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Methodology for Electric Cables Critical Infrastructure Network safety and resilience to climate change analysis

Keywords

energy sector, critical infrastructure network, electric cable critical infrastructure, extreme weather, climate change, resilience, energy security

Abstract

In the paper the energy sector as a critical infrastructure is presented and basic terminology concerned with the energy critical infrastructure is given. The interactions and connections between critical infrastructures are described and the effects of power disruptions to other critical infrastructures are highlighted. Next, presented terminology and taxonomy refer to climate change and resilience to climate change of electric cable critical infrastructure. Finally, taxonomy of electric cable critical infrastructure network in Baltic Sea Region is given, especially in terms of climate change and resilience to climate change. Basic notions related to extreme weather events and climate change having impact on energy generation, transmission and distribution are introduced.

1. Introduction

To ensure compatibility in further safety and resilience analysis of Baltic Electric Cable Critical Infrastructure Network, defined and described in [5], we start with fixing the "working terminology" in terms of climate-weather change impact on this critical infrastructure network.

The Energy Policy for Europe, agreed by the European Council in March 2007, establishes the Union's core energy policy objectives of competitiveness, sustainability and security of supply [15]. Adequate, integrated and reliable energy networks are a crucial prerequisite not only for European Union (EU) energy policy goals, but also for the EU's economic strategy. Developing the energy infrastructure will not only enable the EU to deliver a properly functioning internal energy market, it will also enhance security of supply, enable the integration of renewable energy sources, increase energy efficiency and enable consumers to benefit from new technologies and intelligent energy use [15].

The European Programme for Critical Infrastructure Protection (EPCIP) sets the overall framework for activities aimed at improving the protection of critical infrastructure in Europe - across all EU States and in all relevant sectors of economic activity. A key pillar of this programme is the 2008 Directive on European Critical Infrastructures. It establishes a procedure for identifying and designating European Critical Infrastructures (ECI) and a common approach for assessing the need to improve their protection. The Directive applies to the energy sector distinguishing electricity, oil and gas subsectors. The electricity subsector is defined as infrastructures and facilities for generation and transmission of electricity in respect of supply electricity [18].

Following the European Commission approach, the Critical Infrastructure (CI) is an asset or system which is essential for the maintenance of vital societal functions. The damage to a critical infrastructure, its destruction or disruption by natural disasters, terrorism, criminal activity or malicious behaviour, may have a significant negative impact for the security of the EU and the well-being of its citizens [18].

The term of critical infrastructure is, among others, commonly associated with facilities for electricity generation, transmission and distribution and the energy sector is one of 11 infrastructures specified as being critical and mentioned in the European Commission's "Green Paper" on the European Programme for Critical Infrastructure Protection (EPCIP).

2. State of art

Before the considerations on taxonomy of critical infrastructure of electric cable installations at Baltic Sea Region, we refer to definitions of selected basic notions concerned with energy sector, electric cable critical infrastructures and climate and weather impacts on their safety included in the report [9].

2.1. Energy critical infrastructure terminology

Disruptions in energy sector could have a serious impact on the health, safety and security, economics and social conditions of large human communities and territory areas, thus the energy infrastructure can be included in the so-called critical infrastructures. Moreover, the energy sector can be identified as uniquely critical because it provides an "enabling function" across all critical infrastructure sectors [37]. Without a stable energy supply, the health, safety, security and economic well-being of citizens are threatened.

The energy sector is one of the pillars of growth, competitiveness and development for modern economies. The data contained in the scheme presented in *Figure 1* are drawn from statistics presented in [16].

