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ЕВРОПЕЙСКИЕ ПРИБРЕЖНЫЕ АЭРОПОРТЫ: ПОДЪЕМ УРОВНЯ МИРОВОГО ОКЕАНА, УСЛОВИЯ РАДИКАЛЬНОЙ НЕОПРЕДЕЛЕННОСТИ, ОТВЕТСТВЕННОСТЬ ЛИЦ, ПРИНИМАЮЩИХ РЕШЕНИЕ

До сих пор большинство развивающихся правовых судебных процессов по вопросам климата в основном не касаются экологических ассоциаций или жертв от фирм-энергопотребителей или государств. Тем не менее в ближайшем будущем из-за учащения внезапных наводнений, связанных с изменением климата, будущий судебный процесс может быть связан с управлением инфраструктурой схожим с частными авиакомпаниями или страхованием воздушных трасс. В самом деле к результату судебных разбирательств будут относиться финансовые потери, последние из названных организаций будут терпеть из-за отсутствия инфраструктуры, обеспеченной лицами, имеющими возможность принимать решения. Эта статья рассматривает европейские аэропорты, находящиеся в прибрежной зоне. Статья настаивает на теории ученых о повышении уровня моря и важности климатической среды по причине потенциальной юридической ответственности в случае причинения ущерба.

Ключевые слова: изменение климата; повышение уровня моря; аэропорты; транспортная инфраструктура; юридическая ответственность; неопределенность.

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EUROPEAN COASTAL AIRPORTS: THE RISE OF RISE OF SEA LEVEL, CONDITIONS OF RADICAL UNCERTAINTY LEGAL LIABILITY BY DECISION-TAKERS

Until now, most of the growing climate legal litigations mainly concern environmental associations or victims against energy of energy-users firms or States. However, in a near future, because of exacerbating sudden floods linked to climate change, the future litigation could (will) concern infrastructure governance versus private airways companies or insurance companies. Indeed, sues would (will) concern the financial losses these last ones would (will) endure because of the lack of infrastructures decision-takers lack of care. This paper particularly investigates the case of coastal airports at the European level. It insists on the importance of climate scientists about the sea level rise for decision-takers and their potential legal liability in case of harm.

Keywords: Climate Change; Rise of sea level; airports; transportation infrastructures; legal liability; uncertainty.

The power of the 2 °C target is that it is pragmatic, simple and straightforward to understand and communicate all important elements when science is brought to policymakers.

Thomas Stocker, Intergovernmental Panel on Climate Change's co-chair

Introduction

Nowadays, global warming and anthropic origin of Greenhouse Gases (GHG) emissions are scientifically and indisputably linked. However, in spite of this knowledge, since the 1997 Kyoto protocol, progresses in the fight against GHG's emissions are hardly spectacular. Indeed, GHG's emissions grew more quickly between 2000 and 2010 than in each of the three previous decades as shows it the fifth report of the International Panel on Climate Change (IPCC)[1]. Without additional mitigation, baseline scenarios show that global mean surface temperature could increase in the 2100 year from 3,7 to 4,8 °C (median values) compared to pre-industrial levels. This detrimental situation needs international fast mitigation and prevention measures.

[1] See IPCC (2014) last report.

Among harm induced by global warming, the sea level rise (SLR) is among one of the hottest stakes. The more the seas increase, the more vulnerable the coastal areas become to erosion, salinization but also to storms and hurricanes (Wahl and alii (2015)). Furthermore, as shows it the IPCC AR5, progresses in knowledge of climate change scientists raise new scientific uncertainties about the causes and future evolution of the SLR. However, to efficiently fight against anthropic global warming, governments need reliable scientific certainties. This, all the more, that, nowadays, environmental associations, victims and citizens do no longer hesitate to sue in courts governments and corporations for their alleged liability in GHG's emissions. Indeed, most of the time, spoiled populations sturdily criticize the Public Authorities' inaction[1]. They try to get compensation or supplementary protection against climatic damages. Mainly born in the United State, the climate lawsuit is steadily growing all over the World. Hence, the discrepancy between the populations' safety need and the Authorities' inertia is a serious problem to deal with. Indeed, our societies face a dilemma. Authorities have to insure both a sufficient growth to meet increasing population's needs and parallely to fight against the consequences of global climate change.

The decision-makers' responsibility about climate change is a multifaceted issue. A first level concerns relationships between scientists in charge of studying climate change and governments or private or public decisioners that have to impulse and support prevention and mitigations policies. Sometimes, because of insufficient evidence, scientists could supply inadequate data or forecast about a given environmental phenomenon as, for example, the magnitude of the rise in sea level in IPCC's report in 2007[2]. A second level of responsibility regards the implication of local authorities that could have insufficiently considered the consequences of global warming. These last one have either diluted in time, or undersized protective measures or prevention concerning the infrastructure or the territories that they oversee. Dealing with authorities' legal liability as such is a complex issue. In all cases, identifying decision-makers' responsibilities is fundamental to get compensation, conviction and/or repairs. Hence, concerning the sea level rise, authorities may be held responsible for harm linked with erosion or flooding associated to climate-related phenomena. The jurisprudence's recent evolution shows that, in the future, concerning negligence and fault in this field, judges will be less and less indulgent.

This article highlights the difficulties of infrastructures' managers to make right choices in a context of radical scientific uncertainty. Indeed, rapid and intense rise of oceans may threaten huge infrastructures. Generally, these last ones are managed by private or public operators and their decision can contradict the choices of territories' governance. Furthermore, actual lawsuits oppose victims or citizen associations against governments or energy firms. However, if the climate change accelerates, damaged private firms could sue infrastructures' governance for insufficient environmental due care. To make this point more precise, we analyze the cases of European airports located on the seashore. This choice justifies because airports are stra-

[1] See the Climate litigation Chart made by the Sabin Center for Climate Change Law of the Columbia University that makes an exhaustive recension of the climate case law. http://www.arnoldporter.com/resources/documents/ClimateChangeLitigationChart.pdf.

[2] See for instance Rahmstrofs (2007)' s conclusion.

tegic infrastructure and «structuring entities». Indeed, they generate road networks, railway tracks, housing, etc. In addition, their governance, decision-making system and the definition of responsibilities are complex. For example, airports may be managed by public authorities or private interests or, alternatively, by mixing both.

To investigate this issue we gather the 2013 panel of the European Union airports and we specifically look at the ones close to the seashore. Then, we assess the structural impact of the sea level rise. This involves setting the number of potentially affected airports and the proportion of the damage in terms of activity (rather than in costs). This concern will be still more important and will particularly involve more airports if the pessimistic expectations prove correct.The study's object is supplying sufficient evidences for adopting solutions that apply locally, i.e. to given infrastructure in a given location, starting from a general analysis. Hence, this choice gives the opportunity to local governances to justify their prudential choice by referring to the behavior of similar governances' that meet (or met) similar conditions. This way can partially solve the question of ambiguous choices when decisions-makers face radical scientific uncertainty as the future evolution of the SLR. Scientific uncertainty at the moment they made their choices could contribute to lessen their potential responsibility. Indeed, in all cases, this paper helps understanding that judges will have to consider how airports managers facing similar situations all around Europe made relevant or irrelevant choices. As an important working hypothesis, the analysis core considers mainly that the level of temperature will increase, or has to stay up to 2 °C above the pre-industrial area. Indeed, the Intergovernmental Panel on Climate Change (IPCC) frames the Fifth Assessment to address this objective. Reaching it generates questions for the decision takers about its scientific reliability and above all its economic reliability.

1 Climate Change, SLR: the Impact on Infrastructures

Initially underestimated by IPCC in 2007, the SLR is subject to heated debates. Among oceanographers, climatologists, geophysicists and all specialists related to these issues, the factors under controversy mainly concern the evolution of ocean warming, the melting of polar ice caps and glaciers, specifically Greenland and Antarctic. The question is of particularly importance because the world's population is constantly increasing near the seashores (Brown, Nicholls, Woodroffe, Hanson, Hinkel and Kebede (2013)). However, the SLR involves accelerating wetlands and lowlands, coastal erosion, exacerbating coastal flooding, threatening coastal structures, raising water tables, and increasing the salinity of rivers, bays, and aquifers (Barth and Titus (1984), Neumann and alii (2015)).

1.1 A comprehensive view of the SLR's on infrastructures

Seashores are submitted to climatic SLR and this involves costly consequences. Economic analysis tries to appraise the incurred losses. However, the studies stay either to a too high global macroeconomic level, or, in the opposite, these are monographies that prevents significant comparisons. Hence, in this paper we change the usual way to consider the point by a sector analysis that internationally compares some coastal infrastructures. The scope is limited by gives an overview that allows economic comparison. Furthermore, this puts more into evidence the decision-makers' effective liability. Indeed, it associates a specific problem (the SLR) to specific entities (here the airports' governance choices).

1.1.1 Coastal damages due to SLR: the economic studies' reliability

Coastal damages due to SLR present several facets with visible and invisible impacts. Generally, concerning the SLR, economists give values to exchangeable market assets, public goods (infrastructures) and environmental out of market inheritances (Bruun (1962), Gosselink, Odum and Pope (1974), Gunter (1974)). In the eighties economic studies particularly developed (Barth and Titus, eds. 1984), Everts (1985) Smith, and Tirpak (1989). In the 1990's, Titus and alli (1991) showed that an increase of 1 to 2 meters of the sea level for the next century (now) will involve a loss of around 36.000 kilometers square in the United States. Hence, the study proposed to defend particularly about 1500 square kilometers of particularly densely developed coastal lowlands. In fact, the effective costs of preservation, protection, mitigation is always at stake and the authors recognize the subjectivity of giving costs to such situations.

The assessment can also consider the countries and cities affected by more storms due to the SLR, Dasgupta and alii (2009) show that a 1 meter of SLR involves severe increased impacts. Now, studies begin to evaluate the cost of adaptation to SLR. For instance Hinkel and alii (2014) give an overview of the global costs of defense against the SLR according several scenarios. They find that without adaptation measures, then, around 0,2 to 4,6 % of global population is expected to be flooded annually in 2100 under the assumption of 25 to 123 cm of global mean sea-level rise. This corresponds to expected annual losses of 0,3 to 9,3 % of global gross domestic product. Theses studies favor building dykes as an effective and systematic defense device. The annual cost of such investments (until 2100) would be around US$ (2005) billion 12 to 70. Let us note that on 20 years, without discounting, the range of errors is about US$ (2005) billion 1,160[1].

