Journal of Polish Safety and Reliability Association
Summer Safety and Reliability Seminars, Volume 7, Number 2, 2016

Blokus-Roszkowska Agnieszka

Kołowrocki Krzysztof

Soszyńska-Budny Joanna
Maritime University, Gdynia, Poland

Baltic Electric Cable Critical Infrastructure Network

Keywords

critical infrastructure, Baltic Sea Region, *"Baltic Ring"* network, HVDC link, climate change, power blackout

Abstract

In the paper the Baltic Electric Cable Critical Infrastructure Network (BECCIN) is defined and the main electric cable investments in the Baltic Sea Region, that are components of BECCIN, are described. Next the installations belonging to BECCIN are presented regarding their availability and disturbance outages. Functioning and disturbances in electric grid critical infrastructure network are analyzed in terms of climate-weather change impact. Finally, consequences of power blackouts and their impact on other critical infrastructures are discussed.

1. Introduction

Regarding energy, the European Union's priority is to integrate European markets and networks, which are currently divided under the ENTSO-E structure between two cooperating systems, the European - formerly UCTE and the Nordic - formerly NORDEL. ENTSO-E, the European Network of Transmission System Operators is an association that represents 41 electricity transmission system operators (TSOs) from 34 countries across Europe. ENTSO-E promotes closer cooperation across Europe's TSOs to support the implementation of EU energy policy and achieve Europe's energy and climate policy objectives [11]. To ensure energy market integration, the European Commission proposes the following priorities [15]:

- An offshore grid in the Northern Seas and transmission lines to Northern and Central Europe to transport power produced by offshore wind to consumers and energy storage centres;
- Transmission lines in South Western Europe such as between Spain and France to transport power between EU countries;
- Transmission lines in Central Eastern and South Eastern Europe to strengthen the regional network;
- Integration of the Baltic electricity market – Lithuania, Latvia, and Estonia – with the rest of the EU.

ENTSO-E's 10-year network development plan or TYNDP is the pan – European plan for the development of the electricity transmission grid. ENTSO-E is structured into six regional groups for grid planning and other system development tasks [9]. One of Six Regional Investment Plans is Regional Investment Plan 2015 for Baltic Sea region. There have been distinguished several areas of grid development in the Baltic Sea region, widely described in [9]. We will focus in this paper on the Baltic Sea Region and its areas of grid development.

2. Baltic Electric Cable Critical Infrastructure Network (BECCIN)

Power grid is a sector upon which the other sectors are dependent and any interruption of its service can have significant destructive influence on the health, safety and security, economics and social conditions of large human communities and territory areas. Short term outages and more serious and extended disruptions may have cascading effects on the whole society through different sectors. Thus, according to the definition given in [2], [12], electric grid can be considered as a critical infrastructure and the interconnected and interdependent network of electric cables can constitute the critical infrastructure network. Further, the electric gird operating in the Baltic Sea Region is called the Baltic Electric Cable Critical Infrastructure Network (BECCIN).

Figure 1 presents listed below electric cable installations $E_1, E_2, \ldots, E_{11}$ in the Baltic Sea Region marked on the ENTSO-E Interconnected Network Map of Northern Europe, available at the ENTSO-E website [10].

We distinguish 11 following installations (*Figure 1*) of the Baltic Electric Cable Critical Infrastructure Network (BECCIN):

– the Electric Cable Installation EstLink 1 with Espoo in Finland and Harku in Estonia converter stations E_1,

Figure 1. Part of the ENTSO-E Grid Map showing installations of BECCIN

- the Electric Cable Installation EstLink 2 with Anttila in Finland and Püssi in Estonia converter stations E_2,
- the Electric Cable Installation NordBalt with Nybro in Sweden and Klaipeda in Lithuania converter stations E_3,
- the Electric Cable Installation LitPol Link with Ełk in Poland and Alytus in Lithuania converter stations E_4,
- the Electric Cable Installation SwePol Link with Stärnö in Sweden and Slupsk in Poland converter stations E_5,
- the Electric Cable Installation Fenno-Skan 1 and Fenno-Skan 2 with Dannebo, Finnböle in Sweden and Rauma in Finland converter stations E_6,
- the Electric Cable Installation Konti-Skan with Lindome in Sweden and Vester Hassing in Denmark converter stations E_7,
- the Electric Cable Installation Great Belt Power Link (Storebælt HVDC) with Fraugde, Funen and Herslev, Zealand in Denmark converter stations E_8,
- the Electric Cable Installation Kontek with Bjaeverskov in Denmark and Bentwisch in Germany converter stations E_9,
- the Electric Cable Installation Baltic Cable with Kruseberg in Sweden and Herrenwyk in Germany converter stations E_{10},
- the Electric Cable Installation Vyborg Link with Yllikkälä, Kymi in Finland and Vyborg in Russia converter stations E_{11}.

