findings highlight that policies and institutions play a fundamental role in costs mitigation both in the short as well as in the long term. In addition, the ability to change the local management attitudes based on the trends of the global commodity markets seems to be another important factor to reduce local vulnerability and to minimize the cascading effects on the global supply chain.

Olesen et al., 2011 performed a similar study for 13 environmental zones (EZ) in Europe. A set of qualitative and quantitative questionnaires on perceived risks and foreseen impacts of climate change have been collected to identify: 1) main vulnerabilities of crops and cropping systems; 2) climate change impacts on the production of nine selected crops; 3) possible adaptation strategies and adaptations already adopted. Main results shows that understand the regional differences and the local production possibilities is a fundamental factor in designing effective adaptation strategies. These survey exercises can be particularly useful for decision support systems (DSS).

In spite of a large number of studies investigated the impacts generated by climate change on agriculture, a relatively little work has been made to identify the links and the consequences across regions and sectors (Maracchi et al., 2005). To analyse the system responses and the relationships that exist at different levels of the supply chain is a fundamental step to plan effective management strategies. A recent example is provided by Paterson et al. (2013) that investigated how climate variations affect palm oil production in tropical areas. The increasing fungal diseases generated by temperature and humidity changes could represent a serious constraint for many industrial processes, as for example food, pharmaceuticals, cosmetics and biodiesel production that use pals oil as primary source of vegetable oil (Paterson et al., 2009). The analysis proposed by Paterson et al. (2013) is useful to identify the links existing between different economic sectors located in different world areas. However, the study doesn’t quantify the overall economic costs generated on economy. Other similar works focused the attention on different tropical crops, as for example, sugarcane, coffee or coconut (IPCC, 2012; Ghini et al., 2007; Ghini et al., 2011). All of them agreed in considering tropical areas particularly vulnerable to climate change related diseases.

Some studies have also been devoted to investigate the vulnerability of small island developing states (SIDS) and to quantify the economic costs generated on fishing industry. Fisheries-dependent small island economies are in fact particularly exposed to fish stock variation generated by climate change. Alteration of water temperature, ocean acidification and decline in dissolved oxygen are some of the main factors influencing fish availability (Guillotreau et al. 2010). The decline in fishing activity, the consequent reduction in jobs and rents, together with lower collection of zonal access fees are some of the main economic impacts directly linked to stock availability and distribution. On literature different methodologies have been used to quantify the costs generated by stock reduction and migration. The drop of payment for zonal access, for example, has been used as a proxy of economic impacts generated by climate change. Since zonal access fees represent a significant part of the public budget of several SIDS (53% for Kiribati, 27% for Marshall Island and 10% for Tuvaly and the Federal States of Micronesia (Gillett, 2009)) the large reduction in fees collection represent an important element influencing vulnerability of small island economies. Indicators on climate anomalies, as the “Indian Ocean Index” have also been used as predictors of shifts in economic regimes (Robinson et al., 2010). Economic data on vessels expenditures for fuel, agency and port fees or water stevedore, have also been considered to quantify shifts in fishing activity (Menard et al., 2007).

Costal aquaculture is another important developing countries economic sector that results to be largely affected by climate change. The export-oriented activity of shrimp farming in Bangladesh, for example, has been largely damaged by intensification of extreme weather events. See level rise, cyclones, saline water intrusion, floods and droughts are just some example of the climate change related events influencing productivity of one of the key sector of Bangladesh economy (Ahmed et al., 2013). Since about two-third of the country is less than 5 m above the sea level, a 1 m sea level rise would affect the largest part of shrimp production (World Bank, 2000; Dasgupta, 2011). In addition, the soil and groundwater salinity are predicted to affect the largest part of rice productivity with enormous impacts not only for the Bangladesh economy but also for the sectors using shrimp and rise as production factors. The reduction of employment and rent and the consequent impact on consumption could also have severe effects on other economic productions and reduce the level of imports-export activities (Ali, 2006). In table 2 a review of the main impacts that climate change related events can generate on agriculture and fishing is reported together with some historic examples.

Table 2. Examples of hazards and risks to the safety of products produced by the agricultural and fisheries sectors imposed by climate extremes and other severe weather and hydro-meteorological events

Event	Objects targeted	Hazard	Risk	Historic example(s)
Land-and mudslides	Landfill, mine tips, tailings dams	Contamination of surface water and agricultural land with contaminants contained/deposited by the masses (e.g. mud) released by the slide	Contamination of water organisms used as food, crops grown on contaminated soils	Baia Mara (Romania) tailing dam failure in 2000, leading to release of large quantities of cyanide and heavy metals into local waterways and a major European river (Cunningham, 2005)
Drought	Crops infected with moulds, water reservoirs	Stressful conditions leading to aflatoxin formation by moulds; concentration of contaminants of pathogens in surface water	Contamination of harvested crop commodity with aflatoxins; contamination of irrigated crop or caught fish	Aflatoxin contaminantion maize in Eastern Kenya in droughful years (Daniel et al., 2011); Increased contaminant loads in US lake serving as drinking water reservoir (Benotti, et al., 2010)
Heat waves	Crops infected pre-harvest with moulds	Combination of high temperatures and either drought or humidity that favour aflatoxin and ochratoxin A formation in crops	Contamination of harvested crop commodity with aflatoxins and ochratoxin A	Infection of maize in Northern Italy with *Aspergillus flavus* and aflatoxins following a heat wave in 2003 (Giorni, et al., 2007)
Floods	Agricultural lands in flood plains	Flood water containing pathogens and contaminants that are deposited on the flooded land after retraction of the water	Contamination of crops consumed by humans and animals; and of pasture used for grazing; Infection of food-producing animals with zoonotic pathogens	Higher levels of heavy metals in flood deposits on agricultural land that in the underlying soil following river flooding (Albering et al., 1999)
Heavy precipitation	Seafood organisms and irrigated crops	Contact with freshwater containing runoff with pathogens, contaminants and nutrients, caused by heavy precipitation	Contamination of irrigated crops with pathogens and contaminants; Infection of seafood-producing organisms with human pathogens; Stimulation of harmful algal blooms or cyanobacteria by nutrients	Increased likelihood of contamination of mussels (used as indicator organisms) with *Cryptosporidium* in Californian costal waters following heavy precipitation a week before sampling (Miller et al., 2005)
Tropical storms	Crops and animals grazing on pastures in areas flooded by storm surge	Deposit from the storm surge may contain pathogens and contaminants	Contamination of crops and products derived from livestock residing in the flooded areas	Increased levels of pathogens and contaminants in areas flooded after hurricane Katrina (Abel et al., 2010; Fox et al., 2009; Rotkin-Ellman et al., 2010)

Source: Marvin et al., 2013

2.2 Food production:

Food availability, especially in the wealthier parts of the world, dependents on a network of producers, distributors, processors and retailers that move products from farm to plate. The large complexity and the interrelated grid, make the food production system largely vulnerable to any shock or disturbance that may emerge both in the short and in the long term (Fraser et al., 2003; 2005). Climate change may affect the food supply-chain in many different ways (Gregory et al., 2005). Variation in soil, water, crop productivity or animal production could generate favourable effects in some areas and large production decline in other regions (Hatfield et al., 2011). Alteration of water resources, hydrological balance and change on temperature are responsible for soil erosion and disease. Extreme events as floods and droughts, cyclones or windstorm can largely affect the occurrence of food safety hazards and increase uncertainty related to agricultural production and costs (IPCC, 2012). Since food sector relies on ecosystems' ability to provide resources, the impacts generated by climate change can be large and costly. In addition, hazards can arise at various stages of the food chain, from primary production, to transport, transformation and consumption, making difficult to estimate impacts and to plane effective management strategies. The health implication of food insecurity as poor nutrition, premature death or diseases have been considered as one of the main negative impacts generated by climate change, particularly in poor and developing countries (WHO, 2012).

On literature, different studies have been oriented to quantify the consequences generated on specific productions or in specific regions. The cascading effects generated on food security have also been considered (Miraglia et al., 2009; Paterson and Lima, 2011; Tirado et al., 2010; Tubiello et al., 2008). Schmidhuber and Tubiello, (2007) identified four man dimensions of food security that could be affected by climate change, namely: food availability, stability of food supplies, access to food and food utilization.

Food availability and access are mainly influenced by productivity variation and price change. Reductions of income from animal and crop production as well as increased costs are some of the main risks for developing areas (FAO, 2009). Climate change, influencing stability of primary production, also affects food manufacturing and trade. In addition, the rising average temperatures can increase the hygiene risks associated with storage and distribution. The increasing energy required for refrigeration and the consequences of energy demand could be positive from an economic perspective, but could generated increasing costs in terms of emissions and natural resource depletion (Cline, 2007).

All these impacts have been considered on literature, however, a limited number of analysis have been specifically devoted to quantify the economic impacts related to food affordability, purchasing power or prices (Ericksen, 2008a, 2008b; Gregory and Ingram, 2008). The socio-political conflicts generated by increasing competition for water, food and natural resources need also to be better investigated.

2.3 Industrial sector

Recent studies have been oriented to quantify the production capacity loss rate (PCLR) of industrial sectors damaged by a disaster or by climate change related events. The PCLR is an important source of information to quantify the magnitude of economic disruption in a specific economic sector and the consequences generated on the economy as a whole. Production capacity (PC) refers to the production ability on the supply side and it is different from output.

According to Rose (2004) PC can be both affected by direct damages and by higher order effect, as for example lifeline or supply chain disruptions. Natural disasters generate complex sources of damage as for example buildings and infrastructure disruption or supply chains interruption among economic sectors and regions (Kajitani et al., 2013).

The two main causes of capacity losses are: 1) damage to production facilities and 2) disruption of lifeline system. IO models can be used to apply restrictions of production capacity and quantify the consequent losses. However, a very limited number of studies have been focused on PCLR estimation model.

In a recent paper, Kajitani and Tatano (2014) specifically propose a model for PCLR estimation. By considering inter-related vulnerabilities of business in a context of multi-hazards (earthquake, tsunami and nuclear accident), the model estimates the PCLR generated by the 2011 Japanese Earthquake. Specific data on the facility damage and lifeline disruptions have been considered to quantify the effects across different types of sectors[6]. Results show that refineries, steel, paper and pulp sectors suffered the largest damage. Mainly located along coastal areas these economic activities have been largely affected by tsunami inundation. In a similar way the food industry, and in particular the fish processing industry, resulted to be largely affected.

2.4 Infrastructure

The analysis of the climate change related events and the consequent impacts on infrastructures include a series of studies oriented to analyse disruption in crucial intermediate sectors of the supply chain, as for example transport, communication, energy and water. Infrastructures are generally defined as a set of interdependent networks used to provide reliable flows of products and services essential to maintain the functioning of a socio-economic structure (Sheffi, 2005).

The Joint Research Center of European Commission, within the framework of the European Programme for Critical Infrastructure Protection (EPCIP), is developing models and tools to investigate the economic consequences of infrastructure damage generated by different types of hazard. According to the Council Directive 2008/114/EC the "European Critical Infrastructure" is defined as:

"an asset, system or part thereof located in Member States which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-

[6] The survey has been conducted by Nakano et al., (2012) and it has been specifically oriented to quantify the facility damages and the employee losses for 2,669 business activities, disaggregated between 777 manufacturing industries and 1,892 non-manufacturing industries

being of people, and the disruption or destruction of which would have a significant impact on at least two Member States" (European Council, 2008).

Electricity, oil and gas, together with different types of transports, as road, rail, air, inland waterways and shipping, are included in the classification. To investigate the possible consequences that critical infrastructure failures could have on European economy, Jonkeren and Giannopoulus (2014) recently developed an inoperability input-output model (IIM). Starting from the inoperability-IO model (IIM) proposed by Santos and Haimes (2004), and considering the dynamic extensions oriented to include the effects of recovery and inventories (Haimes et al., 2005; Barker and Santos, 2010), the model investigates how the recovery path depends on the type of shocks. It also refines the concept of inventory as a measure of resilience.

Other analyses have been specifically oriented to investigate failures on energy and transport. According to the World Trade Organization, transport is a key element of the global logistic system. The world's container-shipping capacity, for example, tripled in the last decade and it is expected to increase as a consequence of globalization (UNCTAD, 2012). The ability to identify the parts of the chain that are more prone to disruption and the possibility to have flexible transport-distribution system are critical step in managing the frequency and impact of disruptions (Trkman and McCormack, 2009). By considering that around 80% of the world trade volumes are carried by maritime transportation, ports and shipping constitute critical links in the global supply chain (Ng and Liu, 2010). Being pivotal in international trade and acting as the gateways for local consumption and land transport, ports have been particularly analysed on international literature. Ng et al. (2013) for example considered four ports in Australia to investigate the possible costs and the different adaptation strategies that could be adopted to reduce impacts of climate change. Stenek et al. (2011) used the Terminal Maritimo Muelles el Bosque in Colombia to assess the potential implication of climate change for shippers and ports. More recently Nursey-Bray et al. (2012) performed a vulnerability assessment for the ports in the Australian States of Victoria and Tasmania. The focus of these studies however is predominantly on physical aspects, on engineering solutions or on management strategies. A large gap exists on the quantification of the costs that a shock in transport or port activities could generate in the global supply chain.