Even if these studies are useful to make governments aware of the necessity to undertake adaptation investments, uncertainty about mitigating costs remains quite important. The population increase, the effective relationships between GHG emissions and SLR remains at stake. Furthermore, because of the lack of data, the only effective defense device this study considers is building dykes that correspond to low and proportionate sea water increase. If scientific knowledge about SLR changes then the adaptation process should also change. Under more extreme values, population should abandon flooded areas and new infrastructures will have to build. Furthermore, these necessary and suitable evaluations do not give any clue about how to apply the solutions they propose and who will be in charge of it. Indeed, the considered areas are under the legal responsibility of different entities: National and regional governments, private owners, etc.

1.1.2 SLR and infrastructures: the example of airports

Higher air temperatures threaten coastal airports by raising the sea level and increasing floods surges (storms, hurricane…). This induces changes in geographic

[1] US$ (2005) billion ((70–12).20) = 1,160.

moisture regime and intensifies wind and storms' frequency that involves business interruptions for short or longer periods and costs for mitigation and compliance. It also encompass increasing business costs as change in the insurance premiums, legal liability and all kind of services disruptions, changes in consumers' habits, etc.

The International Civil Aviation Organization (ICAO) recognizes the detrimental consequences of climate change but it seems under-sizing the SLR's consequences. For Burbidge (2013 p. 189)) «*precipitation and storm patterns are expected in the near-term, and certainly by 2030. The impacts of sea level rise will be more gradual and are not expected to be a factor until later in the century. However, more frequent and intense storm surges will have earlier impacts, reducing capacity and increasing delays in the shorter term*». Implicitly, this opinion depends both on the perceived past SLR and new scientific knowledge that could question the well-accepted idea of gradual SLR. Now, the institutional concerns about the SLR on airports and its consequences do not go beyond institutional or scientific reports (Port Authority of New York and New Jersey (2011), DesRoches (2011), Philadelphia International Airport (2010), Los Angeles World Airports (2010)). Except for Alaska (Baglin (2012)), Larsen, and alii (2008)), little is done for protecting airports from the SLR. However, as both scientific knowledge and uncertainty progress about the possible range and speed of the climatic SLR, the question is becoming of the utmost importance.

Expectation of regular and low SLR favors progressive protection. However, some rapid SLR will be accompanied with more violent storms and may lead airports' governance changing their initial plans. For Pümpel (2013 p. 186): «*Scarcity of large areas of level ground near population centers is a main concern for the development of new airports. In many cases, this pressure has led to the location of new hub airports close to the seashore on artificially created islands, or in semi-protected floodplains. With climate change, such installations are likely to become vulnerable to sea level rise, storm surges, and tropical cyclones*». Other more drastic solutions as, for instance, moving to new airports and new infrastructures should to be considered. Furthermore, this kind of harsh change compared to previous plans, make quite dicey global assessments of the SLR's effective costs.

1.2 A sector analysis: The case of the European Airports

Airports are generally located near huge cities and constitute nodes for terrestrial, industrial and urban relationships. Furthermore, they are built on quasi-standard structure (landing strips, transit hubs, transportation ways, etc.) which allows comparing them. Accordingly, studying climate change through the scan of the SLR impact on airports is relevant. Furthermore, focusing on airports does not prevent to combine this analysis with other infrastructures' analysis (terrestrial transport, local utilities, coastal activities, etc.). Now, we study the impact of the SLR on air transport of passengers and goods in the European Union (EU) of airports' located up shorelines.

1.2.1 The data

We start from the year 2013 to delimit a stationary state of the climate system in response to changes in the specific meteorological parameters. Hence, we can assess the possible damages suffered by the EU airports infrastructure. We make a vulnerability analysis of airports and changes in the volume of passenger and air cargo within the EU due to the SLR. This involves identifying the conditions under which it is possible adapting simply the infrastructure to climate change and where building safe to flooding new airports will be necessary. From our airports database we selected 865 airports inside the EU. 146 of them are large one, 458 of average size, 163 small, 15 heliports and 72 closed (see appendix 1).

1.2.2 The research method

The airports network is very unevenly distributed. Most of them are closely located to coasts and tend to be scarce in altitude. Figure 1 perfectly shows that from an altitude of 0 to 4 meters we may find 21 airports. Furthermore, from the sea level to an altitude of 15 meters, 20 percent airports fall. Almost half of Europe's airports are located at an altitude of less than 95 meters. 40,8 % of airport terminals are located in potential flood zones.

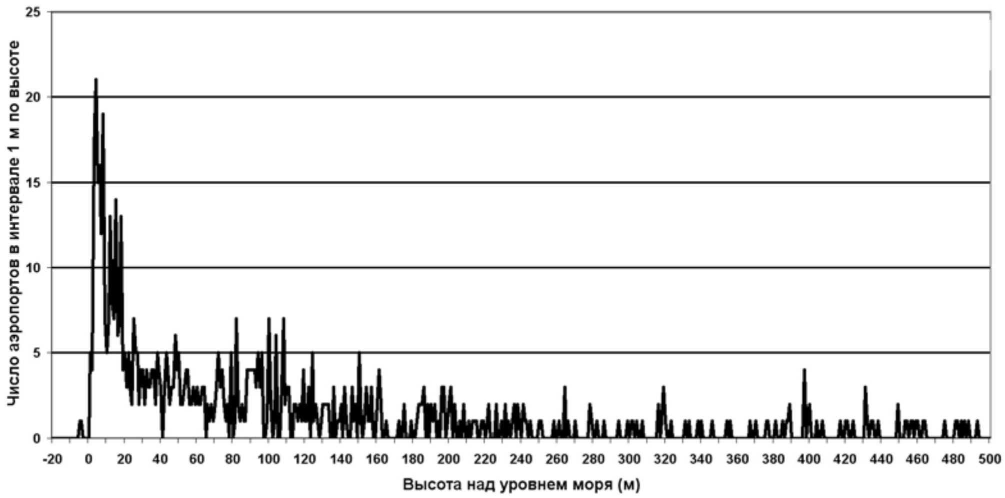

Figure 1. Density (of the order of 1 m) of the distribution of the airports number from the level of the sea to beyond.

Table 1 lists data concerning the air traffic types (domestic and international) and transportation centers. Most of air transport in the European Union consists in passengers’ transport. Table 1 shows that 67,29 % of passengers use major international airports while the proportion of domestic transport accounts for 20,56 %, which gives a leading role to major transport nodes. The mean-sized airports carry 11,725 % of passengers and the proportion of small airports and other air transport structures is insignificant.

Table 1

Transportation of passengers in the European Union for the year 2013

	Domestic air transportation, %	International air transportation, %	All passengers on board, %
Large airports	20,561	67,292	87,853
Secondary airports	5,376	6,349	11,725

	Domestic air transportation, %	International air transportation, %	All passengers on board, %
Small airports	0,026	0,017	0,042
Closed	0,005	0,001	0,006
No data	0,031	0,343	0,374
Total	25,998	74,002	100,000

Sources: Compilation by the authors of data Eurostat.

The data on the transport of freight and mail in the European Union are presented in table 2. Most of the traffic goes through the major airports 95,67 % (see table 2) and medium-sized airports represent only 4,05 % of the total traffic.

Table 2

Freight and mail in the European Union in 2013

	Domestic air transportation, %	International air transportation, %	All freight and mail on board, %
Large airports	5,713	89,961	95,674
Secondary airports	1,104	2,949	4,052
Small airports	0,007	0,000	0,008
Closed	0,000	0,000	0,000
No data	0,011	0,255	0,266
Total	6,835	93,165	100,000

Sources: data Eurostat.

We take away the data on the transport of passengers and cargo by helicopters, airships and marine aircraft because they are insignificant compared with the major carriers. For 2013, several small airports were closed (Table 1 and 2), but their contribution to the overall flow is extremely low. However, airports in the database «airports» are undefined objects corresponding to 0,374 % and 0,266 % of passengers and cargo and mail. Thus, for our analysis, the most important is the integration of large and medium-sized airports, all other types of air carriers' account for less than 1 % of the traffic.

1.2.3 SLR, economic consequences and future litigations

The results of the analysis of the SLR impacts on the reduction of the flow of transport of passengers, cargo and mail in the European Union are presented in table 3 for the whole set of the 865 European airports. The first ones to be flooded will be the two major airports located at the level –4 meters under the sea level. Table 3 corresponds to an abbreviated form. Until an altitude up to 25 m it presents the data in increments of 1 meter. Then, in the range of 25–65 m, the sample values are presented every 5 meters. Using our data base, we calculated the consequences of a mechanical rise of the sea level on airports that potentially may be affected. By simple calculus we also give an assessment of the activity losses in terms of passengers, freight and airmail-post. Rather than expressing them in monetary terms, we evaluate the losses in terms of activity percentages. This choice avoids the approximation of monetary data and, at this analysis level, this way gives more expressive figures.

Numerous large and medium-sized airports lie near major coastal cities. It is interesting to note that considering a given increase of the sea level, we have to take into account not only threaten airports. Hence, for instance, at a height of 2 meters, eleven airports are located under the sea level. However, we have to consider also the airports just above one meter. Hence, in the present case, four airports and the immediate superior range i.e. the ones that are located to three meters above the sea level. Indeed, as the seas rise, the extreme natural phenomena that provoke floods (storms) increase and threaten the whole infrastructure. At the level of 2 meters, not only 15 European airports may suffer but around 28. Obviously, this calculus is made independently from the particular geographical conditions of each airport where the effects of global warming may be increased or decreased. Nowadays, most of the climate litigations mainly concern environmental associations or victims against energy of energy-users firms or States. Even if trials against companies still do not succeed, growingly, corporations are involved by parties for their contribution to global warming. Hence, in a near future, because of exacerbated sudden floods linked to climate change, the future litigation could (will) concern airports governance versus private airways companies or insurance companies. Indeed, until now victims are inhabitants, private persons as under the Katrina event, or still association, however, as shows it table 3, airways corporations could endure financial losses: damaged planes, impossibility of flying or landing for passengers, freight or postal activities, etc. Lawyers could show that necessary prevention investment had not been undertaken in time by the early airports governance and/or local or national authorities.

Obviously, the different decision-takers will have to make decisive choices in a near future to protect the airports activities. To avoid legal liability, the airports governances need sufficient and concordant scientific information about the range of the future SLR and the question we raise is to know if, actually, this one is enough relevant. This information bear upon a huge range of data that concern the specific geographic location of the infrastructure, the local impact of climate change, the expected speed of the sea rise, the frequency of storms, etc. As seen above, the coastal airport governance’s choices cannot suffer contradictory and antagonist scientific views. However, concerning the SLR the field is far from being unified.