3. BECCIN Functioning

Back in 2008, the Baltic countries were effectively an 'energy island'. This situation gave rise to the creation of the Baltic Energy Market Integration Plan (BEMIP). Its aim is an integration of the Baltic States into the European market through reinforcement of their internal networks and strengthening of interconnections with Finland, Sweden and Poland and through reinforcement of the Polish internal grid and interconnections east and westward [17]. Plans of the Baltic Electric Cable Critical Infrastructure Network development are focused on integrated grids to foster sustainable and secure energy supply. Another objective in this corridor is to end isolation of the Baltic States. Thus, under BEMIP LitPol Link and Nordbalt were identified as priority projects.

In this context one of priority corridors for electricity was the creation of the so-called "*Baltic ring*" network, connecting Central Europe, the Baltic States and the Nordic countries. Currently, the Baltic electricity grid is synchronised with the Russian and Belorussian grids. Two new electricity connections between Lithuania, Poland and Sweden, inaugurated officially on 14 December 2015, create "*Baltic ring*". The LitPol Link connects Alytus in Lithuania with Elk in Poland and the Nordbalt links up Nybro in Sweden and Klaipeda in Lithuania. These two links will add 1200 MW of interconnection capacity to the region. This means that, for the first time, the electricity markets of the Baltic States will be connected to the Swedish and Polish electricity networks. Before these projects were completed, the Baltic Sea region was connected to the EU electricity market via just two connections – Estlink 1 and 2 - which run between Finland and Estonia. These interconnections could lay the technical foundations for synchronising the Baltic electricity grid with the rest of Europe [16].

3.1. Availability and utilisation

As it is defined in the ENTSO-E report [8] the technical capacity (E_{max}) of the HVDC link is the maximum energy that can be transmitted from the AC grid to the converter station on the exporting side, including all HVDC link losses. The technical capacity of the link is defined in [8] as a theoretical value and can be divided into available technical capacity (E_A), that equals the capacity used for transmission (E_T) and technical capacity not used E_{TCNU}, and unavailable technical capacity (E_U). The unavailable technical capacity E_U is due to outages or limitations.

Figure 2 presents the overview of the availability and utilisation of HVDC statistics. In this statistical summary of 2014 it has not been included NordBalt and LitPol Link because these interconnections have just been completed at the end of 2015.

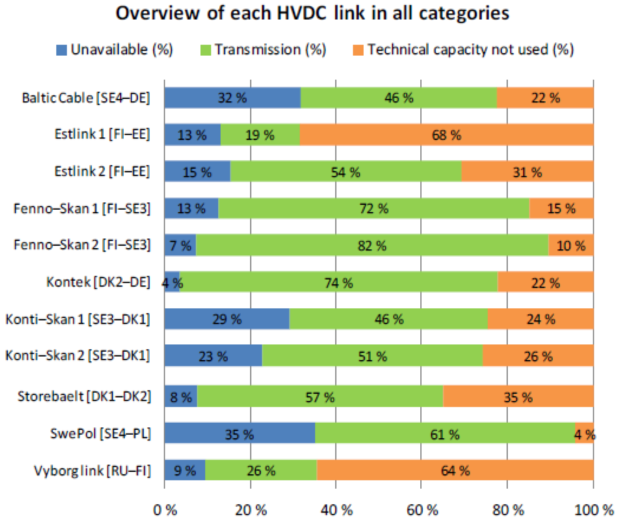

Figure 2. Annual overview of the availability and utilisation of each HVDC link in 2014 [8]

3.2. Unavailability and disturbance outages

Figure 3 presents the percentage unavailable technical capacity (E_U) of the annual technical capacity E_{max} due to the disturbance outages for electric cable installations placed at the Baltic Sea Region listed before.