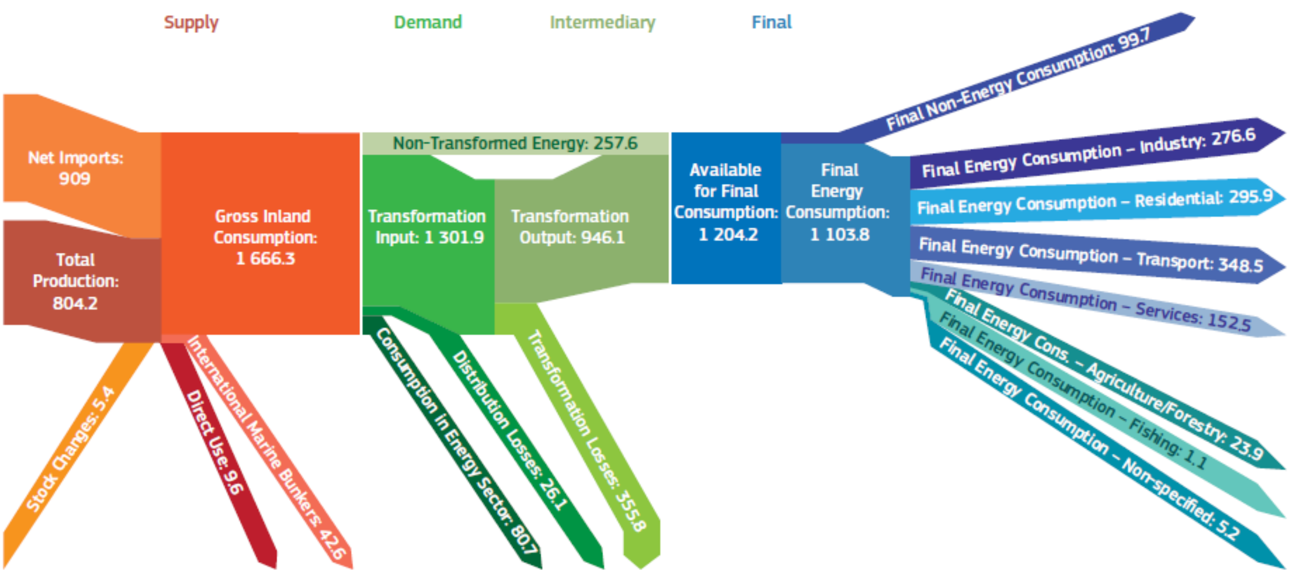

Figure 1. EU Energy flow – 2013 [16]

Before the analysis of extreme weather events and climate change impact on the critical electricity infrastructure, we refer to some definitions concerned with energy critical infrastructure.

We start with the notion of the *energy infrastructure* that is defined in [21] as the total system of generation, transport, distribution, trade, supply and consumption of energy. This means not only the physical network (e.g. power plants, gas pipes, heat delivery stations), but also the social (economic and institutional) network that manages and controls the physical system. Together, these networks form a socio-technical infrastructure system, where the technological, economic, and institutional domains are strongly interdependent [21]. Now we explain some terms used in this definition.

In this paper describing energy sector we focus on electricity and electric cable critical infrastructures. *Electricity* is a form of energy characterized by the presence and motion of elementary charged particles generated by friction, induction, or chemical change and *electric power* is the rate at which electric energy is transferred. Electric power is measured by capacity and is commonly expressed in megawatts (MW) [38].

Further, *electricity generation* is the process of producing electric energy or the amount of electric energy produced by transforming other forms of energy, commonly expressed in kilowatt hours (kWh) or megawatt hours (MWh) [38].

According to EU the notation of *energy trading* means systems used to trade energy commodities [13].

Energy supply is defined as energy made available for future disposition. Supply can be considered and measured from the point of view of the energy provider or the receiver [38].

Energy sector is responsible for electricity generation as well as transmission and distribution, thus the definitions of transmission and distribution in electricity sector are given in the paper. The *transmission* is generally defined as passage through sub-stations, while *transmission in electricity* is defined as the movement or transfer of electric energy over an interconnected group of lines and associated equipment between points of supply and points at which it is transformed for delivery to consumers or is delivered to other electric systems. Transmission is considered to end when the energy is transformed for distribution to the consumer [38].

Transmission grids (*high-voltage*) are meshed networks, connecting large generating stations (e.g. hydro power and nuclear power), sub transmission grids, and very large users. Transmission grids enable power trading with other countries and facilitate the optimization of generation within a country [20]. According to [38], *electric power grid* is a system of synchronized power providers and consumers connected by transmission and distribution lines and operated by one or more control centers.