Table 3

Impact of the increase of the sea level on the reduction of the flow of passengers, cargo and mail in the EU (data Eurostat 2013)

Climat	Airports			Flights	Passengers			Cargo and mail		
Global sea level, m	The number of airports in a range of heights (1 m)	The number of airports below sea level	Airports, %	Flights, %	All passengers on board, %	The domestic airfreight, %	Of them internation alairfreight, %	freight and mail on board, %	domestic airfreight, %	international airfreight, %
0	0	2	0,2	3,1	3,5	0,0	3,4	9,9	0,0	9,9
1	5	7	0,8	3,1	3,5	0,0	3,4	9,9	0,0	9,9
2	4	11	1,3	3,4	3,9	0,1	3,8	10,0	0,0	10,0
3	17	28	3,2	4,4	4,8	0,3	4,5	10,4	0,0	10,4
4	21	49	5,7	8,0	8,3	1,5	6,8	11,6	0,2	11,3
5	15	64	7,4	11,0	11,2	2,6	8,6	12,6	0,4	12,2
6	16	80	9,2	13,9	13,6	3,1	10,5	13,6	0,5	13,1
7	12	92	10,6	14,6	14,4	3,4	11,0	13,7	0,5	13,2
8	19	111	12,8	16,1	15,9	4,0	11,9	13,9	0,7	13,2
9	7	118	13,6	17,6	17,7	4,5	13,2	14,0	0,7	13,3
10	5	123	14,2	17,9	17,8	4,7	13,2	14,0	0,8	13,3
11	7	130	15,0	18,7	18,3	4,8	13,5	14,4	0,8	13,6
12	13	143	16,5	19,6	19,1	5,3	13,8	14,5	0,9	13,6
13	8	151	17,5	20,0	19,4	5,4	13,9	14,6	0,9	13,6
14	7	158	18,3	20,2	19,5	5,5	14,0	14,6	0,9	13,6
15	14	172	19,9	21,4	20,4	5,9	14,5	14,7	1,1	13,7
16	6	178	20,6	21,6	20,4	6,0	14,5	14,7	1,1	13,7
17	7	185	21,4	23,3	22,2	6,4	15,8	14,9	1,1	13,8
18	13	198	22,9	24,0	22,8	6,7	16,1	15,0	1,1	13,8
19	4	202	23,4	24,0	22,8	6,8	16,1	15,0	1,1	13,8
20	5	207	23,9	24,7	23,5	7,3	16,2	15,0	1,1	13,9
21	3	210	24,3	24,8	23,7	7,4	16,3	15,2	1,3	14,0
22	5	215	24,9	25,0	23,8	7,5	16,3	15,2	1,3	14,0
23	3	218	25,2	25,8	24,6	7,7	16,9	15,6	1,5	14,1
24	2	220	25,4	26,4	25,2	7,9	17,3	15,7	1,6	14,1
25	7	227	26,2	26,9	25,6	8,0	17,6	15,7	1,6	14,2
30	4	247	28,6	31,2	31,1	8,8	22,3	25,4	1,6	23,8

Climat	Airports			Flights	Passengers			Cargo and mail		
Global sea level, m	The number of airports in a range of heights (1 m)	The number of airports below sea level	Airports, %	Flights, %	All passengers on board, %	The domestic airfreight, %	Of them internation alairfreight, %	freight and mail on board, %	domestic airfreight, %	international airfreight, %
35	4	263	30,4	31,9	31,8	9,1	22,6	25,5	1,7	23,8
40	3	281	32,5	34,5	34,1	9,9	24,2	26,1	1,8	24,3
45	2	295	34,1	39,4	38,7	11,0	27,6	27,4	2,1	25,3
50	5	316	36,5	43,3	42,9	12,5	30,4	27,6	2,2	25,4
55	4	331	38,3	46,7	46,7	13,5	33,2	29,3	2,3	27,0
60	3	343	39,7	48,6	48,4	13,6	34,8	32,0	2,4	29,6
65	0	353	40,8	50,8	51,2	13,9	37,3	32,6	2,4	30,2

Source: compiled by the authors according to Eurostat and database airports.

2. SLR litigations: the decision-makers' liability

Victims of natural hazards, environmental associations, corporations, Countries and regions, more and more resort to courts to repair or prevent damages due to climate change. Climate lawsuits are the citizen answer to the governments' inertia in their struggle against GHG emissions. Hence, nowadays, decision-takers are growingly concerned by choices made twenty years ago or more before a catastrophic event occurrence.

2.1 The growth of the climate lawsuits

Facing the government inertia in their struggle against global warming, associations and citizens bring to courts the climate change question. They use either tort law, or administrative litigation, or still human rights international jurisdictions. The consequences of floods and flood risk associated to rising sea levels increasingly nourish a new litigation that can be described as climatic lawsuit. Indeed, because they are victims of climatic harm, the applicants no longer hesitate to attribute its causes to human behavior and more specifically to States or large companies. This ones are either guilty of not having taken appropriate measures or of developing polluting activities. For ten years, hundreds of appeals are generated and all are not rejected by courts. This new dispute is mainly developing in the United States, Australia, and New-Zealand with very few cases in Europe. M.G. Gerrard (2015) shows that at the end of 2013 more than 420 cases have been resolved in the USA against 173 in the whole world. It is interesting to note that many lawsuits relate to the consequences of rising sea levels.

Markell and Ruhl (2010) published an empirical study that shows that most quarrels are intended to compel states or agencies in charge of the environment to limit GHG emissions. These trials accounted for nearly 40% of the whole litigations. In other words, most of them are initiated by Civil Society (individuals or associations), States, corporations and non-governmental organizations to require from the Federal government. Lawsuits under the Federal Common law are decreasing while regulatory claims increase. Some authors as Sigman (2007) consider legal litigations as public policy instruments in the struggle against climate warming. Evaluating fairly the decision-makers' responsibility in the wake of damage can only occur in the formal setting of a court. Indeed, recognition of the existence and the degree of a legal liability can only trigger the repair process. In most Earth's countries and regions, this litigation is either in its infancy or almost null. However, it tends to spread and many victims of the vagaries of global warming did not find other way than courts to have their voices heard. However, it is in the USA that climate litigation is spreading over the fastest. The courts fill an institutional vacuum to enforce laws related to global warming they play a «gap-filling role» following Hari Osofsky's words (Osofsky (2010)), or still, quoting Eric Posner: «*Litigation seems attractive to many people mainly because the more conventional means for addressing global warming – the development of treaties and other international conventions, such as the Kyoto Accord – have been resisted by governments*». E. Posner, (2007, p. 1925).

2.2 The importance of the SLR cases law in climate litigation

One among the first main climate lawsuit has been associated to the SLR. Indeed, in 2002, Tuvalu State threatened to take USA and Australia to the International Court of Justice because of their failure to stabilize GHG concentrations. Tuvalu claimed that global warming leads to a SLR (melting of ice caps) which threatens its territory. However, Tuvalu's government changed and the application stopped. One can ask what could have been the legal consequences of such a question without this event. Currently, there is no regime imposing liability for causing climate change – a State cannot be sued for directly causing climate change but for not taking relevant measures. Furthermore, the United Nations Framework Convention on Climate Change (UNFCCC) does have legal provision for such liability regime[1].

The US climate change precedents are mainly of three kinds. First, lawsuits nourish particularly administrative litigation (Statutory claims). Second, plaintiffs more rarely resort to Common Law. Third, they appeal to international courts (Public International Law Claims) that concern very few cases. Hence, civil and statutory claims remain the main court that deal with climate change litigation. Civil actions are intended, either to stop the damage, or to demand compensation. In the administrative courts, plaintiffs are challenging the decisions of the State (or States) in order to force them to effectively fight against global warming. In fact, five well known law cases structure the courts behavior facing climate change litigation. Most of them are related to the SLR. In our limited space, it seems difficult to make a comprehensive account of these various cases law. Hence, we rather concentrate on the cases associated to the rise of the sea level because victims perceive its importance through the damages they suffer (floods due to storms, hurricanes, and the worsening of coastal natural hazards): Native Vill. of Kivalina v. ExxonMobil[2], California v. Gen. Motors Corp.[3], Comer v. Murphy Oil USA[4], Connecticut v. Am. Elec. Power Co[5]. and Massachusetts v. EPA (or Environmental Protection Agency)[6].

Nowadays, judges are sensitive to global warming. Indeed, courts accept on the one hand the interest in bringing the parties. On the other one, they agree to consider that climate change can inflict damage. Hence, the judges not only admit that climate changes cause harmful damage to individuals (Kivali, Comer, op.cit.), regions and States (Massachusetts, op.cit), but also its anthropogenic origin. In addition, although the causal nexus to engage the responsibility of major polluters is not sufficiently demonstrated to allocate them damages, courts admit also that they participate by their activity to global warming.

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[1] For a more complete treatment of this view see for instance D. A. Weisbach (2012).

[2] Native Vill. of Kivalina v. ExxonMobil Corp., 663 F. Supp. 2d 863 (N.D. Cal. 2009)

(granting defendants' motion to dismiss); 2) California v. Gen. Motors Corp., No. C06-05755 MJJ, 2007 WL 2726871 (N.D. Cal. Sept. 17, 2007) (granting defendants' motion to dismiss).

[3] California v. Gen. Motors Corp., No. C06-05755 MJJ, 2007 WL 2726871 (N.D. Cal. Sept. 17, 2007) (granting defendants' motion to dismiss).

[4] Comer v. Murphy Oil USA, No. 1:05-CV-436-LG-RHW, 2007 WL 6942285 (S.D. Miss. Aug. 30, 2007) (granting defendants' motion to dismiss), rev'd, 585 F.3d 855 (5th Cir. 2009), panel opinion vacated en banc, 607 F.3d 1049 (5th Cir. 2010).

[5] Connecticut v. Am. Elec. Power Co., 406 F. Supp. 2d 265 (S.D.N.Y. 2005) (granting defendants' motion to dismiss), vacated, 582 F.3d 309 (2d Cir. 2009), cert. granted, 79 U.S.L.W. 3342 (U.S. Dec. 6, 2010) (No. 10–174).

[6] Massachusetts v. EPA, 549 U.S. 497, 516 (2007) (quoting Flast v. Cohen, 392 U.S. 83, 95 (1968)).