The impacts of climate change on water and energy sectors has been analysed by different studies. Pryor and Barthelmie (2005) investigated impacts on wind energy production. Kopytko and Perkins (2011) examined the several ways in which climate change may affect nuclear power plants. Lucena et al., (2009) looked at how changing climate conditions affect hydro and wind power generation. Mideksa and Kallbekken (2009) investigated the impacts on electricity and Rose et al., (2007) analysed the costs of a two-week blackout due to a potential terrorist attack in Los Angeles[7]. In Table 3 some of the most important studies oriented to investigate the climate change effects on energy sectors are reported. Water and electricity play a fundamental role in the system of production, distribution and consumption. Different attempts have been provided on literature to analyse the possible impacts generated on the local and on the global economic system by disruption generated by socio-economic or natural events.

The largest parts of these studies, however, are based on different methodologies and approaches. This generates different costs estimation, different recovery and different adaptation strategies. In addition, the large uncertainty on the magnitude of the events, on the transmission mechanisms and the multi-dimensionality in disaster impacts make difficult to have accurate estimations

[7] They estimated an approximate $250 million loss of production and a total costs of about $13 billion.

Table 3. Climate change related impacts on energy systems

Energy sector	Climate related events	Related impacts	Literature review
Thermoelectric power generation (natural gas, coal and nuclear)	Air/water temperature; wind and humidity; extreme weather events	Cooling water quantity and quality; cooling efficiency and turbine operational efficiency; erosion in surface mining; disruptions of offshore extraction	Kopytko and Perkins, 2011; Sathaye e tal., 2011; Shaeffer et al., 2008
Oil and gas	Extreme weather events; air/water temperature; flooding	Disruption of offshore extraction; disruption of on-shore extraction; disruption of production transfer and transport; disruption of import operation; downing of refineries; cooling water quantity and quality in oil refineries	Harsem et al., 2011; Burkett, 2011
Biomass	Air temperature; precipitation; humidity; extreme weather events; carbon dioxide levels	Availability and distribution of land with suitable edaphoclimatic conditions (agricultural zooning); desertification; bioenergy crop yield	Fenger, 2007; Siqueira et al., 2001; Lucerna et al., 2009; Pinto and Assad, 2008
Hydropower	Air temperature; precipitation; extreme weather events	Total and seasonal water availability; dry spell; changes in hydropower system operation; evaporation from reservoirs	Fenger, 2007; Vicuna et al., 2005; 2008; Lehner et al., 2005;Harrison and Whittington, 2002; Whittington and Gundry, 1996; Munoz and Sailor, 1998; Limi, 2007
Demand	Air temperature; precipitation	Increase in demand for air conditioning during the; decrease in demand for warming during the winter; increase in energy demand for irrigation	Brown et al., 2000; Fenger, 2007; Siqueira et al., 2001; Lucena et al., 2009; Pinto et al., 2008
Wind power	Wind and extreme weather events	Changes in wind resource (intensity and duration); changes in wind shear; damage from extreme weather	Pryor and Barthelmie, 2010; Lucena et al., 2010; Sailor et al., 2000; Segal, 2001; Breslow and Sailor, 2002; Pryor et al., 2005; Sailor et al., 2008
Solar energy	Air temperature, humidity and precipitation	Isolation changes (cloud formation); decrease in efficiency due to decrease in radiation; decrease in efficiency due to ambient conditions	Fenger, 2007
Geothermal	Air/water temperature	Cooling efficiency	
Wave energy	Wind and extreme weather events	Changes in wave resource	Harrison and Wallace, 2005
Energy transmission	Temperature rise Mud flows, floods, landslides, heavy precipitation and strong winds	Changes in supply	Sathaye et al., 2011; Vlasova and Rakitina 2010; Karl and Melillo, 2009

Source: Shaeffer et al., 2012

Since facilities for energy production, transformation and distribution can be affected both in the short as well as in the long term several analysis need to be performed to investigate the possible impacts generated by climate change and to plane effective adaptation strategies.

2.5 Overall economic system

Increasing attention is devoted to identify the economic impacts generated by climate change on economic system as a whole. The main transmission mechanisms and vulnerability is a fundamental element to increase sustainability in the supply chain and to reduce the costs generated on business and consumers (Wing and Lanzi, 2014). The largest part of analysis, however, focus on the impacts generated on developed countries and minor attention has been devoted to developing ones. In a recent study published by Oxfarm (2012) the costs of climate vulnerability of the supply chain have been investigated for three case studies related to small-scale farmers in developing countries. The first one focuses on coffee production in Colombia; the second one on sesame in Nicaragua and the last one on cotton in Pakistan. Extreme weather conditions, declines in yields productivity, quality reduction and increasing production costs, mainly related to greater need to combat pests and disease are some of the main climate change related events that affect coffee, sesame and cotton production. The large vulnerability of the production system has been the most important factor generating price and supply variation both on the local and in the global market. In recent years, for example, the price instability of cotton largely influenced textile manufactures and producers worldwide. After the flood that devastated large productive land in Pakistan, the price of cotton increased from $0.65-0.70 per pound of cotton in 2009 to $2.48 in 2010, with large costs both for producers and consumers.

According to a recent reports published by Accenture (2013), OECD (2009) and McKinsey (2008), companies are aware of the considerable direct and indirect risks that climate change poses to their activities. For this reason a large number of them are already planning or adopting strategies to reduce the vulnerability linked to shortage in the supply-production chain. Starbucks, Marks & Spencer and the Body

Shop are examples of companies that, together with producers in developing countries implemented a set of initiatives to reduce the climate change vulnerability. Diversification of production, environmental conservation, helps in recovery form unexpected events and increasing amount of stock in reserve are some examples of the adopted strategies (Oxfarm, 2012)

To quantify the economic impacts generated by unexpected events two similar models have been used by Hallegatte to estimate the costs generated by the 2005 hurricane Katrina in Luisiana. In a paper published in 2008, Hallegatte used an input-output model specifically design to take into account the sector production capabilities and the adaptive behaviours. The main objective was to estimate the forward and backward effects generated within the economic system. The main findings of the paper show that indirect losses had a nonlinear increase with respect to direct losses when the latter exceed $50 billion. When direct losses exceed $200 billion, for instance, total losses (calculated as the sum between direct and indirect losses) are estimated to be twice as large as direct losses. On the contrary, when direct losses are lower than $50 billion, aggregated indirect losses are close to zero. From a risk management perspective the results provided in the paper support the idea that the quantification of direct costs is insufficient to plane and manage the consequences of disasters. In addition, propagation effects generated within the economic system need to be taken into account in order to identify both the negative and the positive impacts on production capabilities, reconstruction and adaptation. Disparities between economic sectors, social categories and geographical zones are also an important element that has to be taken into account. In a more recent paper, published by Hallegatte in 2014 a modified version of the Adaptive Regional Input-Output model (ARIO) proposed in Hallegatte 2008 has been used to re-quantify the cost of Katrina. The main objective was to investigate the variation in the estimation of the total costs generated by the introduction of inventories. The main consequence of this modelling approach is that an interruption in stackable-goods sectors does not have immediate impacts on other sectors. By introducing a more flexible approach, able to consider the stocking capabilities of specific economic sectors, the total costs of Katrina in Luisiana have been found to be lower than in the modelling estimation provided in 2008. In particular, the indirect economic losses in Louisiana have been quantified to be around $11 billion, compared to the 42$ billion estimated in 2008. The main dynamics effects included in the model consider that just after the shock the production is reduced by capital destructions, as for example inoperability of equipment, factories or infrastructures. No sectorial interactions are assumed to take place in the very short term. However, the reduction in inventories rapidly generates sectorial bottlenecks responsible for a drop in the overall production. After about 10 months the affected sector stops to be the main responsible for decreasing output and the transportation becomes the main factor limiting the production process. In the long terms, however, the increasing demand linked to process of reconstruction generates a total output higher than the total output before the crisis.

Different analyses have also been performed to quantify the total costs generated by climate change and to assess the possible benefits from adaptation strategy. The Stern Review Report (2006) is a very famous example. It has been specifically oriented to compare the costs and benefits related to GHG emissions variation. By considering the cost of emission abatement and by quantifying the possible impacts on crop and water availability, malnutrition and heat stress, risk of flood, see level rise and ecosystem damage, among other, the Stern Review conclude that the stabilisation of the level of GHGs in the atmosphere is less expensive that the negative impacts generated on ecosystem and society. In spite of the notable successes achieved by the Stern Review Report, some errors, limitation and misleading estimations have been reported on literature (Byatt et al., 2006; Carter et al., 2006). Pielke (2007a), for example criticized the Stern Review based on the fact that the costs of climate change for developed countries resulted to be overestimated by: 1) a misrepresentation of the scientific literature; 2) the assumption that society will not change in response to climate variation. The Stern Review's methodological error seems to be based on the fact that *"rather than telling the reader what losses might be expected in the future, the Stern Review's results instead indicate the effect that future climate change would have on today's world GDP"* (Pielke, 2007a, pp. 307). As a possible methodological solution Pielke suggest to perform an integrated sensitivity analysis oriented to investigate the costs of climate change related events under conditions societal changes. In particular, various combinations of climate events and social organizations could be considered to have a better overview of the possible economic impacts (Pielke, 2007b).

In order to identify the economic sectors and the geographical regions that can be mostly affected by climate change related events, a set of indexes and indicators have been developed. In the next section some of them are reported.

3 Indicators and indexes

Indexes and indicators are generally used in economic, social and environmental analysis to describe and simplify complex system characteristics in a quantitative or qualitative way. The use of indexes and indicators enable comparative analysis and support decision makers both in management and in policy definition (Adger, 1999; Brikmann, 2006; Bebbington, 2007; Munda and Saisana, 2011).

During the last decades a large set of indexes and indicators have been used and proposed to quantify the climate change risk of different economies, areas and societies. The Global Climate Risk Index, the World Risk Index or the Global Adaptation Index are just some examples of index used to rank the magnitude of climate change impacts in different world areas[8]. In every one of them, analysis on vulnerability, adaptability, resilience and exposure are performed to provide estimations of the consequences of climate change.

A minor number of indexes and indicators have been specifically oriented to quantify the risks of different economic sectors or to identify the vulnerability of specific supply chain organizations. The Functional Fragility Curve or the Vulnerability Index for Post-Disaster Key Sector Prioritization, the Climate Change Risk Management, the Indicator Framework for Indirect Industrial Vulnerability Assessment, the Integrated Indicator Framework for Spatial Assessment and Social Vulnerability to Indirect Disaster Losses and the Supply-Chain Vulnerability Index are some of them:

[8] For a detailed analysis of the different index see Miola and Simonet, 2014

1) **Functional Fragility Curve (FFC):** has been originally proposed to quantify the capacity loss generated by earthquakes, but it can be extended to other kinds of disasters, as for example geological, geopolitical or climate change events. The Functional Fragility Curve describes the relationships between the size of the hazard and the damage probability. It is a widely practiced approach to estimate vulnerability from multitudes of uncertain sources. The Functional Fragility curve is usually estimated by using nonlinear dynamic analysis and business survey data on past disasters. The maximum likelihood procedure and the Bernoulli experiments are generally used to quantify the values of the fragility parameters. The main characteristic of the FFC is that it is not estimated based on asset value but it is constructed considering the level of production capacity of a specific economic system. Using data on the maximum production level and by applying constraints on the different inputs that can be affected by a disaster (as for example employees or/and resources) the Functional Fragility Curve quantify the Production Capacity Loss Rate generated by a specific disaster (Shinozuka et al., 2000; Nagano, 2011). Previous applications include the analysis of the capacity loss generated by earthquakes, as for example the 1994 Northridge or the 1995 Kobe earthquakes.

2) **Vulnerability Index for Post-Disaster Key Sector Prioritization:** it is an index that builds upon the foundations of the Input-Output (IO) model and the Inoperability Input-Output Model (IIM). It is used to identify and prioritize the key sectors in the aftermath of disaster. It is able to quantify the benefits that investments to various economic sectors could generate in times of disasters to the entire economy. Monte Carlo simulation and sensitivity analysis are generally used to investigate the impacts that decisions on investments could generate in case of disasters. The degree of failure of economic sectors is quantified on a scale from 0 (normal state) to 1 (competes failure). The main elements constituting the index are: 1) economic impact; 2) propagation length; and 3) sector size. By considering the interdependencies between sectors and the structural diversity in the economy this index is suitable to identify key sectors in times of disasters and to quantify the main benefits

generated by investments. This index can support policy makers in taking decisions on investments and can be useful to improve the efficiency of resource allocation (Danielle et al., 2014). A recent case study has been performed for the tropical storm Bopha that affected Philippines in 2012.

3) **Climate Change Risk Management (CCRM) application:** the University of Notre Dame Global Adaptation Index (ND-GAIN)[9] has recently been used to develop the Climate Change Risk Management (CCRM) application oriented to enable large corporations to quickly map and quantify global supply chain risks due to climate change. The application combines the climate indicators and the country risk ratings developed by ND-GAIN to provide maps of supply-chain risks disaggregated between different commodities. By providing maps of the country of origin of the different goods and services traded on international markets, the Climate Change Risk management application provides an assessment of the exposure to the physical impacts of climate change, The main objective is to identify which countries are best prepared to deal with climate disruptions and to identify the largely affected products and productions. It also provides maps of the country of origin of goods and services and assessment of the exposure to the physical impacts of climate change. By providing a comprehensive mapping of climate change risk for the different commodities along the global supply chain, the index will be particularly useful for industries and production activities. The application also provides data on carbon, energy and water footprint associated to the different productions and transports activities. The Climate Change Risk Management application includes data for 17 years and cover more than 175 countries (http://index.gain.org/)

4) **Indicator Framework for Indirect Industrial Vulnerability Assessment:** it allows to assess the indirect vulnerability of industrial sectors to different types of

[9] The University of Notre Dame Global Adaptation Index (ND-GAIN) is an index that ranks more than 175 countries based on how vulnerable they are to droughts, superstorms, and other natural disasters. It is based on 17 years of data and it considers 50 different variables

disasters. It is a composite indicator that combines a set of sub-indicators into a single quantitative measure. In particular, the sub-indictors considered are:

a. Production factor dependency:
- Value of production equipment
- Number of different materials
- Type of materials
- Degree of specialization of materials

b. Supply-chain dependency
- Vertical integration
- Clustering tendency
- Customer proximity

c. Infrastructure dependency
- Row materials and water consumption
- Row materials and water essentially
- Degree of row materials and water supply
- Transport volume
- Power consumption
- Power essentially
- Degree of power self-supply

The value of every indicator is obtained from literature or statistical data and the different indicators are aggregated by using a standardization process that harmonized the units in a scale from 0 to 1. Different weights can be attributed to the different indicators based on the adopted theoretical vulnerability framework. Different techniques for weight attribution can be used, as for example the analytical hierarchy process (AHP), the SWING method, the SMARTER method or the DIRECT weighting method. Multi-criteria decision techniques can also be used to identify weights and indicators to quantify the main values of the different impacts (Hiete and Merz, 2009).