Sub-transmission grids (*regional grids*) are defined as radial or locally meshed networks connected to the transmission grid via in-feed points. Smaller generating plants (e.g. wind power stations and gas turbines), and large users are connected to these grids [20].

The *distribution in electricity sector* is defined as passage through grid transformers and substations into and from distribution systems [13] and means the delivery of energy to retail customers.

Distribution grids (*low-voltage*) are radial networks that carry the electric power from the higher voltage levels to the final users. The number of levels in a distribution grid depends upon the density and magnitude of demand and the terrain [20].

Distribution provider provides and operates the wires between the transmission system and the end-use customer. For those end-use customers who are served at transmission voltages, the transmission owner also serves as the distribution provider. Thus, the distribution provider is not defined by a specific voltage, but rather as performing the distribution function at any voltage. *Distribution system* is defined as the portion of the transmission and facilities of an electric system that is dedicated to delivering electric energy to an end-user [38].

As consumption of energy is included in the elements of energy infrastructure, the definition of *energy service* can be also given. It is defined as the application of useful energy to tasks desired by the consumer such as transportation, a warm room, or light [24].

Energy transformation means the change from one form of energy, such as the energy embodied in *fossil fuels*, to another, such as electricity [24].

The elements of the energy sector being the critical infrastructure can include electrical power systems and electric cable installations. *Electrical power system* is defined as a critical infrastructure characterized by generation stations, transmission and distribution networks that create and supply electricity to end-users so that end-users achieve and maintain nominal functionality, including the transportation and storage of fuel essential to that system [39]. In [11]-[12] the Baltic Electric Cable Critical Infrastructure Network (BECCIN), composed of 11 electric cable installations placed at the Baltic Sea Region, is defined and widely described.

In energy sector we can also meet the following definitions.

Energy efficiency is defined as the ratio of energy output of a conversion process or of a system to its energy input [24].

Energy intensity is the ratio of energy consumption to economic or physical output. At the national level, energy intensity is the ratio of total domestic *primary energy* consumption or *final energy* consumption to *Gross Domestic Product* or physical output [24].

Primary energy (also referred to as energy sources) is the energy embodied in natural resources (e.g., coal, crude oil, natural gas, uranium) that has not undergone any anthropogenic conversion. It is transformed into secondary energy by cleaning (natural gas), refining (oil in oil products) or by conversion into electricity or heat. When the secondary energy is delivered at the end-use facilities it is called final energy (e.g., electricity at the wall outlet), where it becomes *usable energy* (e.g., light). Daily, the sun supplies large quantities of energy as rainfall, winds, radiation, etc. Some share is stored in biomass or rivers that can be harvested by men. Some share is directly usable such as daylight, ventilation or ambient heat [25].

Renewable energy is obtained from the continuing or repetitive currents of energy occurring in the natural environment and includes non-carbon technologies such as solar energy, hydropower, wind, tide and waves and geothermal heat, as well as carbon-neutral technologies such as biomass. *Embodied energy* is the energy used to produce a material substance (such as processed metals or building materials), taking into account energy used at the manufacturing facility (zero order), energy used in producing the materials that are used in the manufacturing facility (first order), and so on [25].

On one hand energy sector is supported by other infrastructures, such as information and communication technology, water or banking and finance sectors. Examples of infrastructures supporting the electric power infrastructure are described in [34]. On the other hand, other critical infrastructures, such as transport or communications, are dependent on energy sector. Effects of disruptions in electric power systems can affect all critical infrastructures as a result of first order or higher order dependencies. Critical infrastructure dependencies are illustrated in *Figure 2* adopted from [7].