Among the above mentioned five cases, a successful action was the Massachusetts v. EPA case (op.cit). This dispute led by more than twenty parties – including twelve States, four territorial and local governments, and numerous trade associations started because the EPA did not want rule emissions from vehicles. EPA advanced that it had no authority to regulate such emissions and did not get cantilever with President Bush's environmental policy. Among the arguments, plaintiffs stated that:

«*According to petitioners' uncontested affidavits, global sea levels rose between 10 and 20 centimeters over the 20th century as a result of global warming and have already begun to swallow Massachusetts' coastal land. Remediation costs alone, moreover, could reach hundreds of millions of dollars.* Supreme Court of the USA, 2006, P. 23»[1]. This quotation is one among several in this direction. In fact, the Supreme Court argued that beyond CO2 emissions the real issue focused on the emission of pollutants, the position of EPA was regarded as «*arbitrary, capricious... or otherwise not in accordance with (statutory) law*[2]. « Then, a reform of the administrative legislation followed and EPA had to define a GHG emission regulatory framework. In spite of this statutory claim success, most of the time, lawsuits under Common Law failed. This explains by the difficulty of establishing any direct causal link between the effective damages that the Courts admit and the involved entities (mostly energy or related to energy companies). In all cases, regardless of the chosen jurisdiction, the minimum condition for inducing litigation is the existence of large scale damages. This point is summarized by Butti (2011, p. 33):

«*The most difficult standing-related hardship that applicants must face when filing emissions-related court claims is proving an emitter's direct responsibility. It is often argued that there are not a definitive number of entities liable for climate change, or that, on the contrary, this number is too great. Scholars have tried to overcome such hurdles by applying innovative theories on climate change liability, some of which aim to establish a link between local causation and local consequences. These doctrines may prove successful in those cases where the damages at stake are clearly identifiable (and, therefore, the obstacle of locus standi has already been surmounted) and where such damages occur in areas where major emitters directly operate*».

Recourse to civil courts in the context of global warming follows the same rules than «usual» prejudices. Hence, to see their request accepted by courts, the complainants must gather three conditions. The first is the existence of an interest in acting (standing for adjudication) which is associated with the injury. The second is the highlight of a causal link between the damage and the activities of polluters (causation). Finally, the third is the jurisdiction of the tribunal to define remedies and relief. These three elements apply to the civil courts (common law) and for administrative queries (statutory claims). In the United States, the standing question is linked to the nature of the damage. Accordingly, the Kivali village in Alaska argued that the climate change highlighted the strength of storms, the rise of water associated with the melting of the icebergs and the erosion of the shore resulting in a deterioration of

[1] Supreme Court of the USA, 2006, syllabus, Massachusetts Et Al. V. Environmental Pro-Tection Agency Et Al. Certiorari To The United States Court Of Appeals For The District Of Columbia Circuit, 2006. http://www.arnoldporter.com/resources/documents/Mass_v_EPA.pdf.

[2] Massachusetts, 549 U.S. at 528 (quoting 42 U.S.C. § 7607(d)(9) (2006)) (internal quotation marks omitted).

the quality of life of its inhabitants. Plaintiffs questioned all the actors that they thought responsible for global warming that is primarily the EXXON Corporation and major energy companies[1]. In fact, this case falls within litigation which dismisses the plaintiffs' claims. Indeed, these last ones have relied on Common Law which requires the accurate identification of those responsible in the reconstitution of the causal chain that was impossible here.

Victims resorted also to anthropic climate change concerning Katrina disaster in the Mississippi Gulf Coast in 2005. The hurricane victims tried to obtain reparations pursuing thirty four major oil and energy companies actively involved in global warming[2]. However, on May 14, 2013, the U.S. Court of Appeals for the Fifth Circuit affirmed the dismissal of Comer v. Murphy Oil USA, Inc., 718 F.3d 460 (5th Cir. 2013) (Comer II) concerning the plaintiffs' second attempt to recover damages. The Fifth Circuit concluded that the petitioners' claims were barred by res judicata. However, among plaintiffs almost succeed in the Saint Bernard Parish Government, et al., v. the United States[3]. Indeed, landowner's victims for the Hurricane Katrina considered that they suffered a taking of property without just compensation by the United States government. The court found negligent the Army Corps of Engineers' (the Corps) and underlined a failure to maintain the Mississippi River Gulf Outlet (MR-GO), that this Corps constructed in the 1950s. However, court of appeals for the Fifth Circuit dismissed the judgment.

In the California State v. General Motor case[4], California sued six car companies plaintiff arguing about the disorders induced by the Climate Change and among them the consequences of the SLR. Consequently, «*Plaintiff requests monetary damages, attorneys' fees, and declaratory judgment for future monetary expenses and damages incurred by the State of California in connection with the nuisance of global warming*». However, the Court dismissed the case considering that six formulations indicate the existence of non-justiciability. This fact corresponds to political questions, i.e. those questions that are better responded by the legislative or the executive divisions and mainly concern foreign and public policy, and political issues. They are deemed inappropriate for courts by the Constitution.

An important law case remains Connecticut v. Am. Elec. Power Co[5] that after the 2011's Supreme Court decision prevents for a long time to access to federal common law. Indeed, in 2004, eight states, the City of New York, and three land trusts, alleged that the five largest emitters of GHGs in the United States (Am. Elec. Power, Cinergy Co., Southern Co. Inc. of Georgia, and Xcel Energy Inc. of Minneso-

[1] Native Vill. of Kivalina v. ExxonMobil Corp., 663 F. Supp. 2d 863, 877 (N.D. Cal. 2009) (citing *Lujan*, 504 U.S. at 559–60 (1992)) (discussing the need to fulfill standing requirements).

[2] Comer v. Murphy Oil USA, Inc. (S.D. Miss. dismissed Aug. 2007) (5th Circ. partially reversed dismissal Oct. 2009) (en banc petition for rehearing granted Feb. 2010) (appeal dismissed May 2010) (petition for writ of mandamus filed by plaintiffs Aug. 2010) (writ denied Jan. 2011) (complaint refiled May 2011) (dismissed March 2012) (notice of appeal filed April 2012) (5th Cir. affirmed dismissal May 2013).

[3] St. Bernard Parish Government v. United States, No. 1:05-cv-01119 (Fed. Cl., filed 2005), see also Government Found Liable for Hurricane Katrina Flooding Posted on May 11th, 2015 by Jennifer Klein - See more at: http://blogs.law.columbia.edu/climatechange/2015/05/11/government-found-liable-for-hurricane-katrina-flooding/#sthash.nO5AHN1o.dpuf

[4] California v. Gen. Motors Corp., op.cit.

[5] Connecticut v. Am. Elec. Power Co., 406 F. op.cit.

ta, (collectively emitting 650 million tons of carbon dioxide annually in twenty states) are a public nuisance because their carbon-dioxide emissions contribute to global warming which, consecutively, led to serious environmental consequences. After several divergent views between the District Courts that dismissed the claim before trial, considering that global warming are «political questions» that should be resolved by the legislature, not by the courts. The Second Circuit Court of Appeals considered that courts can hear such cases, and, plaintiffs have to bear the burden of proof. Then, the last word remained to the United States Supreme Court that said that because the Clean Air Act (CAA) allocates the controlling of carbon dioxide and other GHG emissions to EPA, the defendants (the electric companies) cannot be indicted for GHG under federal common law[1].

In conclusion, local courts are substituting themselves to the lack of international regulatory bodies concerning responsibilities in the GHG excessive emissions. Consequently, they are appropriate entities that may engage the liability of any State, region, company or individual who, directly or indirectly, contribute in increasing the global warming (Kassman, (2013)), this in so far that statutory claims are required and not federal common law. In other words, although originally, the local courts are created to solve local conflicts, in some cases, if sufficient conditions are met, they can become involved in solving a global phenomenon. Hence, it follows that any decision-maker who is in charge of activities that could contribute damaging the climate can potentially be held responsible for climatic harm.

3. Scientific uncertainty and the decision-makers' liability

Concerning airports, the decision-taker will have either to adapt progressively his/her facility to climate changes (for instance building or reinforcing dykes) or to change the installation location. This is an irreversible choice that does not suffer compromise: either he/she adapts existing infrastructures, or, because of the flooding risks, increased storms, he/she moves them it off on a safer place. About airports, their progressive adaptation to global warming is possible up to 1 meter level, which corresponds to an acceptable economic cost of maintenance of existing infrastructure. Beyond one meter, even if structurally, the adaptation is possible, extreme events (flooding associated to storms or all detrimental coastal hazards associated to global change) could structurally affect the airports and all associated amenities. This fact could deter insurance companies to continuously insure fragile to climate infrastructures. Hence, in this field, bad choices could have deep consequences. After a harm occurrence, the decision-makers' legal liability highly depends on the relevancy of the choices they made a long time previous the catastrophic event. However, this one lays about the available scientific knowledge and, at the present, concerning the SLR, scientists can supply some poor level of certainty.

3.1 Do SLR's scientists offer enough certainties to decision-takers?

Let us consider a coastal airport's governance that is particularly aware about SLR's consequences. He/she intends to plan for the long term future mitigating investments. For instance, airport may be located on the Mediterranean coast for near

[1] See Schwartz, Goldberg , and Appel, 2012.

seashore airports as Barcelona (1m) or Nice (2–3 m) or, still, Roma (Leonardo da Vinci, 3 m). Let us assume that the planner prospects for the future forty years (2055). What are the factors he should take into considerations? Can he reasonably rule out the assumption of the necessity to find another location to build a new airport? To answer this question needs to have a clear view of the scientific state of the art about SLR. Indeed, the decision-maker faces several unknown data. Mainly, we can define three scenarios. The first one corresponds to the IPCC one that considers that the sea rise does not go beyond one meter during the 21st century. The second one comes from scientists that raise doubts about the IPPC's view. This is declined considering the three following points: i) The relevancy of the 2 °C assumption, ii) Sea-level rise and past warm periods and, iii) The relevancy of semi-empirical models that deal with SLR.

3.1.1 Discussing about the 2 °C benchmark

The 2 °C air temperature above the preindustrial area is the assumption that IPCC considers as an effective benchmark. Is the choice of this level based on strong scientific evidence? Clearly, it is not and we will discuss it below. However, beyond this level, IPCC thinks that the risks associated to climate change will dangerously increase. Consequently, States will have to devote financial and economic resources to limit global GHG emissions to a level that does lead global temperature beyond 2 C. However, maintaining and accepting this level raises questions about the effectiveness of the effects of the climate change and especially the SLR. Concerning the projections for 2100, the IPCC 5th report (13, Sea Level Change) or IPCC 5th AR13) admits that its fourth report (2007) underestimated the relationship between global warming and SLR («*Confidence in projections of global mean sea level rise has increased since the Fourth Assessment Report (AR4) because of the improved physical understanding of the components of sea level, the improved agreement of process-based models with observations, and the inclusion of ice-sheet dynamical changes*». In IPCC 5th AR13, p. 1139).