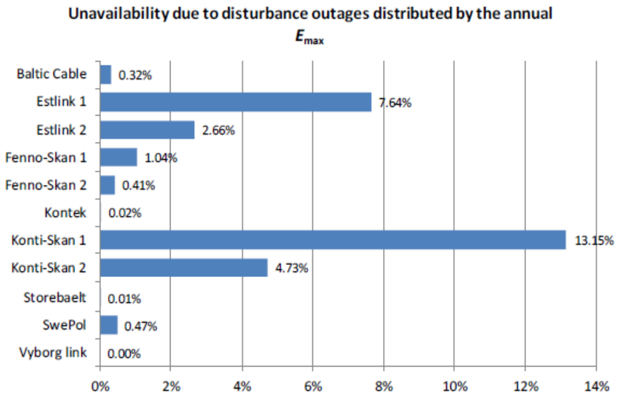

Figure 3. Percentage distribution of unavailable technical capacity E_u due to disturbance outages for each link in 2014 [8]

In the ENTSO-E report [8] there have been distinguished following types of outages:

‒ Disturbance outages ‒ total outages due to a fault on the HVDC link or in the AC grid causing a total outage of the link. This could be a forced outage or an automatic trip.

‒ Maintenance outages ‒ total outages due to all technically motivated actions on the HVDC link or in the AC grid intended to retain an entity in, or restore it to, a state where it can perform its required function.

‒ Other outages ‒ total outages due to any other reason except those mentioned above. This could be for example when the markets do not need the transmission capacity of the link and the link is disconnected.

Limitations of the HVDC link transmission capacity are mostly caused by [8]:

‒ faults on any HVDC link component as long as they do not cause a total outage;

‒ faults, congestions or outages in the AC grid causing a limitation in the transmission capacity of the link;

‒ seasonal variations on the transmission capacity of the HVDC link;

‒ link capacity reserved as power reserves.

First of all, the BECCIN is closely cooperating and interacting with the Baltic Wind Farm Critical Infrastructure Network (BWFCIN) defined in [19]. There can appear technical problems with storage and transmission of wind-generated electricity. Besides wind energy can create instability in electricity grid as a loss of wind can result in power grid interruption [22]. Electricity supply interruptions can have further significant influence on functioning of other critical infrastructure, that are dependent on electricity supply [14]. Interruptions in communication systems, including port operation services, internet and phone services, can have widely felt effects, also in maritime transport. This way power blackouts can affect the Baltic Ship Traffic and Port Operation Information Critical Infrastructure Network (BSTPOICIN) described in [18]. The BECCIN also cooperates and interacts with the Baltic Port Critical Infrastructure Network (BPCIN) and Baltic Shipping Critical Infrastructure Network (BSCIN) defined in [3] and [4], respectively. Port and shipping infrastructures can be affected by problems with loading/unloading of cargo, causing supply chain disruption [5]. Problems in pumping systems can interrupt functioning of pipelines and have influence on the Baltic Gas Pipeline Critical Infrastructure Network (BGPCIN), defined in [1], or the Baltic Oil Pipeline Critical Infrastructure Network (BOPCIN), defined in [7].

4. Climate-weather change impact on BECCIN

Disturbances in electric grid critical infrastructure and loss of power can be caused by natural disasters, bad weather, technical failures, human errors, terrorism and acts of war. A common reason for long-lasting and widespread electric power system blackouts is the weather. Examples include storms, blizzards, ice storms, extreme cold weather and floods. Disturbances caused by a technical failure in electric power systems are often shorter and limited to a smaller area than disturbances caused by weather. In power transmission networks the cascading interruptions may also occur [21].

Typically power blackouts are not caused by a single event but by a combination of several deficiencies. Potential causes of power blackouts are presented in the scheme in *Figure 4*. In the majority of serious electricity blackouts one of the main causes are different weather phenomena, such as storms, snow and ice. Today, extreme weather events such as coastal floods, intense precipitation (snow and rain), heat waves, and droughts are becoming more frequent and severe in some regions. Sea level rise is already worsening coastal floods, and other extreme weather events are likely to become more severe. The electricity system – including the transportation networks and the transmission and distribution lines are often not able to withstand many of the extreme weather events.