5) **Integrated Indicator Framework for Spatial Assessment and Social Vulnerability to Indirect Disaster Losses:** it is an indicator oriented to combine industrial and social vulnerability to analyse the cause-effect relationships and the iterative processes existing between the social and the industrial

dimensions. The main objective is to identify how industrial losses can aggravate social vulnerability and how vulnerability in society can lead to greater impacts from industrial losses. In order to do that, the Integrated Indicator Framework for Spatial Assessment and Social Vulnerability to Indirect Disaster Losses has been specifically designed to captures the multi-layered vulnerability drivers in industrial production together with social fragility. By combining a social vulnerability index (including social inequalities, financial deprivation, lack to access to resources, absence of institutional or community organization…) and an industrial vulnerability index (including capital dependency, infrastructure dependency, labour dependency, supply-chain dependency..) the indicator identify the main fragilities generated by the interactions between social and industrial system. The possibility to map the data according to a ranking of regional and industrial vulnerabilities allows to identify the most vulnerable areas and activities. The information provided can be used to identify the regions that are in a better position to cope with indirect consequence of disasters. Data on previous disasters, expert judgements, multi-criteria decision framework and decision-making trial, and evaluation laboratory (DEMATEL) methodology can be used to identify the main vulnerabilities and the main interdependencies between social and industrial system. The indicator can also be extended to investigate the relationships between industry and ecosystem, industry and supply-chain organization or industry and environment. This methodology has been recently applied to investigate the main fragilities of 16 different industrial sector in the state of Baden-Wuerttemberg in Germany (Khazai et al., 2013).

6) **Supply-Chain Vulnerability Index (SCVI):** based on the idea that supply-chain vulnerability is the result of certain drivers and according to the fact that vulnerability cannot be observed in itself, the Supply-Chain Vulnerability Index quantifies vulnerability based on the observation of specific categories of drivers, namely: the demand side drivers, the supply side drivers and the supply-chain structure driver. For every one of them, specific elements

oriented to describe the main characteristics of the drivers are considered. The main ones are:

a. Demand side:
- Short product life's cycle
- Customers dependency
- Low in house production

b. Supply side
- Small supply base
- Suppliers dependency
- Single sourcing

c. Supply-chain structure:
- Global sourcing network
- Supply-chain complexity
- Lean inventory
- Centralised storage of finished products

The dynamic relationships between drivers and the impacts on vulnerability are modelled and analysed base on specific data from selected industries of economic system organizations. The use of graph modelling approach composed by node (or vertex) and edge (or link) allows to identify the main interdependency between drivers and the main dynamic relationships of the elements of the supply-chain (Wagner and Neshat, 2010).

These indexes and indicators can be used to identify the main areas of vulnerability of different supply chain organization and to provide a magnitude of the possible impacts generated by different kinds of unexpected events[10]. However, to calculate the direct and indirect impacts generated on local and global economies a set of methodologies and databases are needed. The next sections provide an overview of the main methods and data that can be used to estimate the costs and benefits generated along the supply chain.

[10] For a summary of the main characteristics of the different index reported in this section please see Appendix 1.

4 Methodologies

Since the pioneering work of Dacy and Kunreuther (1969) significant progress has been made in the economic analysis of unexpected events. The improved data availability, the increasing attention of international institutions and the multidisciplinary collaborations between socio-economic and natural sciences largely contributed to develop studies and techniques for disaster analysis.

The economic consequences of climate-change related events have been studied in various contexts and perspectives. The largest parts of them focus on long-term analysis and investigate the impacts generated by climate change on different elements of environment and society. Being oriented to support the planning of preparedness and mitigation strategies they are generally defined as ex-ante analysis. The largest parts of short-term analysis, on the contrary, have been carried out as ex-post investigations of actual hazards of disasters costs and recoveries of unexpected events (Okuyama, 2014).

To estimate direct and indirect effects generated by climate-change related events different methodologies can be used. In this section an overview of the main methods used to estimate the market and non-market direct impacts together with the indirect costs/benefits is provided. However, since the focus of the report is the supply chain, special attention will be paid to the data and methods presently available for indirect impact estimations.

Direct market impacts: economic theory generally identifies the value of an asset as the net present value of its expected future production. Based on this approach the costs generated in the short term by a climate-change related event is quantified as the sum of the different capital losses (e.g. factories destructions, infrastructure damages, household losses…) and the replacement value is generally used to quantify the total costs. However, change in prices generated by increasing demand and the length of the reconstruction phase can largely influence the real costs paid for capital replacement. For this reason, some authors used firm or household-level surveys to provide cost estimations oriented to include price variations and reconstruction length (e.g. Kroll et al., 1991; Tierney, 1997; Smith and McCarty, 2006). The data collected can also be useful to approximate the costs of future events or to quantify the indirect impacts generated in other sectors and areas (Boarnet, 1998). Considerable researches are generally conducted after every disaster or climate-change related events to estimate the damage to artificial structures and assets.

Non-market impacts: refer to health, to lives damages or to natural asset and ecosystem losses for which impacts estimation is not directly determined by market. The main methodologies used to determine the benefits and costs generated by unexpected events are generally based on a set of techniques oriented to attribute values to non-market elements. The Contingent Valuation, mainly defined by the Willingness to Pay (WTP) or the Willingness to Accept (WTA), the Hedonic Value Method or the Actual Value of Future Income are some examples of techniques used to attribute market value to human life or environment. Ethical issues, together with the definition of an appropriate discount rate, and the reduction of many preferences and perspective to a single market values are some of the main concerns related to these techniques (Martinez Alier et al., 1998; Funtowicz and Ravetz., 1994).

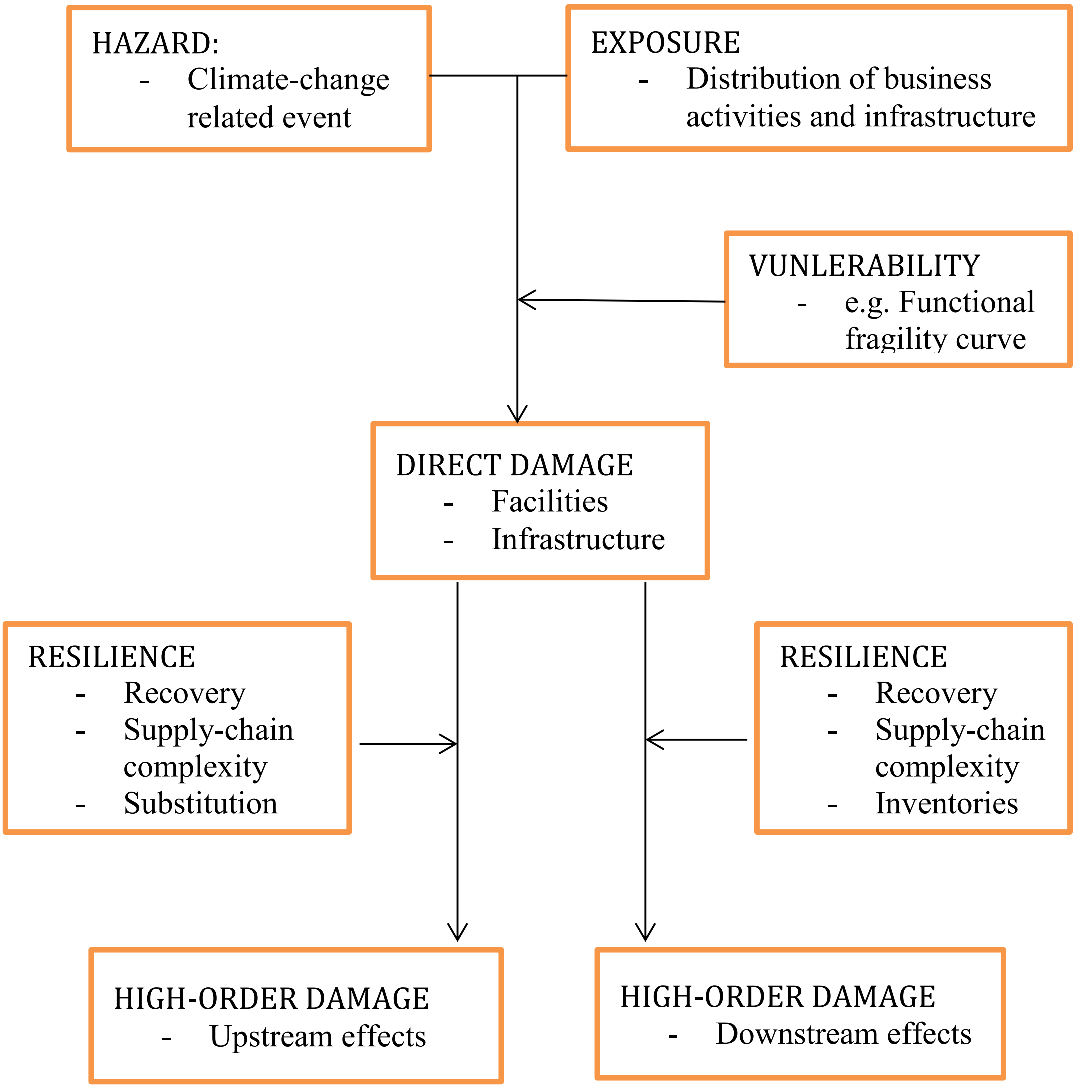
Indirect or High-order impacts: to estimate the economic impacts generated by climate-change related events and to quantify the cascade effects transmitted worldwide by the mechanisms of the supply-production chain, six main methodologies can be used, namely:

1. **Input-output (IO)**
2. **Social accounting matrix (SAM)**
3. **General equilibrium models (CGE)**
4. **Idealized models, hybrid models, public finance coping capacity**
5. **Econometric models**
6. **Bottom-up approach**

The first five are generally defined as top-down methodologies. The last one is part of the so called bottom-up strategies.

In Figure 3 a summary of the main factors and links influencing the magnitude of the direct and indirect impacts generated by climate change related events are reported. Hazard, exposure and vulnerability are some of the most important elements determining the scale of the direct impacts generated in a specific economic sector. From there, a set of indirect effects will be generated along the supply-chain. The magnitude of these upstream and downstream effects will be determined by specific supply-chain resilience and characteristics (Shinozuka et al., 2000).

Figure 3. Factors influencing the magnitude of the cascading effects of the climate change related events



4.1 Input-Output[11]

According to the definition provided by Miller and Blair, 2009: "*The input-output modelling approach consists of a system of linear equations, each one of which describes the distribution of an industry's product through the economy".* Firstly proposed in the beginning of the 1900 by W. Leontief, Input-Output (IO) systems are composed by matrix summarizing the inter-sectoral relationships existing between activities. The input and output used and produced within an economy are used to describe the links across sectors, industries, products and final consumption. Socio and environmental elements can also be taken into account to describe the existing relationships and the impacts generated by economic activities on environment and societies. Trade links between countries can be used to investigate the inter-dependency between world areas.

Input-Output analyses are generally used to:

- Analyse the interdependencies of industries in an economy (at a given point of time or over time)
- Investigate economic, social and environmental impacts generated by economic sectors and activities or by final consumption of households and government (from a static or dynamic perspective)
- Analyse trade relationships between countries and the related impacts on economy, environment and society
- Decompose/determine the main drivers causing changes over time in economic, social or environmental variables
- Investigate the economic, environmental and social impacts using scenario analysis, for example, a shutdown of an industry (short-run analysis)
- Determine the main paths (direct and indirect) of factor generation due to final consumption using structural path analysis
- Compute the volume of emissions, employment, or value added that is embodied in exports and imports which helps to better understand the global production/value chains issues

[11] A well-summarized description of Input-Output principles and techniques can be found in Miller and Blair, 2009.