The main 2007's failure was the lack of relevant data about ice flow from the poles. Taking it into count involves that, basically, IPCC estimates the sea level rise of 28 (low assumption) to 98 centimeters (high assumption) by 2100 (which is more than 50 percent higher than the 2007 projections). However, IPCC recognizes relevant uncertainties about the oceans dynamics. Among them we can quote the steric sea level, the dynamical response of the ocean to meltwater input or the GIA/rotational/gravitational processes associated with this ice mass loss, the necessity of better parametrization of physical models etc.

If we report to the table 3 (or 4), an increase about 98cm (near 1 m) of the sea level, then, this involves that 5 airports will be in a range of heights (1 m) and 7 below the sea level. Consequently, at the European level, taking into account of the IPCC assessment involves that 12 airports will need serious amenities. Furthermore, 5 among them will be in the range of the previous one meter while 7 of them need mitigating or moving off solutions. This will impact on the airports activities like shows it the impact on flights (3,1 %), passengers (3,5 %), freight (9,9 %) and air post-mail (9,9 %). However, the detrimental consequences do not stop here, because airports located in the altitude of today 2 meters, will be also concerned because of the change in the intensity in storms and floods that largely remain unknown. Hence, maintaining the 2 °C assumption does not prevent uncertainties about the effective consequence about the SLR.

Furthermore, Petra Tschakert (2015) shows that the 2 °C benchmark is a highly controversial issue. It appears much more as a compromise than an effective scientific value. Hope and Pearce (2014) recall how this value, previously defined by the economist Nordhaus in 1975, progressively became the actual indisputable benchmark for social scientists that define IAM models and policy makers. Reaching this point, we must distinguish two things. The first one is the relationship between the 2°C benchmark and the rise of sea level in the IPCC's opinion which is limited in its scenario to almost a rise of one meter. The second thing is about the consequence for some threatened Countries by the ocean rise. We can quote Tschakert (2015, p. 2): «*Among parties to the United Nations Framework Convention on Climate Change (UNFCCC), many Caribbean states proclaimed already at COP15 that a 2 °C temperature rise was unacceptable as a safe threshold for the protection of small island states and that even a 1,5 °C increase would undermine the survival of their communities*».

This contestation does not put into question the IPCC's view on the SLR (1m) and will not be considered here. More embarrassing is the analysis of Rogelj and alii (2012) that shows that the 2 °C target involves the formulation of numerous hazardous assumptions on the efficiency of technologies to reach it. Indeed, stabilizing global temperatures requires limiting the emission of accumulating greenhouse gases and this involves technological changes and strong carbon saving innovations (electro-nuclear parks, bio-gases, etc.). This viewpoint adds to the recent comments of Peters and ali (2013) for whom reaching +2 °C or less of global warming is possible but this require cutting CO_2 global emissions by 3 % per year, starting by 2020. This involves attaining peak rate at this date, beyond, as the article says the goal of limiting global warming to 2 °C may become unfeasible.

In conclusion, even if he believes that the relationship between the increases of 2 °C is linked to a rise of the sea level of about one meter, the airport decision-maker may duly raise doubts about the capacity of nations to reduce GHG emissions to an acceptable level. Evidence of the contrary is the continuous use of CO_2 energy emitters. This fact constitutes the first uncertainty cause that should lead coastal airport decisioners to consider alternative locations rather than long term mitigation measures.

3.1.2 Sea-level rise and past warm periods in the range of 2 °C

Another scientific contention source that may influence the air decision-taker concerns some scientists' conception about the effective SLR in a near future regarding the past warming period where the temperatures were over or near 2 °C as by now. Two 2015 contributions insist on the consequences of such changes if the same conditions gather in the present times. Dutton, A.E. Carlson, A.J. Long, G.A. Milne, P.U. Clark, R. DeConto, B.P. Horton, S. Rahmstorf, M.E. Raymo, (2015) underline that present climate is warming to a level similar to significant polar ice-sheet loss in the past. They outline advances and challenges involved in constraining ice-sheet sensitivity to climate change with use of paleo-sea level records. Hansen and alii (2015) show that glaciers in Greenland and the Antarctic could melt 10 times faster than projections put forward by the IPCC. For Hansen and alii (2015) the nowadays average global temperatures are only less than a degree cooler than they were during the last major interglacial or 'Eemian' period 120,000 years ago. In these times, global temperatures stood just 2 °C above the pre-industrial climate and sea levels raised at five to nine meters upper than they are today.

If we rely on these different authors' views, it appears that a progressive increase of oceans about an intermediary level of six meters will concern about 80 airports situated under the sea level, while 16 are in the direct neighboring of 1 meter (table 3). As ever mentioned above, this involves that 12 of them are under the threat of flooding (the one concerned by an increase of water of 7 meters). Globally, this corresponds to 13,6 % of airports and about 13,6 % of the passengers' traffic. Obviously, these last figures have to be cautiously taken because these are data of 2013 for future times. For higher levels of sea rise, the number of concerned airports is much higher. It seems useless to go further in the economic consequences as it is sufficient to look at table 3.

3.1.3 Can airports' managers rule out the semi-empirical models?

Currently, until now, no accepted models that describe the global sea level variations linked to change in the Earth's climate do exist. Climate models contain a large number of parameters and use supercomputers for grid technologies. Secure forecasts involve assessing heat and mass transfers, including phase transitions (melting ice, and freezing and evaporation of water). However, evaluating the correspondent changes in the global sea level is too time-consuming.

In a previous work (Sorokin and Mondello (2013)) following the of Hansen (2007) and Rahmstorf (2007) works' highlighted the links between changes on the planet average surface temperature and rising sea levels compared to pre-industrial times. By hypothesis, this model considers as stationary the present sea level. The study assesses the significance of the rise in sea levels associated with the increase in average temperatures on the planet. This is a semi-empirical model in the Hansen 2007's tradition. Its main feature is exposed in appendix 2. This kind of model considers a close relationship between global warming and the rise of oceans. There are various estimates for identifying some possible levels of climate warming; these vary from 1 °C to 5,8 °C and higher (IPCC (2012)). However, none establishes a unique relationship between the change in temperature and the rise of the sea level. Currently, considering global warming, for a short term (until 2100), the European Union considers that the increase in sea level will be around 1 meter for a temperature increase of 2 °C (European Union Commission (2013)). However, if we assume that currently the average temperatures rose by 0,8 °C compared to the pre-industrial values, then the seas levels increase proportionnally. For the contemporary period, this is an expected value of 0,21 meters compared to the era of industrial development. Table 4 shows that the rising water at 1 m will lead to the flooding of 7 airports (0,08 %) and the reduction of about 3,5 % in passengers and about 9,9 % in transport and cargo and mail. For the sector, such changes in air traffic will not lead to catastrophic consequences. However, it should be noted that at present, such a strategy for adapting to the elevation level of 1 m sea does not exist.

In table 4, we calculate the excess of the average air temperature at the Earth surface ΔT_S for the stationary values of the level of the oceans SL_{st} that corresponds to the preindustrial era, following the formula:

$$\Delta T_S = \frac{SL_{st}}{7,5}, \text{ where } SL_{st} \geq 0.$$

Hence, further increase in the overall level of the sea of 6 m (equivalent to the level currently exceeded by an increase in the average temperature of 0,8 °C relative to the pre-industrial era of development) would inundate 80 airports (9,2 %) and lead to a reduction of air traffic by 13,6 % (see table 4). Similar economic losses are considered to be unacceptable and could lead to many bankruptcies of airlines and the collapse of the whole airline industry.

If we return back to the EU's adaptation strategy to climate change of 2 °C, our model shows that in the long run, this temperature will lead to rising sea levels up to 15 meters (see Appendix 2 for more details). Consequently, this involves the flooding of 172 airports (19,9 %), a reduction of 20,4 % in passenger traffic and cargo by 14,7 % (Table 4). The EU strategy on adaptation to climate change does not consider the possibility of a SLR in the upper level 1 m. In the near future, this restriction could lead to catastrophic economic losses. We do not take the worst-case scenario of a 8,67 ° C warming on the planet. This level melts the icecaps and the rise of the sea level will be 65 meters (National Geographic (2013)). This can lead to a loss of 40,8 per cent of all airports in the European Union, to reduce by half the flights and passenger flows and reduces the amount of cargo and mail by 32,6 % (Table 4).

As mentioned in the introduction we rather stick our analysis to the internationally well-accepted level of 2 °C increase in temperature above the pre-industrial area. Obviously we do not know if in the end of this century this level will be reached or not. Following Table 4, at a level of 2 °C, the rise of the sea level could reach 15 meters according our logistic model.

Table 4

Data from the logistic model and impact of the increase of the sea level on the reduction of the flow of passengers, cargo and mail in the EU (data Eurostat 2013)

Climat		Airports			Flights	Passengers			Грузы и почта		
Tempera-ture °C	Global sea level, m	The number of airports in a range of heights (1 m)	The number of airports below sea level	Airports, %	Flights, %	All passengers on board, %	The domestic airfreight, %	Of them internation-alairfreight, %	freight and mail on board, %	Domestic freight, %	International freight, %
0,00	0	0	2	0,2	3,1	3,5	0,0	3,4	9,9	0,0	9,9
0,13	1	5	7	0,8	3,1	3,5	0,0	3,4	9,9	0,0	9,9
0,27	2	4	11	1,3	3,4	3,9	0,1	3,8	10,0	0,0	10,0
0,40	3	17	28	3,2	4,4	4,8	0,3	4,5	10,4	0,0	10,4
0,53	4	21	49	5,7	8,0	8,3	1,5	6,8	11,6	0,2	11,3
0,67	5	15	64	7,4	11,0	11,2	2,6	8,6	12,6	0,4	12,2
0,80	6	16	80	9,2	13,9	13,6	3,1	10,5	13,6	0,5	13,1
0,93	7	12	92	10,6	14,6	14,4	3,4	11,0	13,7	0,5	13,2
1,07	8	19	111	12,8	16,1	15,9	4,0	11,9	13,9	0,7	13,2
1,20	9	7	118	13,6	17,6	17,7	4,5	13,2	14,0	0,7	13,3
1,33	10	5	123	14,2	17,9	17,8	4,7	13,2	14,0	0,8	13,3
1,47	11	7	130	15,0	18,7	18,3	4,8	13,5	14,4	0,8	13,6
1,60	12	13	143	16,5	19,6	19,1	5,3	13,8	14,5	0,9	13,6
1,73	13	8	151	17,5	20,0	19,4	5,4	13,9	14,6	0,9	13,6
1,87	14	7	158	18,3	20,2	19,5	5,5	14,0	14,6	0,9	13,6
2,00	15	14	172	19,9	21,4	20,4	5,9	14,5	14,7	1,1	13,7
2,13	16	6	178	20,6	21,6	20,4	6,0	14,5	14,7	1,1	13,7
2,27	17	7	185	21,4	23,3	22,2	6,4	15,8	14,9	1,1	13,8
2,40	18	13	198	22,9	24,0	22,8	6,7	16,1	15,0	1,1	13,8
2,53	19	4	202	23,4	24,0	22,8	6,8	16,1	15,0	1,1	13,8
2,67	20	5	207	23,9	24,7	23,5	7,3	16,2	15,0	1,1	13,9
2,80	21	3	210	24,3	24,8	23,7	7,4	16,3	15,2	1,3	14,0
2,93	22	5	215	24,9	25,0	23,8	7,5	16,3	15,2	1,3	14,0
3,07	23	3	218	25,2	25,8	24,6	7,7	16,9	15,6	1,5	14,1
3,20	24	2	220	25,4	26,4	25,2	7,9	17,3	15,7	1,6	14,1
3,33	25	7	227	26,2	26,9	25,6	8,0	17,6	15,7	1,6	14,2
4,00	30	4	247	28,6	31,2	31,1	8,8	22,3	25,4	1,6	23,8