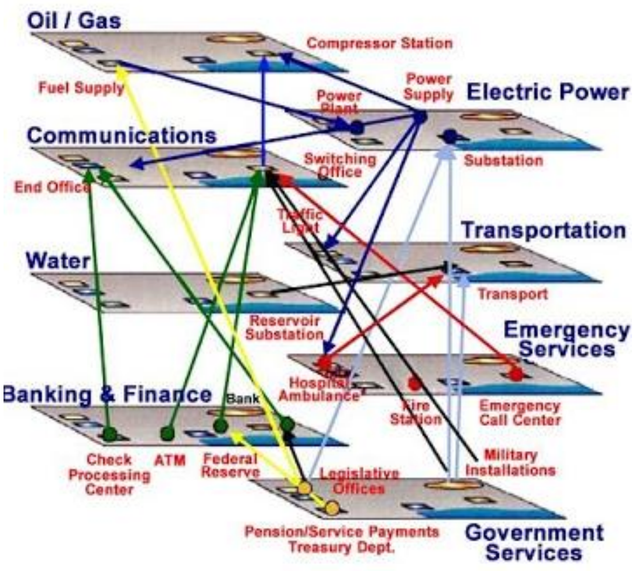

Figure 2. Critical infrastructure dependencies [7]

Electricity supply interruptions can have further significant influence on functioning of other critical infrastructure and cascading disturbances often occur in power transmission networks. *CI network cascading effects* are defined as degrading effects occurring within an infrastructure and between infrastructures in their operating environment, including situations in which one infrastructure causes degradation of another ones, which again causes additional degradation in other infrastructures and in their operating environment [9].

Critical electricity services to other energy sectors are defined as power generators requiring electricity to start generating [13].

2.2. Climate change terminology

Extreme weather events have a significant impact on the critical electricity infrastructure and as a result of interactions and interdependencies between infrastructures they can affect many other critical infrastructures. Severe or extreme weather in this context includes meteorological as well as hydrological events, such as high or low ambient temperatures, heavy precipitation, hail and storms, as well as the combined events of thunderstorms, water temperatures and floods. *Weather and climate extremes* or extreme weather events are defined as rare events within the statistical reference distribution of particular weather elements at a particular place [28].

Power systems are exposed to a great variety of weather conditions that affect both their systems and components' performance in different ways. On the system level, extreme weather can affect the end-use power consumption, and hence the loading on the feeders, lines, transformers, and other components. On the component level, extreme weather can influence the loading and failure rate of components [10].

The Inter-governmental Panel on Climate Change (IPCC) defines *climate change* as [26]: "a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use".

Hydro-meteorological hazard, that can have significant impact on energy sector, is defined as a process or phenomenon of atmospheric, hydrological or oceanographic nature that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. Hydro-meteorological hazards include tropical cyclones (also known as typhoons and hurricanes), thunderstorms, hailstorms, tornados, blizzards, heavy snowfall, avalanches, coastal storm surges, floods including flash floods, drought, heat waves and cold spells [35].

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 [29]. With these changes there is concerned concept of climate variability modes. *Modes of climate variability* are natural variability of the climate system, in particular on seasonal and longer time scales, predominantly occurs with preferred spatial patterns and time scales, through the dynamical characteristics of the atmospheric circulation and through interactions with the land and ocean surfaces. Such patterns are often called regimes, modes, or teleconnections [27].

Referring to climate change, the energy balance and its maintain is also an important issue. Maintain *energy balance* means that the energy budget of the climate system, averaged over the globe and over longer time periods, must be in balance. Because the climate system derives all its energy from the sun, this balance implies that, globally, the amount of incoming *solar radiation* must on average be equal to the sum of the outgoing reflected solar radiation and the outgoing *infrared radiation* emitted by the climate system. A perturbation of this global radiation balance, be it human-induced or natural, is called *radiative forcing* [24].

2.3. Resilience terminology

The International Energy Agency (IEA) [23] defines *energy security* as "the uninterrupted availability of energy sources at an affordable price". Further IEA defined *system security* as the capability of a power system using its existing resources to maintain power supplies in the face of unexpected shocks and sudden disruptions in real-time, such as the unanticipated loss of key generation or network components or rapid changes in demand. Energy security has many dimensions: *long-term energy security* mainly deals with timely investments to supply energy in line with economic developments and sustainable environmental needs, while *short-term energy security* focuses on the ability of the energy system to react promptly to sudden changes within the supply-demand balance [23].