The modelling approach used in Input-Output analysis is generally oriented to investigate the economic, environmental or social consequences generated by changes (or shocks) in:

- Production technologies
- Quantities produced/consumed
- The amount of resources used
- Households or government consumption
- Market based instruments (e.g., taxes) to increase sustainability
- Exports and imports of primary and intermediate products as well as final goods

Based on the idea that the production of one unit in one sector required a fixed amount of input (energy, water, natural resources, intermediate products, labour, transport and financial services…) the input-output (IO) structure is generally grounded on linear assumption. The main hypothesis is that in the short-term the production system is fixed and that total production is constrained by existing capacities, equipment and infrastructures. In addition, the largest part of IO models, have a demand-driven structure with constant technical coefficients, making difficult to model supply shocks or to introduce production dynamics. The rigid structure with respect to input, industries and import make it difficult to model price changes or substitution effects (Oosterhaaven, 1998; Haimes and Jiang., 2001; Oduyama, 2004a; Okuyama, et al., 2004; Santos, 2004). However, in order to address these problems some extensions have been proposed and specific IO models have been adopted to estimate the economic consequences generated by different kinds of unexpected events (Boisvert, 1992; Cochrane, 1997; Oosterhaven, 1988; 1989; Dietzenbacher, 1997). Well-known examples are:

1. **Risk-based models, as the Inoperability Input-Output model** (IIM) and the **Dynamic Inoperability IO models** (DIIM). They are generally used to analyse the recovery of sectors, to evaluate risk management strategies and to measure the efficacy of different preparedness options (Haimes and Jiang, 2001; Jiang and Haimes, 2004; Santos and Haimes, 2004; Haimes et al., 2005;

Lian and Haimes, 2006; Barker and Santos, 2010; Jonkeren and Giannopoulos, 2014).

a. The Inoperability Input-Output Model (IIM) specifically investigates the impacts generated by collapse of specific economic activities due to internal failures or external perturbation. It identifies the degree of failure based on a scale from 0 (normal state) to 1 (complete failure). The main objective is to quantify how the inability of a system to perform its intended functions generates dysfunction on the overall economy (Santos, 2006). Different kinds of unexpected events can be investigated by using the IIM methodology. Climate change related events, terroristic attacks or natural disasters can be some of them. To provide an example in a paper published in 2006, Santos investigates the economic consequences generated by the September 11 attack on the United States. By using input-output tables and data on demand reduction, the study quantifies the economic losses on those sectors that suffered the largest demand reductions. Another example is provided by recent study on "Risk Assessment Methodology for Critical Infrastructure Protection" published by the Joint Research Center (JRC) of European Commission (Giannopoulos, et al., 2013). The main objective is to propose a methodology to estimate the cascading effects of unexpected events. In particular, the failure propagation of a critical infrastructure network is used to quantify the economic impacts of disruption. By providing information on the most critical elements of a network, and by quantifying the main costs generated on different economic sectors the model can be used to support policy in the design of efficient risk management strategies.
b. In the Dynamic Inoperability IO (DIIO) models different resilience measures, as for example the speed of recovery and the inventory can also be included. According to Reggiani (2013) resilience refers to the ability of a system (or network) to returns to its equilibrium after a shock. The large interconnection existing in the global networks of production, consumption and trade and the uncertainty related to the

transmission mechanisms make it difficult to estimate the total economic impacts and to quantify the times for recovery (Andreoni and Duriavig, 2013). However, based on the recognition that local disruptions can affect the whole economic systems with important consequences both in the short and in the long term, an increasing number of studies specifically focused on the concept of resilience trying to quantify the ability and the time for recovery (Modica and Reggiani, 2014). In general terms, two types of resilience can be identified, namely: the static and the dynamic. Static resilience is defined as the ability of a system to maintain the main functions during and after a shock. Substitution of inputs or use of inventories is examples of that. Dynamic resilience refers to the mechanisms and to the period of time needed to recovery after a perturbation. The price mechanism and the demand-supply adjustments are classical examples of dynamic resilience (Rose, 2007; Jonkeren and Giannopoulos, 2014). Different approaches have been used to include the concept of resilience into the analysis performed by DIIO models. One of them is the use of different inventory strategy. An example of that is provided by the model proposed by Barker and Santos (2010) that extend the Dynamic Inoperability Input-Output model by incorporating different inventory options. The main objective is to evaluate the impact of inventories strategies on resilience and disruption. By using data provided by the Bureau of Economic Analysis, Barker and Santos (2010) investigate the cascading effects generated in different economic activities by temporary loss of production capacity in industry sector. The main objective is to identify the best inventory strategies able to reduce the costs and the recovery period. The main applications of the model include policy support analysis devoted to improve resource allocation strategy, budgetary constraints and post-disaster recovery enhancement. Another example is provided by an extension of the JRC model proposed by Giannopolous et al., 2013. In particular, the "restorative resilience", defined as the speed of recovery after a disruption, is included to change the static Inoperability Input-Output Model (IIM) into a Dynamic Inoperability Input-Output Model (DIIO). Based on the rate of recovery of the different economic sectors, inoperability levels and economic costs are estimated across time and sectors. The “adaptive” and the “absorptive” resilience are also be included in the model. The first one refers to the change in the speed of recovery of a sector during the recovery period. The second one is a measure of the buffering capacity of a sector. The main advantages of the model are related to the fact that the dynamic feature and the inclusion of resilience allows to provide a better estimation of the costs by taking into account process of recoveries.

2. **Integrative Approaches** in which IO models are combined with engineering models. The main objective is to estimate the direct and indirect impacts generated by disruption in the physical environment. Example includes links with transportation or lifeline network models and comprehensive disaster network models (namely: HAZUS) (Gordon et al., 1998; Cho et al., 2001; Sohn et al., 2004).

3. **Hybrid I-O and Event Tree Analysis**: can adjust the inoperability parameters to reflect successive events that can either degrade or enhance the predicted paths of sector recovery. A recent example of this approach has been adopted by Santos et al. (2014) to estimate the propagation of disaster effects across interdependent economic sectors for the case study of Nashville region in the USA. The main results of the analysis can be used to identify critical economic sectors and to plane effective policies for disaster recovery.

4. **Adaptive Regional Input-Output model (ARIO):** it is a model that has been used to quantify the cost of hurricane Katrina in 2005, to investigate the risks from floods risks in a climate change context in Copenhagen and in Mumbai and to estimate the costs of the 2008 Wenchuan Earthquake in the Sichuan region (Hallegatte et al., 2011; Ranger et al., 2011; Wu et al., 2012). The

modelling structure is based on the Sequential Interindustry Model (SIM) proposed by Levine and Romanoff, 1989; Romanoff and Levine, 1977; 1986; 1993. Inventories and specific demand dynamics are included to introduce a limited substitution capacity and to account for the heterogeneity within sectors. A similar model has also been used by Okuyama (2004), Okuyama et al., (2004) and Okuyama (2006) to include production chronology and to investigate the temporal distribution of higher-order effects from hypothetical lifeline disruptions.

5. **Regional Econometric Input-Output Model (REIM):** proposed by Donaghy et al., (2007) this model is oriented to increase the time flexibility of a sequential interindustry model (SIM) by adopting a continuous-time structure. The main advantage is the ability to accommodate to a wide range of short and long-term effects in a disaster situation. A recent example of REIM has been developed by the U.S. EPA to investigate climate mitigation policies and their impacts on regional level. In particular, the modelling exercise is suitable to investigate *(i)* how climate changes, changes in emissions and changes in global economy will impact on different regional variables; *(ii)* how long–term changes in transportation infrastructure, technology and power generation will induce regional changes in land–use, transportation, economic activities and greenhouse gas emissions. The model included causal linkages between global and regional factors between now and 2050 (http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.highlight/abstract/90460

6. **Structural Decomposition Analysis:** can be useful to investigate which factors of the economy had changed due to disasters or unexpected events. A well-structured and clear example is provided by Okuyama (2014) that investigate the factors of regional structural change related to the 1995 Kobe earthquake. This technique can be used to investigate if unexpected and catastrophic events can affect the local economy’s structure in the long-run. In addition,

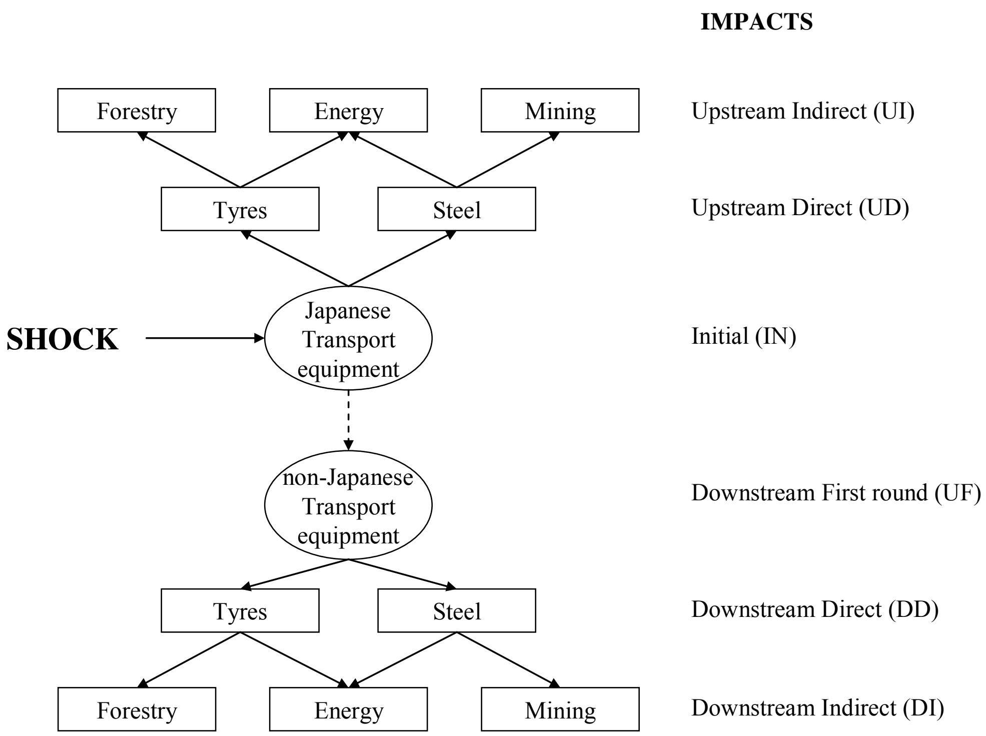
variation in final demand and positive impacts of recovery and reconstruction activities can also be highlighted by this kind of analysis.

Over the years, vast variety of IO models have been used to estimate the economic impacts generated by unexpected events such as natural catastrophes (Okuyama et al., 2004; Okuyama, 2004; Santos and Haime, 2004), energy constraints (Kerschner and Hubacek, 2009; Arbex and Perobelli, 2010) or financial crises (Yuan et al., 2010). Most of these studies, however, mainly focus on a single country/regional perspective rather than including the intra-country/regional impacts produced by the existing links on the international supply chain. Some attempts have been provided by Okuyama et al. (1999) that used a two-region interregional IO model to estimate the cascading effects generated by the 1995 Kobe Earthquake, both in the affected area as well as in the rest of Japan; or by Sohn et al. (2004) that used an inter-regional commodity flow model to quantified the hypothetical multi-regional impact of a New Madrid Earthquake scenario in the US.

The limited amount of inter-regional analyses could mainly be explained by the absence of publicly available and up-to-date inter-regional IO databases. As reported in the section on “data”, some databases exist to summarize the input-output structure of different economies. However it is difficult to have up-to-date and consistent data for all the countries and sectors interrelated in the global supply-chain.

The combined used of an Inter-Regional-Input-Output models, together with appropriate database can allows to estimate the impacts that an event can generate in different world regions and in different economic sectors. In particular two kinds of effects can be estimated, namely: the “upstream” or the “backward” effects and the “downstream” or the “forward” effects. The upstream (or backward) effects are defined as the impacts generated on the sectors that provide input to the affected activity. The downstream (forward) effects are them generated on the sectors that use the goods and services provided by the affected. In the first case the impact propagates from clients to suppliers; in the second case the effects propagates from suppliers to clients (Hallegatte, 2008). In Figure 4 an example of upstream and downstream impacts is reported. It refers to the case of disruption in the transport equipment sector and the consequent impacts on the global economy that took place after the 2011 Japanese Earthquake and Tsunami. The main objective of the graph is to highlight the cascading effects that disruption in the transport industry can generated on the global economy, broken down by industries.

Figure 4. Example of the possible impacts related to disruption in the Japanese transport equipment sector



Note: circles denote exogenous variables; rectangles denote endogenous variables, continuous arrows denote interactions explicitly captured by the IO model; discontinuous arrows denote interactions implicitly captured by the model; arrow heads denote the direction of the impacts.

Source: Arto et al., 2014

By considering the structural connectivity of economic system, input-output models have proven to be effective in quantifying economic impacts generated by disasters. However, being based on constant technical coefficients they are not suitable to estimate the long-term economic costs generated by climate change related events (IPCC, 2014).

4.2 Social Accounting Matrix (SAM)

Similar to IO models the Social Accounting Matrix (SAM) can been used to estimate the socio-economic impacts generated by climate-change related events. Describing the relationships between income, production, consumption and capital accumulation, the Social Accounting Matrix are particularly useful to analyse distributional issues and expenditures among household groups.

The data included in a SAM are generally provided by Input-Output tables, national income statistics and household surveys. In a context of climate-change related events, SAM can be used to investigate the distribution of impacts across the income categories of a specific economic system. However, being based on Input-Output structure the Social Accounting Matrix has a linear and rigid structure with no possibility to change price, supply or imports. In particular, two of the major drawbacks of a Social Accounting Matriz are: 1) prices are fixed and cannot be adjusted to reflect changes in demand and supply; 2) simulation results are largely dependent by the assumptions made on exogenous and endogenous variables.

The limited flexibility of SAM and the inability to include substitution mechanisms usually generate an overestimation of the impacts generated by climate-change related events. However, being based on a large income group's disaggregation, the Social Accounting Matrix is useful for analysis oriented to identify the relationships among activities, factors, household and institutions (Cole, 1995, 1998, 2004).