Climat		Airports			Flights	Passengers			Грузы и почта		
Tempera-ture °C	Global sea level, m	The number of airports in a range of heights (1 m)	The number of airports below sea level	Airports, %	Flights, %	All passengers on board, %	The domestic airfreight, %	Of them internation-alairfreight, %	freight and mail on board, %	Domestic freight, %	International freight, %
4,67	35	4	263	30,4	31,9	31,8	9,1	22,6	25,5	1,7	23,8
5,33	40	3	281	32,5	34,5	34,1	9,9	24,2	26,1	1,8	24,3
6,00	45	2	295	34,1	39,4	38,7	11,0	27,6	27,4	2,1	25,3
6,67	50	5	316	36,5	43,3	42,9	12,5	30,4	27,6	2,2	25,4
7,33	55	4	331	38,3	46,7	46,7	13,5	33,2	29,3	2,3	27,0
8,00	60	3	343	39,7	48,6	48,4	13,6	34,8	32,0	2,4	29,6
8,67	65	0	353	40,8	50,8	51,2	13,9	37,3	32,6	2,4	30,2

The above scenarios question the well accepted opinion of a close relationship between a 2 C° rise of temperature with a one meter SLR. Our object is not discussing about the effective SLR but to understand how could behave an airport manager when he must take strategic decision facing divergent scientific opinions. In fact, the clue lies partially in the definition of liability.

3.2 Sharing liability as a consequence of scientific uncertainty

In what follows, we assess how decision-makers could be considered as legally liable when they have to take decisions in a controversial scientific environment. This involves also the scientists' liability without that this last one could issue on a *stricto sensus* legal liability.

3.2.1 The scientists' liability question

Concerning technological or natural hazards, decision-takers are increasingly requiring scientists' advices and councils. This may be done by referring to specialized risk agencies or experts. About the SLR, for Marzeion and Levermann (2014) this involves dealing with quantifiable and unquantifiable uncertainty. However, this high uncertainty factor does not prevent the legal liabilities of decision-makers that have to face the necessity to make irreversible choices. Hence, as ever mentioned above, populations can attempt indicting experts as in the Katrina case where, in a first round trial, the Army Corps of Engineers' (the Corps) has been considered as partially liable. Hence, nowadays, scientists cannot fully escape liability.

Indeed, in case of major harm, too low prevention level could induce victims to sue both decision-makers and experts. Consequently, to avoid liability, all of them must be sensitive to the nature of the economic decisions they take. Facing a kind of «bang-bang» choice (hugely investing in safety or not), the decision-takers face a kind of dilemma whenthe experts' advices give a fifty-fifty chance for each option. A cautious behavior will lead them to invest, but scarce resource or their high degree of optimism could involve the reverse. However, when clear decision rules are lacking, the judge should make weaker the regulator's liability. Indeed, the Courts can take into consideration the lack of information or the expert's ambiguous opinion and they can exonerate the decision makers.

Nevertheless, when the scientists' advice is fundamental this can lead them to prosecution. We recall that after the Aquila earthquake on April 6, 2009, a trial, lasted from September 2011 until October 2012 and found six scientists and a former government official guilty of involuntary manslaughter. They were criticized in court for being «falsely reassuring» and Judge Marco Billi gave them a six-year jail sentence on 22 October 2012. According the judge, they had provided «*an assessment of the risks that was incomplete, inept, unsuitable, and criminally mistaken*», see Hall (2011). This kind of trial is not the rule but exception; however, public decision and scientific advices bear liabilities that can lead their authors to face Courts. Italian scientists' viewpoint was too clear about the Aquila earthquake risk and misled the Authorities. It was a kind a take-or-leave decision as «acting» against «doing nothing» and they induced the decision makers to choose the second decision. Hence, the weight associated to weak earthquake consequences was stronger than the opposite.

3.2.2 Threaten airports and governance's liability

Under radical uncertainty it seems difficult to make the governance of airports' (or more generally infrastructures) fully responsible for potential damages. In fact, their liability depends heavily of how the local and national authorities, the European Union have considered (or consider) the rise of seas associated to climate change. Indeed, we could distinguish two main cases that depend on either the convergence of scientists' views about a given event (here the strength and the range of the rise of the seas) or their divergence.

Case 1: *Convergent views among scientists*.

The convergence of views may bear on a high or a moderate increase of the sea level. The important thing is the decision-makers' beliefs about it. We may suppose that convergence on a low increase will reach more easily decision-takers agreement than a high one. Nevertheless, the important thing is scientists' consensus about the causes and above all the consequences of a given phenomenon. Indeed, in any case, the airport's governance should accept the scientists' opinion. Scientific consensus about a given increase of the sea level, in case of harm, and the judge can verify that no relevant protection measures have been undertaken in time, then the airports governance will be fully liable. Indeed, the judge will consider that no complying with expert and scientific opinion is clearly negligence and consequently a fault (Klein (2015)). More interesting is the second case in which scientists have divergent opinion.

Case 2: *Divergent views among scientists.*

Obviously, the divergence bears upon the range of the rise of the sea level. Hence, some scientists may consider that this one could be high, while the second ones will consider the reverse. What does this scientific opinion discrepancy means for the infrastructures' decisioners? In this case allowing liability in case of harm on infrastructures could be quite difficult.

In fact, if we consider table 4 (or 3), it appears that different opinions among scientists involve ipso-facto uncertainty on the future of a lot of airports. For instance, let us consider the actual discrepancy between IPCC and the scientists that consider past warming periods. In this case, the dispute between scientists concern among one hundred airports.

Under a moderate rise of the oceans (as for instance around 1 meter as IPCC and European Union assess it), few airports will be involved. Hence, and in case of severe harm on one given airport, if its governance did not take serious precaution in due time to prevent the harm, then, this last one will be fully liable (whatever the legal for of this responsibility (strict liability, negligence, criminal, etc.)). This involves that the evidence for a moderate increase of the seas is strong enough to convince stakeholders to undertake light mitigation works to protect the airports. However, the question is not how moderate will be the ocean rise under climate change, but how relevant is the scientific knowledge and sufficiently convincing to induce decision-makers to take due care in due time?

In fact, under strong scientific divergence as it is actually the case, the judges will have to understand how was shared and accepted the scientific common knowledge of this time among the airports decision-takers at the international level.

Here, the relevant level is the European Union governance. Indeed, if we consider the actual uncertainty about the SLR, the interval of concerned airports on 85 years (2015–2100) regards almost one hundred airports. This means that at the European Union level, the question does not bear only on airports alone, but on the whole activities (airports, roads, railways, stations, metro, real estates, industrial and commercial activities) linked with airports. The question is then quite simple even if the answers are extraordinarily complex: Is it preferable to defend in place the infrastructures or to moving away the whole infrastructure on a new area. At the EU level, the answers depend on the beliefs and consensus among the stakeholders about the scientific debate.

4. Conclusion

The rise of oceans due to changing climate is one among the main stake that faces the scientist who studies the causes and effects of global warming. This paper's main concern bears on the collaboration between scientists and economists concerning the liability of governance of coastal airports facing the SLR. Hence, its object is not bringing light about the scientific roots and the extent of the SLR in the future. The point we mainly focus on is about how responsible stakeholders should behave facing radical scientific uncertainty. Can they believe fully the European Union and IPCC conclusions about the rise of the sea level that associates a 2 °C rise of temperature and a related increase of 1 meter of the sea level around 2100? This means that they consider these values as sufficiently relevant or, in the opposite, should they take also in consideration other scientific views considering that the above benchmarks are too low estimates?

We conclude that if new scientific knowledge and scientific opinions are sufficiently convincing for raising sufficiently doubts, then, the airports decision-takers should apply the precautionary principle that roughly says that «*When human activities may lead to morally unacceptable harm that is scientifically plausible but uncertain, actions shall be taken to avoid or diminish that harm*». This means that they should adopt cautious decisions that consist for a great panel of airports to consider moving of toward less threaten areas.

The paper did not advance specifically this direction because several point had to be seen before. This is the object of a future paper more explicit on this point.

Bibliography

ACRP Synthesis Project – *Airport Climate Change Adaptation and Resilience*. In progress. http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3106.

Baglin, Chris (2012). «Airport Climate Adaptation and Resilience A Synthesis of Airport Practice», Airport Cooperative Research Program.

Barth, M. C., and J. G. Titus, eds. 1984. *Greenhouse effect and sea level rise: A challenge for this generation*. New York: Van Nostrand Reinhold Company.

Brown S, Nicholls R, Woodroffe C, Hanson S, Hinkel J, Kebede AS, et al. (2013). «Sea-Level Rise Impacts and Responses: A Global Perspective». In: Finkl CW, editor. Coastal Hazards. Netherlands: Springer: pp. 117–149.

Bruun, P. 1962. Sea level rise as a cause of shore erosion. *Journal of Waterways and Harbor Division. American Society of Civil Engineers* 88:117–130.**o**

Burbidge, Rachel (2013) «Adapting to Climate Change – The Time to Act is Now», ACRP_Synthesis 33.