Promoting sustainable, competitive and secure energy for Europe is one of the European Union's strategic priorities. Also, sustainable energy production is required to reduce negative environmental effects. Hence, particular emphasis is putted on developing renewables, diversifying supply and reducing energy consumption by improving efficiency [14]. *Sustainable supply* refers to the amount of resources that can be extracted and used for production and consumption before the threshold of a safe operating space is surpassed. Safe operating space reflects a corridor for human development where the risks of irreversible and significant damage to global life-sustaining systems seem tolerably low [31].

According to [38], *competitive transition charge* means a non-bypassable charge levied on each customer of the distribution utility, including those who are served under contracts with nonutility suppliers, for recovery of the utility's stranded costs that develop because of competition.

The Europe 2020 strategy for sustainable growth and resource-efficient economies focuses the energy-related lending on five priority areas [14]:

- renewables,
- efficiency,
- research, development and innovation,
- diversification and security of supply, especially across borders,
- economic development.

All sectors of critical infrastructures are dependent on the energy sector through the reliance all industries on electric power and fuels. The energy sector is well aware of its vulnerabilities and is making significant efforts to meet the growing demand of electricity consumption. The *energy emergency* term relates any significant deviation from a planned or expected course of events that could endanger or adversely affect people, property, or the environment. Energy emergencies encompass, but are not limited to, supply crises caused by international political causes (e.g., embargo), defense mobilization, natural disasters, energy system sabotage, major accidents, and labor strikes or lock outs [36].

To challenges in energy sector belong the sustainable resource management and the adequate security supply maintenance. *Sustainable resource management* means both ensuring that consumption does not exceed levels of sustainable supply and that the earth's systems are able to perform their natural functions. It requires monitoring and management at various scales. The aim of sustainable resource management is to ensure the long-term material basis of societies in a way that neither resource extraction and use nor the deposition of waste and emissions will surpass the thresholds of a safe operating space [31]. *Adequacy* in electric sector is defined as the ability of the electric system to supply the aggregate electrical demand and energy requirements of the end-use customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements [38].

Balancing authority is the responsible entity that integrates resource plans ahead of time, maintains load-interchange-generation balance within a balancing authority area, and supports interconnection frequency in real time [38].

According to the Commission, implementing a European energy policy should be built on three core objectives [17]:

- sustainability − to actively combat climate change by promoting renewable energy sources and energy efficiency;

- competitiveness − to improve the efficiency of the European energy grid by creating a truly competitive internal energy market;
- security of supply − to better coordinate the energy supply and demand.

To explain some terms used above we apply the glossary introduced by U.S. Energy Information Administration [38]. According to it, *energy efficiency* is a ratio of service provided to energy input (e.g., lumens to watts in the case of light bulbs). Services provided can include buildings-sector end uses such as lighting, refrigeration, and heating: industrial processes; or vehicle transportation. Unlike conservation, which involves some reduction of service, energy efficiency provides energy reductions without sacrifice of service. Energy efficiency may also refer to the use of technology to reduce the energy needed for a given purpose or service. *Demand in electricity* is described as the rate at which energy is delivered to loads and scheduling points by generation, transmission, and distribution facilities [38].

Uninterruptible power supply means a power supply that provides automatic, instantaneous power, without delay or transients, on failure of normal power. It can consist of batteries or full-time operating generators. It can be designated as standby or emergency power depending on the application [36].

Ranging from the completion of the internal market through to the implementation of a common external energy policy, these proposals should help Europe to ensure a supply of energy which is secure, competitive and sustainable [17].