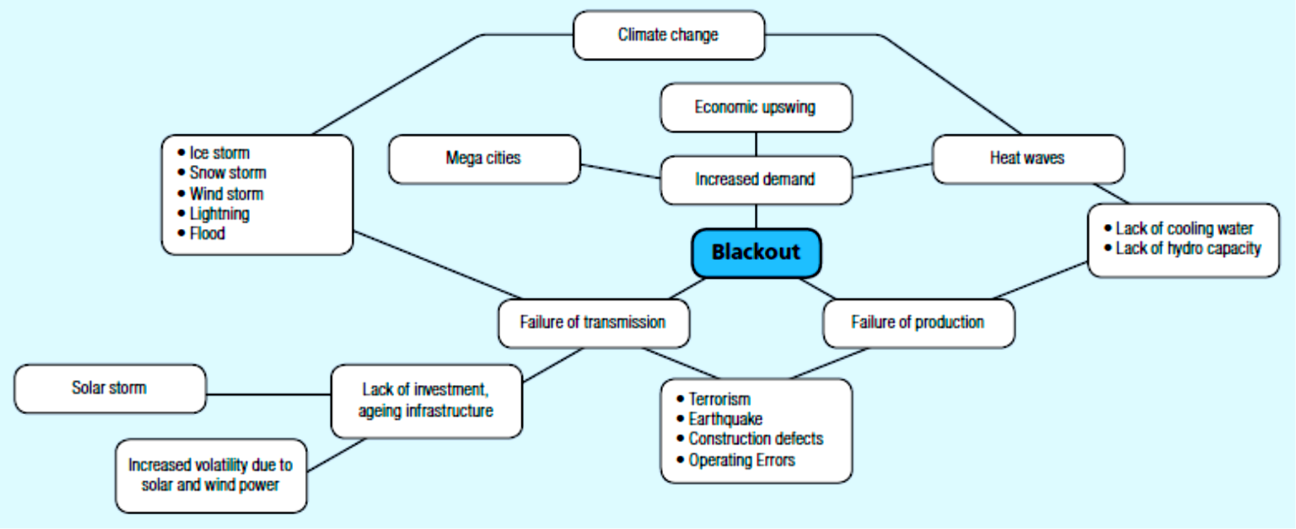

Figure 4. Potential causes of power blackouts [5]

Many parts of the electricity grid are old, outdated, and in poor condition, making the system even more vulnerable [6]. These, mentioned above problems, causing electricity blackouts, also apply to energy infrastructure in the Baltic Sea Region, i.e. to the BECCIN.

Aerial lines are often struck by lightning, in which case short circuits or earth faults may occur. Lines or transformers may also be damaged, sometimes permanently. The underground cables are seldom damaged by lightning; however, if they are, the recovery times are longer compared to damages in the aerial lines. If the power stations or distribution networks are also damaged, the interruptions may affect widespread areas.

During winter, snow may cause power interruptions, mainly by pressing tree branches onto the lines. Subzero temperatures may damage disconnectors, switches or protective fixtures, or even break entire lines. It is important to point out that even shorter power distribution disruptions may have severe consequences to the customers in subzero weather. On rare occasions, snow masses may press entire lines to the ground. Floods and heavy rainfall may cause disruptions in the underground cable networks, mostly by damaging transformers. Aerial lines are not affected to the same extent [21].

The electricity system can be even more vulnerable to extreme weather in the future. The increase of extreme weather conditions caused by the climate change is a threat to the electricity distribution in the future, and the warmer atmosphere will contain more humidity, increasing the possibilities of heavy rainfall and floods [21]. Rising levels of carbon dioxide and other heat-trapping gases in the atmosphere have already caused average global temperatures to increase. Higher temperatures add moisture to the atmosphere, intensify storms, and raise sea levels. Higher sea levels increase the risk of coastal flooding from storm surges associated with hurricanes and coastal storms. This puts the electricity infrastructure along the coasts – including transmission and distribution lines, transformers, substations, power plants and refineries – at greater risk of damage and outages from flooding [6].

Climate change, which is characterized by a rise in average temperatures in most regions, changes in precipitation and seasonal patterns as well as changes in the intensity and pattern of extreme weather events, and sea level rise, has influence on electricity markets through both energy supply and demand. The most direct and obvious effect is that higher temperatures imply lower demand for heating and higher demand for cooling. Changes in precipitation also involve changes in thermal and non-thermal power production. Extreme weather events could affect the electricity generation and transmission, and often cause electricity outages [20].

The periods of extreme heat decrease the efficiency of power plants during periods when electricity demand is highest, placing additional stresses on the electricity system. The electricity sector is highly dependent on water for cooling. As temperatures continue to rise, droughts and reduced water supplies are likely to become the norm in some regions, increasing the risk to the power sector [6].