Butti, Luciano. (2011). «The Tortuous Road to Liability: A Critical Survey on Climate Change Litigation in Europe and North America», *Sustainable Development Law & Policy* 11, no. 2: 32–26, 82–84.

Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013: Sea Level Change. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1137–1216, DOI:10.1017/CBO9781107415324.026.

Dasgupta, Susmita, Benoit Laplante, Siobhan Murray, David Wheeler(2009), «Sea-Level Rise and Storm Surges: A Comparative Analysis of Impacts in Developing Countries Policy Research Working Paper 4901, The World Bank, WPS4901.

Dutton, A., A. E. Carlson, A. J. Long, G. A. Milne, P. U. Clark, R. DeConto, B. P. Horton, S. Rahmstorf, M. E. Raymo, (2015) «Sea-level rise due to polar ice-sheet mass loss during past warm periods»: Science 10 July 2015: Vol. 349 no. 6244: DOI: 10.1126/science.aaa4019.

Everts, C. H. 1985. Effects of sea level rise and net sand volume change on shoreline position at Ocean City, Maryland. In *Potential impacts of sea level rise.* See Titus, 1985. Hull, C. H. J., and J. G. Titus, eds. 1986. Greenhouse effect, sea level rise, and salinity in the Delaware Estuary.

Eurostat. URL: http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database.

European Union Commission, (2013). «An EU Strategy on adaptation to climate change. Impact Assessment»; Part 2. 16/04/2013 – SWD (2013) 132. URL: http://ec.europa.eu/clima/policies/adaptation/what/docs/swd_2013_132_2_en.pdf.

Gosselink, J. G., E. P. Odum, R. M. Pope. 1974. *The value of tidal marsh*. Baton Rouge: Center for Wetland Resources, Louisiana State University.

Gunter, G. 1974. An Example of Oyster Production Decline with a Change in the Salinity Characteristics of an Estuary – Delaware Bay, 1800–1973. *Proceedings of the National Shellfish Association*. 65:3.

Hansen J.E. (2007): Scientific reticence and sea level rise. *Environ. Res. Lett*., 2, 024002 (6 pp.)

J. Hansen, M. Sato, P. Hearty, R. Ruedy, M. Kelley, V. Masson-Delmotte, G. Russell,

Hinkel Jochen, Daniel Lincke, Athanasios T. Vafeidis, Mahé Perrette, Robert James Nicholls, Richard S. J. Tol, Ben Marzeion, Xavier Fettweis, Cezar Ionescu,, and Anders Levermannc,(2014), «Coastal flood damage and adaptation costs under 21st century sea-level rise», PNAS, March 4, 2014 , vol. 111,no. 9, 3297 http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3948227/#r1.

Hope, Chris. 2006. «The Marginal Impact of CO2 from PAGE2002: An Integrated Assessment Model Incorporating the IPCC's Five Reasons for Concern». Integrated Assessment, 6(1): 19–56.

Hope Mat and Rosamund Pearce, (2014), «Two degrees: The history of climate change's 'speed limit', Carbond Brief Dec 2014, in http://www.carbonbrief.org/blog/2014/12/two-degrees-a-selected-history-of-climate-change-speed-limit.

Intergovernmental Panel on Climate (IPCC), (2012). Chapter 3: Changes in Climate Extremes and their Impacts on the Natural Physical Environment in Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.

Intergovernmental Panel on Climate (IPCC), (2013) or Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013: Sea Level Change. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1137–1216.

Kassman, Erica D., 2013. «How Local Courts Address Global Problems: The Case Of Climate Change», Duke Journal Of Comparative & International Law, Vol 24:201–247.

Klein, J. (2015), «Potential Liability of Governments for Failure to Prepare for Climate Change», August, http://blogs.law.columbia.edu/climatechange/2015/08.

Larsen, P. H., S. Goldsmith, O. Smith, M. L. Wilson, K. Strzepek, P. Chinowsky, and B. Saylor, 2008: Estimating future costs for Alaska public infrastructure at risk from climate change. *Global Environmental Change*, 18, 442–457, DOI:10.1016/j.gloenvcha.2008.03.005. http://linkinghub.elsevier.com/retrieve/pii/S0959378008000216.

Los Angeles World Airports (2010), Climate Change Adaptation Planning Excerpts from *LAWA Sustainable Airport Planning, Design, and Construction Guidelines*, Version 5.0, February. 2010. URL: http://www.lawa.org/uploadedFiles/LAWA/pdf/LSAG%20Version%205.0%20021510.pdf.

Makiko Sato & James Hansen. Updating the Climate Science. What Path is the Real World Following? ColumbiaUniversityEarthInstitute. URL: http://www.columbia.edu/~mhs119.

Markell, David L. and Ruhl, J. B. (2010). «An Empirical Survey of Climate Change Litigation in the United States»; FSU *College of Law, Public Law;* Research Paper No. 433; FSU College of Law, Law, Business & Economics Paper No. 10–5. Available at SSRN: http://ssrn.com/abstract=1585341 or http://dx.doi.org/10.2139/ssrn.1585341.

National Geographic. URL: http://ngm. Nationalgeographic.com/2013/09/rising-seas/if-ice-melted-map.

Neumann, B., Vafeidis, A. T., Zimmermann, J., & Nicholls, R. J. (2015). Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding-A Global Assessment. *PloS one*, *10*(3), e0118571.

OurAirports. URL: http://ourairports.com/data.

Hari M. Osofsky, (2010). *The Continuing Importance of Climate Change Litigation*, 1 Climate L. :1878–1886.

Peters Glen P., Andrew Robbie, M. Boden Tom, Josep G. Canadell, Philippe Ciais, Corinne Le Quéré, Gregg Marland, Michael R. Raupach, Charlie Wilson, (2013), «The challenge to keep global warming below 2 °C», *Nature Climate Change* 3, 4–6, DOI:10.1038/nclimate1783

Philadelphia International Airport, (2010). «*Climate Change: Impacts and Adaptation Strategies», Urban Engineers*, December 2010.

http://www.urbanengineers.com/pdffiles/Climate%20Change%20Impacts%20and%0Adaptation%20Strategies%20at%20PHL%20Decemb.pdf

Port Authority of New York and New Jersey, (2011). «Anticipating Climate Change»; *The Magazine of the American Society of Civil Engineers*. April 2011.

Posner, Eric A. (2007). «Climate Change And Human Rights Litigation », *University of Pennsylvania Law Review*, Vol. 155: 1925-1945.

Pümpel Herbert (2013). «Leading the Way toward Mitigating the Effects of Climate Change», International Civil Aviation Organization (ICAO) report 2013.

http://cfapp.icao.int/Environmental-Report-2013/

Rahmstorf, S. (2007). «A semi-empirical approach to projecting future sea-level rise»; *Science*, 315: 368–370.

Smith, J. B., and D. A. Tirpak, eds. 1989. *The potential effects of global climate change on the United States*. Washington, DC: U.S. Environmental Protection Agency etc..

Susanne DesRoches (2011) Assessment of Port Authority of NY & NJ Facilities to the Impacts of Climate Change, – The Port Authority of NY & NJ. May 2011.

The Third National Climate Assessment. U.S. Global Change Research Program, 841 pp. DOI: 10.7930/J0Z31WJ2.

Rogelj, J., D.L. McCollum, B.C. O'Neill, and K. Riahi, 2012: 2020 emissions levels required to limit warming to below 2 °C. Nature Climate Change, 3, 405-412, DOI: 10.1038/nclimate1758.

Sigman, H. (2007). Legal Liability as Climate Change Policy; University of Pennsylvania Law Review, Vol. 155:1953–1959.

Sorokin L.V., Mondello G. (2013). «The Cost of Adaptation for Climate Change: Future Sea Level Estimation» Belgrade: Institute of Economic Sciences, 2013 (Beograd : Čigoja štampa)., Pp. 557–565, ISBN: 978-86-89465-10-5 http://www.ien.bg.ac.rs/images/stories/Izdavastvo/IEN/economic_sciences_on_crossroad13.pdf.

Sorokin L.V., Mondello G. (2013). «The Cost of Adaptation for Climate Change», *Bulletin of Peoples' Friendship University of Russia*, Series Economics. No S5, 2013: 63–72. ISSN 2408-8986 (ISSN 0869-8732), In Russian, http://elibrary.ru/item.asp?id=21074092.

Sorokin L.V. (2015), «Simplified Sea Level estimation based on Logistic equation», Abstracts of the LI All-Russia conference on problems in Dynamics, Particle Physics, Plasma Physics and Optoelectronics Russia, Moscow, 12–15 May 2015. Pp. 63–65.

Sorokin L.V. (2015). «Simplified Sea Level Estimation Based on Logistic Equation and Paleoclimate Data», *Bulletin of PFUR*. Series Mathematics, Information Sciences, Physics. No 4, 2015. ISSN 2312-9735.

Sorokin L.V., Mondello G. (2013) Price policy for adapting to climate change//Bulletin of Peoples' Friendship University of Russia, Economy Serie. 2013 # S5. S. 63-72, ISSN 0869-8732. URL: http://elibrary.ru/item.asp?id=21074092.

Schwartz, Victor E., Goldberg Phil, Christopher E. Appel, 2012. «Does The Judiciary Have The Tools For Regulating Greenhouse Gas Emissions?», *Valparaiso University Law Review*, Vol. 46: 369–409.

Titus, J.G., R.A. Park, S.P. Leatherman, J.R. Weggel, M.S. Greene, P.W. Mausel, S. Brown, C. Gaunt. M. Trehan, and G. Yohe, (1991). «Greenhouse Effect and Sea Level Rise: The Cost of Holding Back the Sea». *Coastal Management*, 19:171–210.

Tschakert, Petra, (2015), «1,5 °C or 2 °C: a conduit's view from the science-policy interface at COP20 in Lima, Peru», Climate Change Responses 2:3 DOI: 10.1186/s40665-015-0010-z.

Tselioudis, G., J. Cao, E. Rignot, I. Velicogna, E. Kandiano, K. von Schuckmann, P. Kharecha, A.N. Legrande, M. Bauer, and K.-W. Lo, (2015) «Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2 °C global warming is highly dangerous», Atmos. Chem. Phys. Discuss., 15, 20059-20179, DOI: 10.5194/acpd-15-20059-2015, 2015.

Wahl, Thomas, Shaleen Jain, Jens Bender, Steven D. Meyers & Mark E. Luther, (2015), «Increasing risk of compound flooding from storm surge and rainfall for major US cities», Nature Climate Change (2015) DOI: 10.1038/nclimate2736.