3. Electric cable critical infrastructure network at Baltic Sea region taxonomy

Considering definitions of main notions from the above methodology, concerned with energy and electric cable critical infrastructures and their networks, and further taking into account the nature and features of the industrial installations at the Baltic Sea Region, we distinguish 11 following installations of the Baltic Electric Cable Critical Infrastructure Network (BECCIN), described in [12]:

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

3.1. Critical infrastructure taxonomy

Considering electric cable installations operating in the Baltic Sea Region we start with the term of *"Baltic Ring"* network, the idea of which was linking the power grids of all the states bordering the Baltic Sea into a gargantuan so-called "*Baltic Ring*". The work on the Ring started from the creation of the 'Nord Pool', a supranational smaller-scale version of the Baltic Ring built by the Scandinavian countries. ABB has provided much of the knowledge and advanced equipment required for the Baltic Ring. The aim of the Baltic Ring is to unite all private and public power resources of the states around the Baltic Sea.

The 'Baltic Ring Electricity Co-operation Committee' BALTREL, established in 1998 by 18 electricity supply companies representing 11 countries in the Baltic Sea Region, oversees the entire apparatus and a control center will direct energy distribution and trade. BALTREL is working for increased cooperation in the electricity supply industry in order to create an open and integrated electricity market in the region. Such a concept is supported by the Council of Baltic Sea States, the Nordic Council of Ministers and the European Union [2]. An *electricity market* is a system enabling purchases, through bids to buy; sales, through offers to sell; and short-term trades.

The Baltic Energy Market Interconnection Plan (BEMIP) constitutes a comprehensive action plan on energy interconnections and market improvement in the Baltic Sea Region. Its aim is an integration of the Baltic States into the European market through reinforcement of their internal networks and strengthening of interconnections. Plans of the Baltic Electric Cable Critical Infrastructure Network development are focused on integrated grids to foster sustainable and secure energy supply [15].

Considering the Baltic Electric Cable Critical Infrastructure Network as a part of the Global Baltic Network of Critical Infrastructure Networks (GBNCIN), defined in [3] and [11], we can introduce the concept of energy supply chain. *Energy supply chain* is the global network of systems of generation, transmission and distribution, responsible for energy trade and supply to end customers through an engineered flow of information, physical distribution, and cash [1]. *Energy supply chain community* is the set of trading partners and nominal trading partners that define a complete energy supply chain.

In this paper we focus on electric cable installations operating in the Baltic Sea Region in terms of climate-weather change impact. Considering the influence of climate change on the BECCIN functioning one of the main issues are power disturbances and their classification.

Power disturbances are disturbances that affect power delivery or quality. Some may only briefly interfere with the most highly sensitive equipment. Others, due to extensive damage on an electric delivery system, could result in the total loss of power for days [32]. There can be distinguished following types of disturbances: sag, surge, noise, momentary interruption and power outage. *Sag* is a short duration drop in voltage. *Surge* is a short-duration increase or spike in voltage lasting as little as a few millionths of a second and varying from a few hundred volts to several thousand volts. *Noise* is a continuous distortion of normal voltage. *Momentary interruption* occurs when power is briefly cut off, lasting from a fraction of a second to as long as a minute. A *power outage*, also called a power cut or a *power blackout*, is an outage is registered whenever the electricity is completely interrupted for a minute or longer. Outages may last from a few minutes to a few weeks depending on the nature of the blackout and the configuration of the electrical network [32].

Embedded and *intermittent generation* are small scale power generation linked to the lower voltage distribution network [13].

In the ENTSO-E report [8] outages are categorized into three different groups:

- *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.

Power blackout i.e. the total loss of electric power to an area, can result in supply bottlenecks that have significant impact and catastrophic consequences on citizens functioning through disturbances in all sectors of public life. In the analysis of potential bottlenecks of the transmission system, fist stage is the identification of transmission weak points. Then grid reinforcements, that would enable a safe and profitable grid operation, can be suggested. The grid extension planning in the transmission system faces usually two major challenges that are identification of the "real" transmission corridors and consideration of the mutual influence.