Until now a limited number of analyses have been specifically devoted to use the SAM to quantify the impacts generated by climate change on the global supply chain. An example is provided by Cole (1998) that proposed a multi-country SAM based on country-level economic data and geographic information system (GIS) to quantify the lifeline failures in the Memphis region.

Some attempts have also been devoted to develop Event Accounting Matrix (EAM) and Insurance Accounting Matrix. The first one accounts for the post-disaster costs and the recovery planning (Cole, 1998, 2004a; Cole et al., 1993). The second one introduces protection investments as a buffer for an economy to be used in case of disasters (Cole, 2003, 2004).

Some analyses have also been performed to quantify the socio-economic effects generated in specific areas. Willnbockel et al. (2008), for example, used a dynamic multisectoral modelling framework to quantify the impacts on production and poverty generated by extreme weather events in Ethiopia. The model incorporates social accounting matrix and data on regional temperature, precipitation and extreme weather. The main objective is to assess the medium-run adaptation needs and to increase the potential impacts that adaptation strategies can generate in the local socio-economic system.

Other example can be find in the list of projects promoted by the World Bank and specifically oriented to investigate the poverty implication of climate change.

4.3 General Equilibrium Models

General Equilibrium Models (Computable General Equilibrium Models - CGE) are designed to investigate the impacts generated by climate change related events on the economy as a whole. The main objective is to capture the flow-on effects of an impact in a specific region/market/sector/activity to the aggregate economic system. CGE describe the economy through the behaviour of optimising agents, the producers and the consumers, where supply and demand are regulated by markets. The adjustment process of prices is the main element used to capture and adjust the propagation mechanism induced by localized shocks.

In general terms, CGE are based on quantitative and aggregated analysis and are composed by a set of parameters that use observed economic data and assumptions to describe the relationships between economic variables. Within this structure, the economic impacts generated by unexpected and risky events can be estimated by introducing changes in exogenous variables. The shock generated and the flow-on impacts to the overall economic system can by estimated by running the model within the new shocked conditions and by assuming that changes in relative prices are able to balance supply and demand (Rose and Liao, 2005; Rose et al., 2007; Nunes and Ding, 2009).

From a theoretical perspective, two main theories are generally used in CGE to describe economic trends and to investigate costs and recoveries generated by shocks. The first one is the *real business cycle* (RBC) that assumes that economic fluctuations arise from exogenous shocks. The second one is the *endogenous business cycle* (EnBC) that considers fluctuations as endogenous process that destabilize the economic growth path. Both of them have been used on literature as macroeconomic framework for CGE (Hallegatte et al., 2007; Hallegatte et al., 2008). However, since the underlying economic assumption can strongly influence the results of a modelling exercise, a clear definition of the macroeconomic settings is needed for every one of the selected approach.

To model the impacts associated to climate change, dynamic interactions and long term perspectives need to be introduced in the modelling framework. For this reasons, CGE are generally based on a set of simplifying assumptions oriented to forecast the relationships between variables and to reduce the complex and dynamic interactions existing between economic elements and natural environment. If from one side this approach allows to provide long term estimations, on the other side, the cost paid in terms of accuracy reduction can generate uncertainty and misleading estimations (Jotzo, 2010; Hallegatte et al., 2008).

GEMs are composed by much more complex structures than an input-output approach. That is because they need to model and estimate the responses of the affected activity and their interaction with the other economic sectors, both in the short as well as in the long term. To do that, they need to integrate economic and environmental models and data.

The large flexibility of CGE models generally leads to an underestimation of the economic impacts generated by unexpected events. According to Rose (2004, p. 27) "not all causation in CGE models are unidirectional, i.e., functional relationships often offset each other". In addition, the optimizing behaviour of CGE models can be considered unrealistic in a situation of disaster, where the psychological effects of unexpected damage and the large uncertainties on the near and distant future can lead to non-optimizing behaviour. Examples are provided by depressions and post-traumatic stress disorders (PTSD) that can lead to adverse consequences as reduction in consumption or productivity. These patterns have been reported both in the case for 1995 Kobe Earthquake in Japan and after the terrorist attacks on September 11 201 in the US (Hewings and Okuyama, 2003). To address this weakness some attempts have been specifically designed to incorporate behavioural changes and shifts of the supply and demand generated by sympathetic behaviour of mutual aid as for example international assistance. Community responses, adaptive strategies and resilience across economic sectors have also been introduced in some CGE models (Rose and Liao, 2005; Kajitani et al., 2005a, 2005b).

To investigate the economic costs generated by climate change, empirical literature proposes different solutions. Starting form biophysical analysis, for example, it is possible to estimate variations in the production factor(s), as for example in agriculture or in land productivity, and introduce in the model the quality/quantity change as an exogenous shock in the production process. In a similar way, a production capital destruction generated by a catastrophic event is translated into a reduction on production and, as a consequence, into a price increase. The readjustment process in terms of price, quantity and consumption generates a new equilibrium with a different value on welfare and utility (Deke et al., 2001; Darwin and Tol, 2001). Variation on energy demand, costs for investments, productivity and consumption changes can also be computed in the model to estimate positive and negative economic impacts generated in specific markets or regions (PESETA II website). In addition, when the production function of the CGE models are based on Cobb-Douglas or Constant Elasticity of Substitution the short-term effects on input substitution can be modelled and estimated. The large flexibility and the adjustment process included in CGE models generally smooth the short-terms economic consequences generated by disasters and mitigate the long-terms economic adjustments (Hallegatte, 2014).

Because of their great flexibility of CGE models are largely used to investigate the consequences and the costs generated by climate change. Well know examples are the Garnaut Climate Change Review that used a CGE to quantify the costs on the Australian economy, or the models used by the World Bank to estimate interactions over different sectors and regions (Garnaut 2008a; 2008b; World Bank, 2010). An example of that is the EACC project (Economic Adaptation to Climate Change) developed to estimate the impacts of climate change and the costs of adaptation. Based in a CGE structure, the model quantifies for each time period from now to 2050 the differences between the world with climate change and the world without climate change. By considering different kinds of data and indicators, as GDP and population forecasts, precipitation, temperatures, stock of infrastructure assets, water supply and extreme events probabilities, the model predicts the possible impacts and quantify the costs in terms of economic activities and physical capital, people's behaviour (consumption, health,…) and environmental conditions (water availability, forests…).

By providing an overview of the costs and impacts disaggregated by countries and socio-economic and environmental elements the EACC model can be used to provide policy support and to increase the efficiency of the adaptation strategies (World Bank, 2010).

Within European Union, PESETA II project (Projection of Economic impacts of climate change in Sectors of the European Union base on bottom-up Analysis) has been specifically designed to investigate the impacts and costs generated by climate change in Europe for the period 2071-2100. The main objective is to provide analysis supporting policies in the design of efficient adaptation and mitigation strategies. The methodology adopted is structured in two different but integrated phases. The first one is a bottom-up biophisical impact models that analyse the relationships between climate change and biophysical elements. The second one is an assessment of the main costs generated by climate change. In particular, starting from the analysis of the physical consequences generated in different areas (as agriculture, energy, river floods, droughts, forest fires, transport infrastructure, coasts, tourism, habitat suitability of forest tree species and human health) a CGE model (GEM E-3) is used to aggregate the different impacts and to quantify the costs in terms of household welfare and economic activity. Since the analyses are provided for different sectors and geographical areas the main results are particularly useful to identify the main vulnerable elements and to design specific policies (PESETA II website).

A recent example of general equilibrium model in a context of climate change is also provided by the ENV-Linkages that is a OECD's dynamic global general equilibrium model used to assess the consequences of a selected number of climate change impacts in various world regions for different macroeconomic and sectoral categories. Sea level rise, health, ecosystems, agriculture, tourism, energy demand and fisheries are some of the most important variables included in the model. The main impacts are quantified in terms of GDP variation. In addition, long-run analysis are also performed by combining ENV-Linkages with AD-RICE that is an integrated assessment model that allows to estimate the long terms economic effects of climate change. The present version of the model quantify the impacts up to 2060 and estimate a global GDP reduction ranging between 0.7% and 2.5%. The main losses are expected to take place in the areas dominated by agriculture, as for example the South and the South-East Asia. The impacts of extreme weather events, water stress and large-scale disruption are not included in the present version of the model. Investigating the main economic impacts generated by different climate change events, the ENV-Linkages and the AD-RICE models are particularly useful in a context of policy support. The identification of the costs and the possible benefits generated by adaptation and risk reduction strategies are important elements to design effective and efficient strategies for climate change reduction and socio-economic resilience (Dellink et al., 2014)

4.4 Idealized models, hybrid models

To address the limits of the IO and CGE approaches and to consider the complex and integrated relationships between physical and socio-economic system, hybrid and idealized models have been proposed.

1. **Idealized models** aim at analyse the mechanism that play a crucial role in influencing the magnitude of the costs and the propagation effects. The main objective is not the quantification of the costs but the identification of the transmission mechanisms (Hallegatte et al., 2008; Hallegatte and Ghil, 2008).
2. Different kinds of **hybrid models** have been proposed and used on literature. They are mainly oriented to integrate the main advantages of IO and CGE models. Hallegatte (2008), for example, increased the flexibility of IO models by introducing inventories, specific demand dynamics and by including a limited substitution capacity and to account for the heterogeneity within sectors. To take into account the limited flexibility of the production system in the short term, Rose et al., (2007) proposed a CGE model with reduced substitution elasticity. IO-CGE hybrid model have also been used by Hottidge et al., 2005 to analyse the Australian drought in 2000-2003. Other hybrid models combine physical aspects and economics as for example the hydrological-economic model proposed by Booker in 1995, or the biophysical-agroeconomic model in Holden and Shiferaw (2004).

4.5 Econometric Models

Econometric models with time-series and cross-section data are generally used for long-run analysis of climate-change. Based on the idea that past trends can be used to estimate future changes, econometric models are oriented to identify the relationships between macro-economic variables and to estimate the impacts generated by climate change. In a context of global supply chain, econometric models considering trade relationships between countries can be used for stochastic estimates of impacts and responses (Okuyama, 2014). The econometric models used to investigate the economic impacts of climate change-related events generally describe economic trends moving along a balanced pathway. The consequences of weather or geological events, or more in general the consequences of an unexpected disaster, can be included by introducing disequilibria during transient phases. Examples are provided by the Non-Equilibrium Dynamic Model (NEDyM) proposed by Hallegatte et al., (2007), that introduce large-scale extreme weather events as shocks in a long-term Solow model, or by various studies that analysed the tendency between economic growth and disasters occurrences (Skidmore and Toya, 2002; Rasmussen, 2004; Cuaresma et al., 2008; Cavallo et al., 2010). Strobl (2008), for instance, estimated that the country-level impacts of at least one hurricane a year in the US can be quantified in around 0.79% economic growth reduction. The increasing demand for reconstruction, however, can generate a production increase of 0.22 percentage point the following year. In a similar way Noy and Vu (2009) investigated the impact of disasters at the province level in Vietnam. Main findings shows that short term costs can be partially compensated by GDP increase generated by reconstruction demand. Another example of climate change econometric model is the Multisectoral Dynamic Model MDM-E3 developed and maintained by Cambridge Econometrics (CE). Specifically designed to quantify the impact of climate change mitigation measures on UK, the model generate forecasts and alternative climate change scenarios to investigate the impacts on households, businesses and macroeconomic variables. MDM-E3 is constituted by detailed and disaggregated information on industries, sectors, regions, commodities, government expenditures, foreign trade and investments.

In particular, the model includes:

- 86 industries, covering information on industry output, prices, exports, imports and employment;
- 51 categories of household expenditure;
- 27 categories of investments.

For the former Government Office Regions, Wales, Scotland and Northern Ireland, projections of value added output and employment by 46 industries, plus aggregate household income and expenditure; Dynamic interrelationships between macroeconomic variables and industrial factors. Input-output data summarizing the structure of the economy

The main analysis provided for the year 2030 shows that investments in energy efficiency measures and low-carbon technologies can lead to the creation of 190,000 jobs together with a 1.1% GDP increase. An additional example of dynamic econometric model is provided by FIDELIO, described in the next section (5.e).

4.6 Bottom up approach

The "bottom up" or "starting point" approach aims to identify the processes and conditions that influence the vulnerability and the recovery capacity of a system (Polsky et al., 2003). Contrary to the IO, SAM and CGE models[12], where the process, the conditions and the relationships influencing vulnerability are assumed, the bottom up approach quantifies the impacts of climate change by investigating the existing relationships between elements and forces (Wing and Lanzi, 2014). A set of interviews conducted with the different stakeholders that could be potentially affected by climate change events are performed to identify costs, impacts and transmission mechanisms. Examples are provided by Pittman et al. (2011) and Olesen et al. (2011) that performed interviews to investigate climate change vulnerability and costs in Canada and Europe. The data collected can be useful to build damage functions, to identify specific factors of vulnerability or to identify the main transmission mechanisms. These interviews allow to gain insights in the structures and dynamics of the supply chains and to increase the awareness of stakeholders. They are useful to design effective adaptation strategies, to increase resilience or to prepare recovery measures. One of the main limitations is linked to the fact that it is very costly and time consuming to perform this

[12] Generally classified as "top down" or "end point" approaches

kind of analysis in a context of global supply chain where the different stakeholders are located in different geographical areas and where a large quantity of stage and network are involved. An example of bottom-up approach is provided by the biophysical models of PESETA II project that integrate climate change and biophysical elements to estimate the impacts in several areas, as for example health, transport, energy, agriculture, etc.

In table 4 a summary of the main methodologies is reported.