Power blackouts can result in supply bottlenecks and further have significant impact on other critical infrastructures causing disturbances in all sectors of public life and even have dramatic consequences. The diagram presented in *Figure 5* below presents potential consequences of blackout.

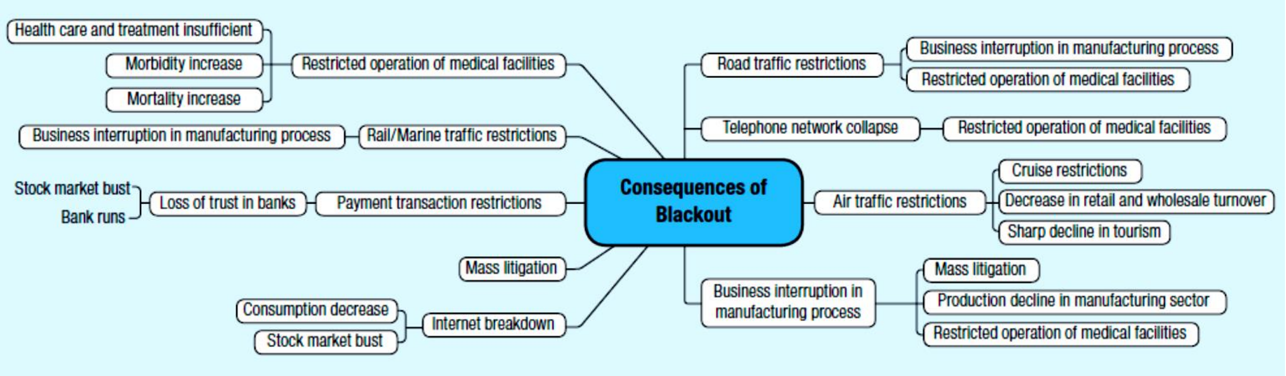

Figure 5. Consequences of blackouts [5]

As indirect impacts of power blackouts some areas may experience water distribution and sewerage problems. The loss of water systems due to a power outage can lead to many cascading effects. Water is used for drinking, sanitation, and in heating and cooling systems. Not operating heating systems can pose a serious threat to the lives of citizens, especially during the winter. The lack of public transportation and traffic lights may cause blocking roads and logistic problems. Passenger trains as well as flights can be suspended or cancelled. This can led to disruption in national public transport networks. Many shops, banks, offices and schools are closed. Sometimes the evacuation of patients in hospitals affected by the blackout has to be executed. Critical systems such as hospitals or first responder facilities usually have backup power generation, that ensure the possibility of working for several hours to a maximum of a few days [5].

As a result of a blackout most fuel stations and the refineries can be closed down, leaving the public without fuel for cars and public transport. Backup generators could not work due to the inoperative pumps or problems with the distribution of fuel to backup power generators may occur. Many systems may have sustain irreversible physical damage after few hours without electricity. A long-lasting and widespread electric power system blackouts may led to a domino effect that ultimately led to the disaster.

The production and distribution of electricity is dependent on climate variables such as temperature, precipitation, wind speed, wind direction, extreme weather events, etc. Changes in any of these variables would change the supply of power from both thermal and non-thermal sources. Extreme weather events could affect the delivery of electricity through disruption of infrastructure [20].

5. Conclusion

The big question in electricity production in the future is how to meet the growing demand of electricity consumption and how to maintain the adequate security supply. Extreme weather events such as a large severe frost may hit many areas at same time causing increased demand. Then, the electricity consumption could be restricted in the entire area [21].

The consequences of electricity blackouts can be reduced by improving the electricity network structure or speeding up the maintenance or mitigated through regulations. Nowadays, building strategies for strengthening of energy infrastructure, and in particular of the BECCIN, is an important and current problem.

Acknowledgments

The paper presents the results developed in the scope of the EU-CIRCLE project titled “A pan – European framework for strengthening Critical Infrastructure resilience to climate change” that has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 653824. http://www.eu-circle.eu/.

References

[1] Blokus-Roszkowska, A., Bogalecka M., Dziula, P. et al. (2016). Gas Pipelines Critical Infrastructure Network. *Journal of Polish Safety and Reliability Association, Summer Safety and Reliability Seminars* 7, 2, 1-6.