Electricity supply bottleneck can mean the power station, substation or other part of transmission and distribution system whose capacity is less than the demand of electricity consumption. A bottleneck (or constraint) in a supply chain means the resource that requires the longest time in operations of the supply chain for certain demand. Usually, phenomena such as increase of inventory before a bottleneck and insufficiency of parts after a bottleneck are often seen. Operationally, usually the asset, machine or resource that takes the longest amount of time is recognized as the bottleneck. Therefore, in a supply chain, a bottleneck governs its throughput, efficiency, productivity and profitability [22]. *Transmission constraint* is a limitation on one or more transmission elements that may be reached during normal or contingency system operations [38].

A common reason of long-lasting and widespread electric power system blackouts are different weather phenomena, such as storms, snow and ice. More precisely the influence of weather on the Baltic Electric Cable Critical Infrastructure Network is described in the next section. Disturbances in electric grid can be even more noticeable due to the fact that many parts of the electricity grid are old, outdated, and in poor condition. The increasing demand on electricity further worsen the situation. With high electricity demand there are concerned following terms adopted from [38]. *Peak demand* is the maximum load during a specified period of time. *Coincidental demand* defined as the sum of two or more demands that occur in the same time interval and *coincidental peak load* defined as the sum of two or more peak loads that occur in the same time interval.

3.2. Climate change taxonomy

Infrastructure of electricity generation, transmission and distribution is vulnerable to high winds, blizzards, ice storms, extreme cold weather and flood. Changes in precipitation and the intensity extreme weather events, and sea level rise, has also influence on the Baltic Electric Cable Critical Infrastructure Network. High winds and storms can cause both local and widespread outages, usually when trees or tree limbs fall onto the power lines. *Storms* are defined as atmospheric disturbances involving perturbations of the prevailing pressure and wind fields, on scales ranging from tornadoes (1 km across) to extratropical cyclones (2000-3000 km across) [40].

The National Weather Service of the United States [30] defines a blizzard as a snowstorm with sustained wind or frequent gusts to 56 km (35 miles) per hour or greater for at least three hours and falling and/or blowing snow reducing visibility frequently to less than 0.4 km (0.25 mile).

To common causes of power outages belongs also ice storms. Term of *ice storm* is used to describe occasions when damaging accumulations of ice are expected during freezing rain situations. Significant accumulations of ice, defined as accumulations of 6.4 mm or greater on exposed surfaces, pull down trees and utility lines resulting in loss of power and communication [30]. *Ice storms* can create a heavy buildup of ice on power lines and trees. In rare cases, the buildup can be so great that wooden utility poles and metal lattice transmission towers collapse under the enormous weight [32].

Focusing on electric cable critical infrastructure in the Baltic Sea Region, we can also meet maritime storm *maritime storm* defined as an elevation of sea level caused by a combination of change in atmospheric pressure, currents, waves and the topography of the coastal shelf [9].

Heavy rains can cause flooding that damages both above-ground and underground electrical equipment. Flooding may also make travel difficult for repair crews. Concerning the definition of *rainfall intensity*, according to [19], *very light* means that the scattered drops do not completely wet a surface; *light* means it is greater than a trace and up to 2.5 mm an hour; *moderate* means the rate of fall is between 2.6 mm to 7.5 mm per hour and *heavy* means 7 mm per hour or more [9]. According to "*Slandail terminology*" [35], *flood* is defined as a general and temporal condition of partial or complete inundation of normally dry land areas from overflow of inland or tidal waters, unusual or rapid accumulation or runoff of surface waters, or mudslides/mudflows caused by accumulation of water.

Extreme weather events such as coastal flooding, intense precipitation, heat waves and droughts are becoming more frequent and severe in some regions, and can affect the delivery of electricity through disruption of the Baltic Electric Cable Critical Infrastructure Network. *Coastal flooding* is defined as inundation of normally dry, low-lying coastal land, primarily caused by severe weather events along the coasts, estuaries, and adjoining rivers [9]. The main causes of coastal inundation is *storm surge*, defined as the abnormal increase in sea level caused by the combined effects of low atmospheric pressure, strong wind and a high tide [9]. Sea level rise is already worsening coastal floods, and other extreme weather events are likely to become more severe.