All the models reported can be used both for ex-ante and for ex-post analysis of climate-change related events. Ex-ante analysis can be done by designing a set of hypothetical scenarios. Monte-Carlo simulation can be run to produce probabilistic impact estimates (Shinozuka and Chang, 2004; Cardenasa et al., 2007). They can be useful for policy and adaptation purposes. However, the time period considered, the uncertainties related to events and magnitude and the resilience of the socio-economic structure are important variables to be taken into account. Ex-post analysis can be used to quantify the impacts generated by disaster and to plan recovery and reconstruction. Real and reliable data on the magnitude of the direct impacts generated in a particular sector and area can be needed to quantify the costs (and/or benefits) generated along the international supply-chain.

Table 4. Summary of methodologies

Methodology	Main Scope	Data needed	Advantages	Disadvantages
Input-output	To describe the links across sectors, industries, products and final consumption. Socio and environmental extensions can be added to summarize the relationships between society, environment and economy. Trade links between countries can be used to investigate the inter-dependency between world areas. I-O can be used to quantify the upward and downward impacts generated by different kinds of shocks in one or in different regions/markets/sectors/activities	To quantify the upward and the downward impacts generated by climate change related events the following data are at least needed: 1) Input-output table including trade links 2) Micro-data describing the impacts generated by the considered events on a specific region/market/sector/ activity	Allows to quantify the impacts generated on the economy as a whole as well as the impacts generated in the different regions/markets/sectors/ activities	1) Limited flexibility given by linearity and rigid structure with respect to input and import substitution and price changes 2) Lack of explicit resource constraints, lack of responses to price changes. 3) Being based on constant technical coefficient it is suitable to estimate the impacts generated in the long term
SAM	To describe the relationships between income, production, consumption and capital accumulation. SAM can be used to quantify the socio-economic impacts generated by different kinds of shocks in one or in different regions/markets /sectors/activities	To quantify the socio-economic impacts generated by climate change related events the following data are at least needed: 1) Socio-accounting matrix 2) Micro-data describing the impact generated by the considered events in a specific region/market/sector/ activity	Being based on a large disaggregation, it is suitable for detailed analysis on the interdependencies among activities, factors and institutions. It is also particularly useful to analyse distributional issues and expenditures among household groups	Being based in an IO structure, the SAM has the same disadvantage of the IO methodology
General equilibrium models	To model and describe the relationships between economic variables. CGE can be used to quantify the impacts generated by climate change related events on the economy as a whole. The main objective is to capture the flow-on effects of an	To quantify the impacts generated by climate change related events the following data are at least needed 1) Micro and Macro economic data are needed to estimate the parameters and to model the relationships between variables	Large flexibility: they can be non-linear, can respond to price change, can incorporate input and import substitutions, can explicitly handle supply constraints. They allow to quantify the costs	Underestimation of the impacts due to its flexible adjustment feature. Modelling the relationships between economic variable, they can be characterized by large uncertainty, particularly for long time period estimations

	impact in a specific region/market/sector/activity	2) Micro-data quantifying changes in exogenous variables that are used to introduce the shock into the model	generated on the economy as a whole	
Idealized and hybrid models	To address the main limits of the IO and CGE approaches.	To quantify the impacts generated by climate change related events the following data are at least needed 1) Input-output table + CGE modelling elements 2) Micro-data describing the impacts generated by the considered events on a specific region/market/sector/ activity	They are particularly suitable to analyse the mechanism that play a crucial role in influencing the magnitude of the impacts and the propagation effects. They integrate the main advantages of IO and CGE models.	Being specifically designed based on the characteristics of the case taken into accounts, they are more time consuming than a standard IO model.
Econometric Models	To model and describe the relationships between economic variables. To estimate long-term trends of different economic elements.	To quantify the impacts generated by climate change related events the following data are at least needed 1) Time-series and cross-sectoral data are needed to estimate the econometric model 2) Micro-data describing the impacts of climate-change related events need to be introduced as disequilibria into the model.	Can be used for long-term analysis	Being based on the idea that past trends can be used to estimate future changes, they could under valuate the uncertainty and the complexity describing the relationships between economy, environment and society
Bottom up approaches	To identify the processes and conditions influencing the vulnerability and the recovery capacity of a system.	Economic and environmental data, qualitative analysis, interview, stakeholders participation	Being based in a bottom-up approach (interviews and stakeholders participation) they include detailed data and estimations	Costly and time consuming

5 Data and databases

This section provides an overview of the different databases that can be used to assess the direct and indirect impacts generated by climate change related events on the global supply chain. In general terms, at least three different kinds of information are usually needed:

1) Micro data on the direct economic impacts generated by climate change related events in a specific economic sector, as for example the reduction in the total output generated by disruption in a particular production;
2) Data describing the relationships between the different economic sectors and the structure of the economy;
3) Trade links between sectors and countries.

The first set of data can be provided by studies specifically oriented to quantify the direct impacts generated by climate change related events or natural disasters. These data are generally provided by specific analysis or by databases on loss and damage as the EM-Dat, MunichRE and SwissRE. Since a detailed review of these databases has been already provided in Miola and Simonet (2014), this report will mainly focus on the databases describing the relationships between economic sectors and the trade links between sectors and countries. The largest parts of them are compiled according to an input-output structure. However, other databases providing data on micro and macro-economic variables can also be used. In the next section an overview of the main input-output databases will be provided together with lists of the most important micro and macro-economic databases.

5.1 Input-Output databases

Input-output data can be used to estimate both the direct and the indirect effects generated by climate-change related events. By describing the relationships existing between sectors they allow to track the impacts generated on activities or the consequences along the production chain.

Different geographical disaggregation can be included in an input-output database. However, three main coverages are generally compiled:

Sub-national or Regional Input-Output Databases: very few input-output databases are presently available at a sub-national or regional level[13]. Regional data are useful to quantify the cascading effects that a climate change related event can generate across regions of the same country. Since very few regional databases are presently available some attempts have been done to "regionalise" the national input-output tables (Flegg and Weber, 1997; Fleg and Tohmo, 2010).

National Input-Output Databases: they are compiled by a large number of countries. They identify the economic relationships taking place between sectors and activities. Import, export, final consumption and value added are also included to provide an overview of the production/consumption activities taking place within a country. The impacts generated by climate change related events can be tracked along the national production system. If the trade links with other countries are available, it is possible to quantify the impacts generated on the global supply chain.

International Input-Output Databases: they are oriented to provide a set of supply, use and input-output tables for different world areas. They are generally constructed based on data provided by countries or estimated using different sets of national and international information. Since trade links between

[13] Japan and Italy are two of the few countries that compile input-output table at regional level. Japan, for examples, designated cities with more than 700,000 inhabitants have compiled city's I-O tables every five years. These data have been particularly useful for all the studies that have been oriented to investigate the impacts generated by earthquakes, as for example the Kobe regional and interregional impacts generated by the 1995 Kobe earthquake (Okuyama, 2014). For Italy, regional IO tables are regularly compiled but they are not publicly available.

countries are generally available, these databases can be used to quantify the impacts along the global supply chain.

To estimate the direct and indirect impacts generated by climate change related events along the global supply chain, international input-output databases covering the trade links between countries are needed.

Within European Union, input-output tables are annually compiled by Member States and are collected by Eurostat that also provides a consolidated IO table. Input-Output data generally refers to national scale even if some regional IO tables are available. The main input-output databases available at European level are:

5.2 European System of Accounts - ESA 95 – Supply, Use and Input-Output tables

It is compiled by Eurostat based on the information provided by European Member States. It is broadly consistent with the System of National Accounts of the United Nations (1993 SNA). ESA95 includes:

- **Annual supply and use tables:** identifying the relationships between products and industries and showing the transactions taking place between them, they provide useful information on the production process.
  In the supply tables the flows of goods and services are valued at basic prices. In the use table they are valued at purchaser's prices. Trade and transport margins and taxes less subsidies on products are added to the supply table. The use table also contains information of gross fixed capital formation, stocks of fixed assets and labour inputs by industry. For a detailed methodological explanation on construction and definition please refer to Eurostat website

- **Five-yearly symmetric input-output tables**: they combine both supply and use tables into a single table. The symmetric input-output tables accounted in the ESA95 are generally the product-by-product tables. However, some countries compiled the tables as industry-by-industry. The product-by-product input-output tables are compiled by converting the supply and the use tables at basic prices. They are accompanied by other two tables showing the use of imports and the domestic output, namely:

- **Five-yearly symmetric input-output tables of domestic production**

- **Five-yearly symmetric input-output tables of import**

The ESA95 provides detailed information on production activities, supply and demand of goods and services, intermediate consumption, primary inputs and foreign trade. The tables are disaggregated between 64 products (CPA2008) and 64 industries (NACE rev 2. A64).

From September 2014 a new set of rules will be implemented according to the ESA 2010. The European System of National and Regional Accounts (ESA 2010) is a new accounting framework oriented to update the ESA95 system according to the development in "measuring modern economies advances in methodological research and the needs of users" (Eurostat website). The ESA 2010 will be consistent with the worldwide guidelines on national accounting reported in the System of National Accounts 2008 (2008 SNA).

5.3 TIMESUT / TIMESUT 2

TIMESUT / TIMESUT 2 include a full set of annual Supply, Use and Input-Output Tables covering years from 1995 to 2009 with a distinction between export and import, to and from other EU countries.

The TIMESUT database includes supply and use tables for EU Member States for the period 1995-2007. The data are classified according to NACE 1.1 and are disaggregated between 59 products and 59 sectors.

TIMESUT 2 is basically oriented to revise and update the information included on TIMESUT according to NACE 2 classification. It includes 64 sectors and 64 products and the time period covered is between 1995 and 2009.

TIMESUT and TIMESUT 2 have been constructed through a joint collaboration between Eurostat and European Commission's – IPTS Joint Research Centre[14]. At the present stage the database are not publicly available because they include confidential information provided by some member States.

To have Input-Output information on extra-EU countries, different databases are presently available: OECD Input-Output Database; WIOD, EXIOPOL- EXIOBASE, CREEA, GTAP, CEDA and Eora are some of them. They provide IO tables for some of the most important non-EU countries. All the other areas, as small island states or some developing countries are aggregated in the Rest of the World region (which is different from one database to the other).

5.4 OECD Input-Output Database

OECD Input-Output Database consists of 48 countries (OECD Countries, except Iceland plus 15 non-member countries) covering data for year 1995, 2000 and 2005[15]. The tables are compiled on an industry-by-industry base covering 48 sectors based on the ISIC Ref 3[16], 2009 Classification (in Appendix 2 a detailed classification of the 48 sectors is reported). The matrices of inter-industrial flows of transactions of goods and services (domestically produced and imported) are included in current prices. The compilation of OECD Input-Output Database is based on the information provided by the National Statistical Institutes of the different countries that are required to provide data in accordance with the harmonised industry structure based on the International Standard of ISIC. However, since not every country produce input-output table, the

[14] For more details, see: http://epp.eurostat.ec.europa.eu/cache/ITY_SDDS/Annexes/naio_esms_an1.pdf
[15] For a detailed classification of countries/years please visit: www.oecd.org/trade.input-outputtables
[16] International Standard - Industrial Classification of all Economic activities

supply and use tables provided are converted into IO tables based on standard assumptions.

5.5 WIOD

The World Input-Output Database (WIOD) is a publicly available database that provide a set of harmonized inter-regional supply, use and symmetric IO tables for 41 world countries (27 EU countries, 13 non-EU countries and the Rest of the World as an aggregated region) covering the period from 1995 to 2011. The tables have been compiled based on officially published input-output tables, national accounts and international trade statistics. The database is disaggregated between 35 industries and 60 products (s detailed sectoral disaggregation is reported in Appendix 3). Satellite accounts related to socio-economic and environmental indicators are also available. The socio-economic accounts include industry-level data on capital stocks, gross output, value added at current and constant prices and data on employment disaggregated between number of workers and educational attainment. The industry classification is the same used for the world input-output database. The environmental accounts include data on energy, emissions, materials extraction, land and water use. The data on emissions includes CO_2 by sector and energy commodity and a set of other pollutant, as N2O, CH4, NOX, SOX, NH3, NMVOC and CO. The materials extraction cover used and unused material by extraction sector and material types. The land accounts include the agriculture and the forestry use disaggregated between land type. The water accounts cover water use by sector and water type. Being linked to the core tables of WIOD, these information are particularly useful to identify the socio-economic and environmental impacts generated by production, consumption and trade. In addition, by providing trade links between the 41 countries included in the database, WIOD is particularly suitable to estimate the climate change effects generated on the global supply chain[17]. WIOD is an EU – FP7 project and the table are publicly available at www.wiod.org.

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[17] For a detailed methodological description please refer to Timmer et al., 2012.

5.6 EXIOPOL – EXIOBASE

EXIOPOL – EXIOBASE is a Multi-regional Environmentally Extended Supply and Use Input-Output database covering the 43 countries accounting for 95% of global economy plus the Rest of the World as an aggregated region. Full trade matrices with insights on which products from which country is exported to which industry sector in another country is included in EXIOBASE. The base year is 2000. It distinguishes between 129 industries and includes 30 emitted substances and 80 resources by industry. EXIOBASE is particularly useful to estimate the environmental impacts generated by production, consumption and trade. However, being update to the 2000 it has a limited flexibility to describe the present and future situation. EXIOBASE files are available for purchase.[18]

5.7 CREEA

Compiling and Refining Environmental and Economic Accounts (CREEA) is a EU – FP7 project oriented to i) refine and elaborate economic and environmental accounting principles; ii) update and expand the environmentally extended supply and use tables (EE SUT) included in the EXIOPOL database; and iii) compile SUT in physical terms (PSUT). 163 sectors, 200 products, 30 emissions and 80 resources are included in CREEA. The geographical disaggregation is 43 world countries plus 5 rest of world groups. The reference year is 2005[19].