Weisbach, David A. (2012) «Negligence, Strict Liability, and Responsibility for Climate Change», *Iowa Law Review*, 97:521.

APPENDIX ONE

Details on the Data Base

We mainly use the Eurostat statistics (Eurostat) – Statistical Office of the European Union and the Database airports [2]. The Eurostat database [1] for 2013 contains statistical data on 865 airports. The database contains detailed information on the situation and the length of airstrips, their geographical coordinates and altitude of the airstrips above the sea level, as well as information for international codes, names and types of airports. This broad information base includes:

- The number of flights;
- The volume of passengers, cargo and mail;
- The number of seats on board;
- Domestic and international air transport;

– Monthly and annual reports;
– Other details as well.

Usually, the sectoral analysis of the air transport in the European Union is carried out for the year 2010 because, there, the transport volumes reached their local maximum. This is related to the air traffic variations over time. The reduction of air cargo is linked to the economic crisis and the European support for US sanctions against the Russian Federation. However, the content of the Eurostat database on air transport is constantly improving and up 2013, the number of airports in the database increased. The statistics for 2014 are not yet fully integrated into the base, which is associated with a delay in processing the data. Thus, for our analysis, 2013 is the most representative year.

APPENDIX TWO

A semi-empirical model of the rise of sea level

The definition of the Global Mean Sea stationary state level (SL_{St}) that responds to a fixed change of the average air temperature (T_{S_t}) must conform to the main characteristics mentioned below. Hence, to reach a stationary state solution, Earth's climate system needs a sufficiently large relaxation time (Sorokin L.V., 2015) and (Sorokin L.V., Mondello G., 2013) from a few hundred years up to the millennium. The present applied approach gives an estimate of the upper bound of the sea level rise due to changes in the fixed air temperature on the overall globe in the long run. The boundaries definition for a stationary state of the climate system induced by the fixed change of meteorological parameters allows verifying this hypothesis.

In Sorokin and Mondello (2013a), the following equations ((1), (2)) associate both future sea level (SL) and average air-temperature (Ts) on Earth:

$$SL_{St} = 7.5\, T_{S_t} - 106.875 \qquad (SL>0) \qquad (1)$$

$$SL_{St} = 24.793\, T_{S_t} - 353.306 \quad (SL<0) \qquad (2)$$

The assessment of the average temperature in pre-industrial era development ($T_{S_{SL=0}}$) for (SL = 0) follows from equations (1) and (2):

$$T_{S_{SL=0}} = 14.25°C \qquad (3)$$

The Global Surface Air Temperature (GSAT), corresponds to the current sea level $SL_{t=0} = 0.21\ m$:

$$T_{S_{SL=0.21}} = 14.278°C \qquad (4)$$

Hence, the GSAT in the present time (t=0) expresses as:

$$T_{S_{t=0}} = T_{S_{SL=0}} + 0.8 = 15.05\ °C \qquad (5)$$

Comparing with the era before the industrial development (SL=0) in terms of the present time (t=0) we get the following current climate conditions concerning the Global Mean Sea Level (GMSL) rise:

$$SL_{t=0} = 0.21 \text{ m} \quad (6)$$

due to the Global warming and the GSAT exceeds by

$$\Delta T = T_{S_{t=0}} - T_{S_{SL=0}} = 0.8°C \quad (7)$$

Hence, from equations (1) and (5), an increase of GSAT of 0.8ºC corresponds to a 6m stationary Sea level. Furthermore, from equations (1) and (4) it is clear, that in the aim at preventing any Sea level rise and maintaining it on the current level (6) the GSAT compared with the era before the industrial development should be reduced by 28.5 times

$$\Delta T = T_{S_{SL=0.21}} - T_{S_{SL=0}} = 0.028°C \quad (8)$$

For the transient modeling of the Sea-level (GMSL) growth in response to the temperature (GSAT) jump it is reasonable to apply the saturation model, which can be formalized using the logistic equation (Sorokin L.V., 2015):

$$LE_{(T,t)} = \frac{SL_{St} * SL_{t=0} * (1+\Delta T)^{\left(\frac{t*m_{(\Delta T)}}{k}\right)}}{SL_{t=0} * (1+\Delta T)^{\left(\frac{t*m_{(\Delta T)}}{k}\right)} + SL_{St} - SL_{t=0}} \quad (9)$$

The logistic equation (9) should meet the following requirements:

- t – time scale (t=0 corresponding to the present time);
- equation (9) for the present time t=0 is equal to $LE_{t=0} = SL_{t=0} = 0.21\text{m}$
- equation (9) at a value $\Delta T = T_{S_{SL=0.21}} - T_{S_{SL=0}} = 0.028°C$ is equal to
- $LE_{(\Delta T=0.028)} = SL_{t=0} = const = 0.21\text{m}$
- equation (9) at a value $\Delta T = 0$, $a = (1+\Delta T) = 1$, consequently $LE_{(T,t)} = SL_{t=0} = const$;
- The coefficient $\frac{m_{(\Delta T)}}{k}$ defines the relaxation time for the transient function;
- Considering the condition (6), the coefficients tuning $a = (1+\Delta T)$, $\frac{m_{(\Delta T)}}{k}$ should initially provide an exponential growth model (9) up to the present time. This one considers that the global sea level doubles every 10 years (Hansen J.E., 2007);
- at a value $t \to -\infty$, equation (9) tends to zero, $LE_{((\Delta T>0, t\to-\infty)} = 0$;
- at a value $t \to +\infty$, equation (9) reaches the stationary level (1) , $LE_{((\Delta T>0, t\to+\infty)} = SL_{St}$.

For the current climate conditions we estimate the future sea level change, using the logistic equation (9) with parameters (1), (5), (6), (7) and coefficients $m_{(\Delta T)} = 9$, $k = 100$.

Figure 4 illustrates the future Sea level model based on the logistic equation (9) and we consider two significant cases. The first one shows the current climate conditions. This one corresponds to a 0,8 ºC global warming above the pre-industrial level (7). The second one starts from the equation (8) where the temperature is 0,028 ºC which is 28,5 times less than the first one.

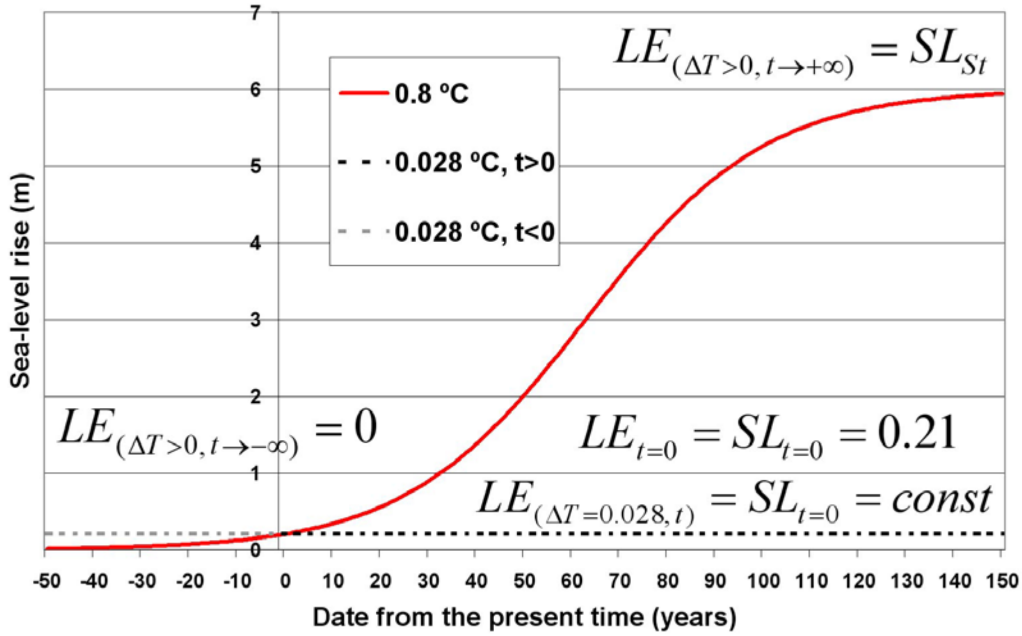

Figure 4. The future Sea level rise model based on logistic equation for the current climate conditions

Figure 4 shows that, maintaining the global warming at the current value of 0,8ºC for 95 years will increase the sea level to +5 m level. This value fits well with Hansen's prognosis (Hansen J.E., 2007). Furthermore, during a 150 years relaxation time it will reach +6 meters.

If global warming could reduce of 28,5 times (equation (8)) to the value of 0,028 ºC, the sea level would stabilize to 0,21 meter which is represented by the black dotted line for t>0, on Figure 4. The grey dotted line for t<0 (Figure 4) is only virtual because time does not reverse.

The above optimistic scenario is not real because the EU Strategy on adaptation to climate change aims at stabilizing to 2ºC the global warming (see the discussion in the text).

We discuss now this widespread assumption. Hence, if Earth's average temperature increases to 2 ºC above the prior industrial era, this will lead to an inevitable rise of the global sea level by +15 meters according our logistic model. In the current time, we have no data to estimate the relaxation time for reaching this sea-level.

However, we can conceive three possible scenarios:

– The relaxation time does not change;
– It will happen faster or;
– It will take more time.

How fast such catastrophic changes in the Earth's climate can occur? If Hansen (2007) is right and if the rise of sea levels continues to double every 10 years that it seems reasonable expecting that the sea level will rise to a +5 meters level in 2100 compared to the preindustrial era level.

For the current climate conditions (global warming on 0,8 ºC), the logistic equation (9) provides us a solution according which, within the next 95 years, the sea level will rise up to +5 m and stabilize at +6 m level within a 150 years relaxation time. If the global warming reaches the 2 ºC, then we dispose of three possible scenarios for a +15 meters sea level rise: the relaxation time does not change; it will happen faster or it will take more time. To answer this question we need new data on global warming and sea level rise.

The highest level of Pleistocene period sea-level rise was 9,8 m above the level before the industrial era. It means that we can fall in the next glacial period faster than reaching the limit to below 2 ºC above pre-industrial level and corresponding for it sea-level increase of +15 m. In the millennium time scale the Global Warming and the Sea-level rise will provoke the next glacial period that starts with fast temperature falling down and the 7,5 m sea-level declining per 1 ºC (equation 1) up to «zero» sea-level and after that accelerating 3.3 times to 24,79 m per 1 ºC (equation 2). The new infrastructure should be adopted both for 2 ºC higher temperatures as for the extreme low temperatures of the future glacial period.