[2] Blokus-Roszkowska, A., Bogalecka, M. & Kołowrocki, K. (2016). Critical Infrastructure networks at Baltic Sea and its seaside. *Journal of Polish Safety and Reliability Association, Summer Safety and Reliability Seminars* 7, 2, 7-14.

[3] Blokus-Roszkowska, A., Guze, S., Kołowrocki, K. et al. (2016). Port Critical Infrastructure Network. *Journal of Polish Safety and Reliability Association, Summer Safety and Reliability Seminars* 7, 2, 15-28.

[4] Bogalecka, M., Kołowrocki, K., Soszyńska-Budny J. et al. (2016). Shipping Critical Infrastructure Network. Journal of Polish Safety and Reliability Association, Summer Safety and Reliability Seminars 7, 1-2, 43-52.

[5] Bruch, M., Münch, V., Aichinger, M. et al. (2011). *Power Blackout Risks*, Risk Management Options.

[6] Davis, M. & Clemmer, S. (2014). *Power Failure. How Climate Change Puts Our Electricity at Risk - and What We Can Do*. Union of Concerned Scientists [available at: www.ucsusa.org/powerfailure; last accessed: 13.01.2016].

[7] Drzazga, M., Kołowrocki, K. & Soszyńska-Budny, J. (2016). Oil Pipeline Critical Infrastructure Network. *Journal of Polish Safety and Reliability Association, Summer Safety and Reliability Seminars* 7, 2, 53-60.

[8] ENTSO-E. (2015). Nordic HVDC Utilisation and Unavailability Statistics 2014, Brussels, Belgium.

[9] ENTSO-E. (2015). Regional Investment Plan 2015 Baltic Sea region, Brussels, Belgium.

[10] ENTSO-E. The ENTSO-E Interconnected System Grid Map [available at: https://www.entsoe.eu/publications/order-maps-and-publications/electronic-grid-maps/Pages/default.aspx; last accessed: 13.01.2016].

[11] ENTSO-E. Who Is ENTSO-E? [available at: https://www.entsoe.eu/about-entso-e/Pages/default.aspx; last accessed: 13.01.2016].

[12] EU-CIRCLE Report D1.1-GMU1. (2015). *EU-CIRCLE Taxonomy*.

[13] EU-CIRCLE Report D1.2-GMU1. (2016). *Identification of existing critical infrastructures at the Baltic Sea area and its seaside, their scopes, parameters and accidents in terms of climate change impacts*.

[14] EU-CIRCLE Report D1.4-GMU3. (2016). *Holistic approach to analysis and identification of critical infrastructures within the Baltic Sea area and its surroundings – Formulating the concept of a global network of critical infrastructures in this region ("network of networks" approach).*

[15] European Commission. (2015). *Infrastructure. Connecting energy markets and regions* [available at: https://ec.europa.eu/energy/en/topics/infrastructure; last accessed: 13.01.2016].

[16] European Commission. (2015). *New electricity connections between Lithuania, Poland and Sweden create "Baltic Ring"*. [available at: https://ec.europa.eu/energy/en/news/new-electricity-connections-between-lithuania-poland-and-sweden-create-baltic-ring; last accessed: 13.01.2016].

[17] European Union. (2011). *Energy infrastructure. Priorities for 2020 and beyond – A Blueprint for an integrated European energy network*. Luxembourg: Publications Office of the European Union.

[18] Guze, S. & Ledóchowski, M. (2016). Ship Traffic and Port Operation Information Critical Infrastructure Network. *Journal of Polish Safety and Reliability Association, Summer Safety and Reliability Seminars* 7, 2, 65-72.

[19] Kołowrocki, K., Kuligowska, E. & Reszko, M. (2016). Methodology for wind farms critical infrastructure network safety and resilience to climate change analysis. *Journal of Polish Safety and Reliability Association, Summer Safety and Reliability Seminars* 7, 2, 179-186.

[20] Mideksa, T. K. & Kallbekken, S. (2010). The impact of climate change on the electricity market: A review, *Energy Policy* 38, 3579–3585.

[21] Pursiainen, Ch. (2007). *Towards a Baltic Sea Region Strategy in Critical Infrastructure Protection*. Nordregio Report 2007:5, Stockholm, Sweden.

[22] Tupi, B. S. (2010). *Wind energy is not the answer* [available at: http://docs.wind-watch.org/Tupi-Wind-Energy-Is-Not-the-Answer.pdf; last accessed: 13.01.2016].