5.8 GTAP

Global Trade Analysis Project (GTAP) is a publicly available database covering bilateral trade information, transport data, social accounting matrix, input-output tables and other macroeconomic and environmental variables as tariffs, taxes, energy and carbon dioxide emissions. The current release[20] includes 2004 and 2007 as reference years as

[18] For a detailed methodological description please refers to: http://www.feem-project.net/exiopol/

[19] For a detailed methodological description please refers to: http://creea.eu/index.php/documents2

[20] GTAP 8 Data Base

well as 129 regions and 57 GTAP commodities (see Appendix 3 for a detailed sectorial disaggregation). However, since the data available in GTAP are generally uploaded on a voluntary bases, the information included are heterogeneous in source, base years and sectorial details. For this reason, GTAP is not particularly suitable for economic comparisons between countries and years.

5.9 CEDA

Comprehensive Environmental Data Archive (CEDA) is an environmentally extended input-output database including information for US, UK and China. It is disaggregated between 430 products and sectors and the time period is between 2002 and 2010. It is particular suitable for life cycle assessment and for different kinds of environmental analysis, as carbon and water footprint or embodied energy analysis. It includes different emissions to air, water and soil, as well as a the amount of natural resources use disaggregated between fossil fuels, water, metals ores and minerals.

5.10 Eora

Eora is a multi-region input-output database originally supported by the Australian Research Council (ARC). It is compiled based on data drawn from the UN's System of National Account, COMTRADE databases, Eurostat, IDE/JETRO and a set of national agencies. It includes 187 countries at a detail of 20-500 sectors. The time period considered is between 1970 and 2011. 35 environmental indicators, related to air pollution, energy use, greenhouse gas emissions, water use, ecological footprint, human appropriation of net primary production, are also included in the database. The main advantages of Eora are related to the large disaggregation of countries and sectors, making possible to use the database for life-cycle and footprint-type assessment of production and international trade. The tables are available in basic prices as well as margin and taxis and in current and constant US$. The database is freely available for academic purposes[21].

In table 5 an overview of the main IO database is reported

[21] For a detailed methodological description please refers to Lenzen et al., 2013

Table 5. Summary of the main IO database

	Sectors	Products	Socio Environmental extensions	Years	Countries	Tables	References/Website
ESA 95	64	64	NO	1995-2007	27 EU MS + SOME ACCEDING AND CANDIDATES COUNTRIES	SUIOT	http://epp.eurostat.ec.europa.eu/ portal/page/portal/ esa95_supply_use_input_tables /introduction
TIMESUT	59	59	NO	1995-2007	27 EU MS, EA	SUIOT	http://epp.eurostat.ec.europa.eu/ cache/ITY_SDDS/Annexes/naio_esms_an1.pdf
TIMESUT 2	64	64	NO	1995-2009	27 EU MS, EA	SUIOT	http://epp.eurostat.ec.europa.eu/ cache/ITY_SDDS/Annexes/naio_esms_an1.pdf
OECD IO DATABASE	48		NO	1995, 2000, 2005	48 COUNTRIES (OECD COUNTRIES, EXCEPT ICELAND PLUS 15 NON-MEMBER COUNTRIES)	IOT	www.oecd.org/trade.input-outputtables
WIOD	25	60	YES	1995-2009	27 EU MS + 12 TRADE PARTNERS	MRSUIOT	www.wiod.org
EXIOPOL - EXIOBASE	129	129	YES	2000	27 EU MS + 16 TRADE PARTNERS	MRSUIOT	http://www.feem-project.net/exiopol/
CREEA	163	200	YES	2000,2007	27 EU MS + 16 TRADE PARTNERS	MRSUIOT	http://creea.eu
GTAP	COUNTRY SPECIFIC	COUNTRY SPECIFIC	YES	2004,2007 AS REFERENCE YEARS	129 REGIONS AND 59 GTAP COUNTRIES	SUIOT	https://www.gtap.agecon.purdue.edu/
CEDA	430	430	YES	2002-2010	UK, US, CHINA	SUIOT	http://cedainformation.net/
EORA	20-500 COUNTRY SPECIFIC HARMONIZED IO DATABASE 25 SECTORS	20-500 COUNTRY SPECIFIC	YES	1970-2011	187	MRSUIOT	http://worldmrio.com/

6 Macro and micro economic databases

A set of macroeconomic databases can be used to complement the information provided by the input-output databases. Some of them are:

6.1 World Bank

The World Bank regularly compiles a large set of data and indicators providing an overview of the socio-economic and environmental situation of different world countries. The main databases are disaggregated between macroeconomic and microeconomic variables. The macroeconomic dataset include 20 different topics ranging from agriculture, poverty, labour, trade, financial sector, urban development and many others. The microeconomic information, collected through sample surveys of household and business activities provide an overview of the living standards, institutions and communities. The data are available for the largest parts of the world countries including both developed and developing areas. In order to estimate the main socio-economic impacts generated by climate change related events and transmitted through the global-supply chain different information collected in the World Bank database can use used. Particularly useful are the data on agricultural production, energy and mining, labour, trade and infrastructure as well as the data on the economic situation of the different world countries. These information can be used to model the socio-economic structure of different countries and to identify the main links and dynamics existing between production, consumption and trade. Within this context the microeconomic information related to living standards and business activities can be particularly useful to identify the main impacts that unexpected events could generate on production and demand. In addition to that, the GEM commodities database (http://data.worldbank.org/data-catalog/commodity-price-data) collected information on commodities prices and indices from 1960 to present and it can be used to quantify the economic impacts that disruptions in one specific sector can generate in other economic activities, geographical areas or production sectors.

6.2 Food and Agricultural Organization

The Food and Agricultural Organization (FAO) regularly compiles different kinds of databases mainly related to agriculture and natural resources. Information on water use, scarcity and quality, pollution, forestry, fishing, agricultural production, trade and poverty are some of the most important available information. Since data are generally collected both for developed and developing countries a set of analysis can be performed to investigate the impacts that climate change related events can generate in different world areas with different levels of vulnerability. In addition to that, the availability of time series data allows performing decomposition analysis oriented to investigate the main drivers responsible for variations in socio-economic and environmental variables. Decomposition analysis is a widely applied tools used in several disciplines to identify the main factors contributing to changes in selected elements. In a context of climate change, decomposition analysis can be used to identify the main factors able to increase or reduce the vulnerability of a particular region or economic organization. Within the different data available in the FAO website, the information related to agricultural productions and trade are particularly useful to investigate the impacts that different kinds of unexpected events could generate on the global supply chain. Information on production, disaggregated between products, countries and time, together with data on trade relationships between different world countries can be useful to analyse how a specific event taking place in a particular area can affect the global system of production, consumption and trade. These information are publicly available in the FAO STAT website (http://faostat3.fao.org/home/E). Data on prices, emissions, land use, investments, emergency responses and input can also be useful to investigate the dynamic relationships existing between countries, sectors and socio-economic and environmental dimensions.

6. 3 International Labour Organization

The International Labour Organization (ILO) provides a set of statistics related to labour. It covers both developed and developing countries and provides data and variable variations over time. The main information included in the ILO database cover topics related to:

- income from employment of paid and self employed persons during a particular period as well as the earnings of persons in paid employment;
- their working time;
- their participation in strikes and lockouts, union participation, collective bargaining and other social dialogue characteristics;
- their occupational injuries and diseases resulting from exposure to risk factors at work;
- their occupations;
- their status in employment;
- industry or branch of economic activity of the establishment where they work;
- institutional sector (whether corporation, household, public);
- demand for labour or vacancies,
- cost of employing labour, or labour cost,
- extent and characteristics of their social security coverage,
- their training experience (lifelong learning),
- income and expenditures of the households where they live.

These data are particularly useful to monitor the performance of the economy, to complement the poverty and the inequality analysis and to plan for job creation. Between them, the information related to employment, working time and income generation, disaggregated between industrial sector and countries are particularly useful to investigate the impacts that climate change related events could generate on the socio-economic system[22]. These information can be used to model the relationships that exists between production, consumption, and trade and to analyse the main impacts that a disruption in a particular economic sector, or region, can generate on the overall level of employment, and as a consequence, on the overall level of expenditures and production. The dynamic relationships exiting between these

[22] These information can be downloaded by using the following websites: ILOSTAT (http://www.ilo.org/public/english/support/lib/resource/subject/labourstat.htm) and LABORSTA (http://laborsta.ilo.org/)

variables need to be considered and modelled in order to identify the social impacts that climate change related events and disruption in the supply-production chain can generate both in the short and in the long term.

6.4 Wold Trade Organization

The World Trade Organization (WTO) regularly compiles a set of statistics oriented to monitor the trade across world countries. Data on tariffs, trades on merchandise and services, together with trading information in terms of values and commodities are reported. The database is particularly useful to investigate the import-export activities of different world countries and to analyse the activities and partners involved in the global supply-chain. The trade and products statistic database, publicly available at STAT WTO (http://stat.wto.org/Home/WSDBHome.aspx?Language=E) includes information related to the trade activities of different world countries disaggregated by different commodities including food, fuel, iron and steel, chemical, pharmaceuticals and a set of industrial products as automotive products, clothes or transport equipment. Time series data are available for the period of time included between 1980 and 2013. In addition to that, the online tool available at the WTO website allows to select specific trade partners and to quantify the trade relationships taking place between them, both at aggregate level and disaggregated by products categories. These information are particularly useful to investigate the costs and disruptions that climate change related events can generated in particular areas and the consequent effects generated all over the world by the transmission mechanisms of the global supply-chain.

6.5 EU KLEMS

Another database that can be used to quantify the impacts generated by climate change related events is the EU KLEMS database supported by European Commission - FP6 and FP7. It includes measures of economic growth, productivity, employment creation, capital formation and technological change at the industry level for all the EU Member States from 1970 onwards. The main objective of the project was to create a database suitable to support analysis oriented to quantify competitiveness and economic growth potentials. A detailed list of variables and geographical/time coverage included in the EU KLEMS database is reported in Appendix 5 and Appendix 6. The data on gross value added and labour are particularly useful to estimate the possible socio-economic impacts that disruptions in the global supply-chain can generate in specific countries. The data provided in the EU KLEMS database have been recently used in different modelling exercises. Just to provide an example, the Full Interregional Dynamic Econometric Long-term Input-Output (FIDELIO) model developed by the European Commission's Joint Research Center in collaboration with the Austrian Institute of Economic Research and the Joanneum Research use the EU KLEMS data to model the interactions between consumption, production, labour, international trade and environment. The main applications are oriented to estimate the main socio-economic impacts generated by different kinds of events or policies. The current version of FIDELIO covers 27 EU countries[23] and one rest of the world as aggregated region, 59 products, 59 sectors, 3 labour skill levels in two dimensions and 5 satellite extensions including energy, air emissions, land, water and materials. The model allows to capture in an integrated way the interactions between different elements of the economic system and it is particularly useful to identify the dynamic interactions existing between economic sectors and countries (Kratena et al., 2013).

[23] The geographical coverage will be extended to include US, Brazil, Russia, China, India, Japan and Turkey

Conclusions

The present economic system is characterized by large interconnectivities between production and consumption activities taking place all over the world. The global supply chain and the coordinated system of networks that link socio-economic elements localized in different countries are paradigmatic examples of factors making the present economic system globally interconnected. The optimization of production, the comparative advantages and the cost reductions are some of the main elements that during the last decades lead to the success of the so called "globalization" process. If from one side the increasing economic interconnections allow to reduce costs and to increase the consumption possibilities, on the other side the large complexity and the spatially distributed networks of activities make modern society largely vulnerable to any kind of disturbance. Terroristic attacks, local conflicts, earthquakes or natural disasters taking place in a specific area can generate disruptions along the chain, with domino effects on the global supply.

Climate change related events are one of the most important elements influencing the efficiency of the present economic networks. The increasing rate of unexpected and extensive disasters taking places both in developed and developing areas make climate change a serious factor of concern in terms of safety, stability, food security, environmental degradation and economic costs. During the last decades an increasing number of studies investigated the main elements of risk and vulnerability, together with the possible impacts in terms of human life, recovery expenses, productivity loss and natural environment degradation. The largest part of these studies focused on the main direct impacts generated in a specific sector of analysis or in a specific geographical area. More recently, however, an increasing attention has also been devoted to analyze the overall vulnerability of the socio-economic system and a particular focus has been placed on the domino effects that a disruption in a specific part of the supply chain can generate along the system. A good understanding of the most vulnerable entities is in fact a fundamental step to avoid, reduce and mitigate the potential costs generated all over the world.

A combination of climate modelling, data and intra-regional and intra-sectoral analysis are the fundamental elements needed for this kind of analysis. At the present stage, however, the lack of up-to-date international databases able to capture the trading relationships among countries and sectors, and the consequent limited use of inter-regional models make it difficult to estimate the cascading and the domino effects resulting from the disruption of the international supply chain. In addition, the large data gap existing for developing countries and small island developing states, where climate change related events are expected to generate the largest catastrophic impacts, makes even more difficult to estimate the costs generated all over the world.

The main objective of the present report is to provide an overview of the main studies, methodologies and databases used to investigate the climate vulnerability of the supply chain. Six main methodological approaches have been considered, namely: (1) Input-Output; (2) Social accounting matrix; (3) General equilibrium models; (4) Idealized models, hybrid models, public finance coping capacity; (5) Econometric models; (6) Bottom-up approach. For every one of them, the main structure, applications, advantages and disadvantages are reported, together with examples of previous studies or policy applications. In terms of data, the main input-output and macro and micro-economic databases presently available have been reviewed. Being based on different assumptions, geographical coverage, and time period compilation, the different databases need to be selected based on the adopted methodological approach and based on the purpose of the analysis. In general terms, however, a wide data gap is existing for developing countries, where climate change-related events are expected to generate the biggest catastrophic impacts. In addition, the lack of updated and detailed information covering the trade links between economic sectors and geographical areas is one of the main limits for the quantification of the potential impacts that climate change related events can generate along the global supply chain.

A flexible methodology able to include the different elements that compose the global supply chain, together with the possibility to include complexity and uncertainty are some of the main features that would be needed to quantify the domino and cascading effects generated along the chain. In addition, reliable information on the links between economic activities and countries, covering data related to developing and vulnerable areas are some of the most important elements that are needed to quantify the potential costs that climate change related events can generated in the present economic network.

A clear identification of the most vulnerable elements together with a good understanding of the transmission mechanism is one of the fundamental steps to design effective mitigation and adaptation strategies and to reduce the costs generated by climate change.

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Appendix 1 Table A1. Summary of the main Index reported in Section 3

	Main objective	Components	Main estimated elements/ impacts	Methodology	Data sources	Time of references	Geographical coverage	Reference
Functional Fragility Curve (FFC)	To quantify the capacity loss generated by disasters based on specific levels of production capacity	Functional Fragility Curve; Production Capacity Loss Rate	Capacity loss	Non-linear dynamic analysis, maximum likelihood procedure and Bernoulli experiments are used to analyse the relationships between the size of the hazard and the damage probability	Business survey data on past disasters; damage data associated with past catastrophic events	Previous studies includes analysis from past earthquakes as the 1994 Northridge or the 1995 Kobe earthquakes	Local dimension, specific infrastructure and specific level of production capacity	Shinozuka et al., 2000; Nagano, 2011
Vulnerability Index for Post-Disaster Key Sector Prioritization	To identify and prioritize key sectors in the aftermath of disasters – To improve planning and efficiency of resource allocation	Economic impacts; Propagation length; Sector size	Vulnerabilities of different economic sectors; Benefits generated by investments in key economic sectors	Input-Output methodology and Inoperability Input-Output Model	Input-Output data + Monte Carlo simulation and Sensitivity Analysis	The most recent study focus on the tropical storm Bopha that affected Philippines in 2012	National or regional dimension, based on Input-Output data	Yu et al., 2014
Climate Change Risk Management (CCRM)	To map and quantify the global supply chain risks due to climate change. To identify which countries are best	Global adaptation index and Maps	Maps of exposure of physical impacts of climate changes for	Combination between global adaptation index and maps	Data on physical vulnerability of climate change disaggregated between countries and	1995-2013	National coverage	http://index.gain.org/

	prepare to deal with climate disruptions and unexpected events		different countries and commodities		commodities			
Indicator Framework for Indirect Industrial Vulnerability Assessment	To assess vulnerability of industrial sectors	Production factor dependency; Supply-chain dependency; infrastructure dependency	To analyse the indirect vulnerability of industrial sectors to different kinds of disasters	Combines different sub-indicators into a single quantitative measure. It uses a standardization process with a scale from 0 to 1 to harmonize the units of the different indicators. It also attributes weights	The value of every indicator is obtained from literature or statistical data	Analysis related to case studies or specific disasters	Industrial sectors of different countries	Hiete and Merz, 2009
Integrated Indicator Framework for Spatial Assessment and Social Vulnerability to Indirect Disaster Losses	To identify how industrial losses can aggravate social vulnerability and how vulnerability in society can lead to greater impacts from industrial losses	Social vulnerability index and industrial vulnerability index	Mutual relationships, iterative processes and cause-effect relationships existing between social and industrial dimensions	It aggregates a social vulnerability index and an industrial vulnerability index. Multi-criteria evaluation method and DEMATEL	Data on previous disasters and expert judgements	A recent case study analyse the main vulnerabilities of 16 different industrial sectors in the state of Baden-Wuerttemberg in Germany	Industrial sectors in different regions and countries.	Khazai et al., 2013
Supply-Chain Vulnerability Index (SCVI)	To estimate the supply-chain vulnerability based on the observation of different vulnerability drivers	Demand side vulnerability drivers; Supply side vulnerability drivers; Supply-chain vulnerability drivers	Supply-chain vulnerability and vulnerability drivers	Graph theory approach	Data from business activities and data describing the main characteristics of the economic structure	A recent case study investigates the supply-chain vulnerability of German firms	Supply-chain vulnerability of a specific industry, among industries or supply-chain vulnerability of the whole economy	Wagner and Neshat, 2010

Appendix 2. OECD I-O Database – Industry classification and concordance with ISIC Rev. 3, 2006 edition

ISIC Rev. 3 Code	IO Industry	Description
1 + 2 + 5	1	Agriculture, hunting, forestry and fishing
10 + 11 + 12	2	Mining and quarrying (energy
13 + 14	3	Mining and quarrying (non-energy)
15 + 16	4	Food products, beerages and tobacco
17 + 18 + 19	5	Textiles, textile products, leather and footwear
20	6	Wood and products of wood and cork
21 + 22	7	Pulp, paper, paper products, printing and publishing
23	8	Coke, refined petroleum products and nuclear fuel
24e + 2423	9	Chemicals excluding pharmaceuticals
2423	10	Pharmaceuticals
25	11	Rubber and plastics products
26	12	Other non-metallic mineral produts
271 + 2731	13	Iron and steel
272 + 2732	14	Non-ferrous metals
28	15	Fabricated metal products, except machinery and equipment
29	16	Machinery and equipment, nec
30	17	Office, accounting and computing machinery
3	18	Electrical machinery and apparatus, nec
32	19	Radio, television and communication equipment
33	20	Medical, precision and optical instruments
34	21	Motor vehicles, trailers and semi-trailers
351	22	Building and repairing of ships and boats
353	23	Aircraft and spacecraft
352 + 359	24	Railroad eqipment and transport equipment n.e.c.
36 + 37	25	Manufacturing nec; recycling (include Furniture)
401	26	Production, collection and distribution of electricity
402	27	Manufacture of gas; distribution of gaseous fuels through mains
403	28	Steam and hot water supply
41	29	Collection, purification and distribution of water
45	30	Construction
50 + 51 +52	31	Wholesale and retail trade; repairs
55	32	Hotels and restaurants
60	33	Land transport; transport via papelines
61	34	Water transport
62	35	Air transport

63	36	Supporting and auxiliary transport activities; activities of travel agencies
64	37	Post and telecommunications
65 + 66 + 67	38	Finance and insurance
70	39	Real estate activities
71	40	Renting of machinery and equipment
72	41	Computer and related activities
73	42	Research and development
74	43	Other business activities
75	44	Public administration and defence; compulsory social security
80	45	Education
85	46	Health and social work
90 – 93	47	Other community, social and personal services
95 + 99	48	Private households with employed person and extra-territorial organisations and bodies

Appendix 3

GTAP Data Bases: GTAP 8 Data Base Sectors

Number	Code	Description (Detailed Sector Breakdown)
1	PDR	Paddy rice
2	WHT	Wheat
3	GRO	Cereal grains nec
4	V_F	Vegetables, fruit, nuts
5	OSD	Oil seeds
6	C_B	Sugar cane, sugar beet
7	PFB	Plant-based fibers
8	OCR	Crops nec
9	CTL	Bovine cattle, sheep and goats, horses
10	OAP	Animal products nec
11	RMK	Raw milk
12	WOL	Wool, silk-worm cocoons
13	FRS	Forestry
14	FSH	Fishing
15	COA	Coal
16	OIL	Oil
17	GAS	Gas
18	OMN	Minerals nec
19	CMT	Bovine meat products
20	OMT	Meat products nec
21	VOL	Vegetable oils and fats
22	MIL	Dairy products
23	PCR	Processed rice
24	SGR	Sugar
25	OFD	Food products nec
26	B_T	Beverages and tobacco products
27	TEX	Textiles
28	WAP	Wearing apparel
29	LEA	Leather products
30	LUM	Wood products
31	PPP	Paper products, publishing
32	P_C	Petroleum, coal products
33	CRP	Chemical, rubber, plastic products
34	NMM	Mineral products nec
35	I_S	Ferrous metals
36	NFM	Metals nec
37	FMP	Metal products
38	MVH	Motor vehicles and parts
39	OTN	Transport equipment nec
40	ELE	Electronic equipment
41	OME	Machinery and equipment nec

42	OMF	Manufactures nec
43	ELY	Electricity
44	GDT	Gas manufacture, distribution
45	WTR	Water
46	CNS	Construction
47	TRD	Trade
48	OTP	Transport nec
49	WTP	Water transport
50	ATP	Air transport
51	CMN	Communication
52	OFI	Financial services nec
53	ISR	Insurance
54	OBS	Business services nec
55	ROS	Recreational and other services
56	OSG	Public Administration, Defense, Education, Health
57	DWE	Dwellings

Appendix 4

WIOD Sectoral classification

Classification	Description
c1	Agriculture, Hunting, Forestry and Fishing
c2	Mining and Quarrying
c3	Food, Beverages and Tobacco
c4	Textiles and Textile Products
c5	Leather, Leather and Footwear
c6	Wood and Products of Wood and Cork
c7	Pulp, Paper, Paper , Printing and Publishing
c8	Coke, Refined Petroleum and Nuclear Fuel
c9	Chemicals and Chemical Products
c10	Rubber and Plastics
c11	Other Non-Metallic Mineral
c12	Basic Metals and Fabricated Metal
c13	Machinery, Nec
c14	Electrical and Optical Equipment
c15	Transport Equipment
c16	Manufacturing, Nec; Recycling
c17	Electricity, Gas and Water Supply
c18	Construction
c19	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel
c20	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
c21	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
c22	Hotels and Restaurants
c23	Inland Transport
c24	Water Transport
c25	Air Transport
c26	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
c27	Post and Telecommunications
c28	Financial Intermediation
c29	Real Estate Activities
c30	Renting of M&Eq and Other Business Activities
c31	Public Admin and Defence; Compulsory Social Security
c32	Education
c33	Health and Social Work
c34	Other Community, Social and Personal Services
c35	Private Households with Employed Persons

Appendix 5

Variables in EU KLEMS database, November 2009 release

VARIABLES	
Values	
GO	Gross output at current basic prices (in millions of national currency)
II	Intermediate inputs at current purchaser's prices (in millions of national currency)
VA	Gross value added at current basic prices (in millions of national currency)
COMP	Compensation of employees (in millions of national currency)
EMP	Number of persons engaged (thousands)
EMPE	Number of employees (thousands)
H_EMP	Total hours worked by persons engaged (millions)
H_EMPE	Total hours worked by employees (millions)
Prices	
GO_P	Gross output, price indices, 1995=100
II_P	Intermediate inputs, price indices, 1995=100
VA_P	Gross value added, price indices, 1995=100
Volumes	
GO_QI	Gross output, volume indices, 1995=100
II_QI	Intermediate inputs, volume indices, 1995=100
VA_QI	Gross value added, volume indices, 1995=100
LP_I	Gross value added per hour worked, volume indices, 1995=100
Growth accounting	
LAB	Labour compensation (in millions of Euros)
CAP	Capital compensation (in millions of Euros)
LAB_QI	Labour services, volume indices, 1995=100
CAP_QI	Capital services, volume indices, 1995=100
VA_Q	Growth rate of value added volume (% per year)
VAConH	Contribution of hours worked to value added growth (percentage points)
VAConLC	Contribution of ICT capital services to value added growth (percentage points)
VAConKIT	Contribution of non-ICT capital services to value added growth (percentage points)
VAConKNIT	Contribution of labour composition change to value added growth (percentage points)
VAConTFP	Contribution of TFP to value added growth (percentage points)
TFPva_I	TFP (value added based) growth, 1995=100
Additional variables	

CAPIT	ICT capital compensation (share in total capital compensation)
CAPNIT	Non-ICT capital compensation (share in total capital compensation)
CAP_GFCF	Capital compensation (in millions of Euros) adjusted for negative rental prices
CAPIT_QI	ICT capital services, volume indices, 1995=100
CAPNIT_QI	Non-ICT capital services, volume indices, 1995=100
CAPIT_QPH	ICT capital services per hour worked, 1995 reference
CAPNIT_QPH	Non-ICT capital services per hour worked, 1995 reference
LAB_QPH	Labour services per hour worked, 1995 reference
LAB_AVG	Labour compensation per hour worked
H_AVG	Labour compensation per hour worked

Appendix 6

Country and period coverage in EU KLEMS database, November 2009 release

Country and region	Last year in the database
Australia	2007
Austria	2007
Belgium	2006
Cyprus	2007
Czech Republic	2007
Denmark	2007
Spain	2007
Estonia	2007
Finland	2007
France	20074
United Kingdom	2007
Germany	2007
Greece	2007
Hungary	2007
Ireland	2007
Italy	2007
Japan	2006
Korea	2007
Latvia	2007
Lithuania	2007
Luxembourg	2007
Malta	2007
Netherlands	2007
Poland	2006
Portugal	2006
Slovak Republic	2007
Slovenia	2006
Sweden	2007
United States	2007
EU-15	2007
EU-10	2006
EU-25	2007
Eurozone	2007

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