A frequent cause of localized power outages during the summer months is also *lightning*, defined as a visible electrical discharge produced by a thunderstorm. The discharge may occur within or between clouds, between the cloud and air, between a cloud and the ground or between the ground and a cloud [30].

During heat waves and droughts, generation of electricity of power plants has to be often reduced due to the scarcity and high temperatures of the adjacent water bodies which are substantial for cooling purposes. A *heat wave* means a period of abnormally and uncomfortably hot and unusually humid weather. *Heat waves* are defined as persistent hot conditions (extreme temperatures) often associated with drought and high pressure blocking and typically last two or more days [30]. *Drought* is a period of abnormally dry weather long enough to cause a serious hydrological imbalance [27].

Prolonged heat waves, that coincide with a high electricity demand and increasing instability in the power grid, may also result in serious electricity blackouts [6]. Then, increasing instability in the power grid can cause *congestion* that occurs when insufficient transfer capacity is available to implement all of the preferred schedules for electricity transmission simultaneously [38].

3.3. Resilience taxonomy

Considering climate-weather change impacts on critical infrastructures in the Baltic Sea Region, and particularly the Baltic Electric Cable Critical Infrastructure Network, in the next step we will describe consequences and resilience strategy of the BECCIN. We understand *critical infrastructure resilience* to climate change as the CI capacity being able to absorb and to recover from hazardous events appearing as a result of climate change [9].

Strengthening critical infrastructure resilience to climate change means increasing CI capacity through its components and subsystems parameters improving and its operating environment parameters modification to achieve its characteristics stronger what allow its functioning in its operating environment to be able to absorb and to recover from hazardous events appearing as a result of climate change [9]. Analyzing the strategy of resilience strengthening of CI located in Baltic Sea Region we distinguish robustness, resourcefullness, redundancy, response and recovery. These concepts are defined generally in [4] and in this paper in the context of the energy sector.

Response is defines as activities to address the immediate and short-term effects of an emergency or disaster. Response includes immediate actions to save lives, protect property, and meet basic human needs [36]. In general, response activities are terminated when the situation has been stabilized. Then, conditions no longer meet established emergency categorization criteria and the emergency is declared terminated, and further activities focus on recovery. *Recovery* includes those actions taken after a facility has been brought to a stable or shutdown condition to return the facility to normal operation. The recovery phase continues until the facility and any affected areas meet predetermined criteria for the resumption of normal operation or use. The types of activities that could be conducted during the recovery phase include, but are not limited to: damage assessment, environmental consequence assessment, long-term protective action determinations, facility and/or environmental restoration, and dissemination of information [36].

Recovery procedures include dissemination of information to federal, state, tribal, and local organizations regarding the emergency and possible relaxation of public protective actions; planning for decontamination actions; establishment of a recovery organization; development of reporting requirements; and establishment of criteria for resumption of normal operations [36].

Further, *recovery organization* is responsible for coordinating all recovery activities. Responsibilities include, but are not limited to: prioritization of activities, protection of worker and general public health and safety, dissemination of information, coordination of site and offsite activities, collection of data and assessment of long-term effects associated with the release of hazardous materials, formulation and implementation of long-term protective actions for the affected areas, and providing assistance as requested to state and local agencies in formulation of long-term protective actions for affected offsite areas [36].

Risk in terms of energy sector can be defined as the combination of the probability of an incident releasing radioactive and/or hazardous materials and the consequences of the release on the public and the environment which, taken over all events relating to system operation, provides a meaningful picture of the adverse impact of the operation [36].

The concept of reliability is closely related to the vulnerability. *Vulnerability* in energy sector is defined as a weakness or system susceptibility that, if exploited would cause an undesired result or event leading to loss or damage. In [36] there have been distinguished major vulnerability, which, if detected and exploited, could reasonably be expected to result in a successful attack causing serious damage to the national security; and unspecified major vulnerability which is a major vulnerability, but specified in no greater detail than the specific security system (or one of its major components) when it occurs. In this paper we adopt definition introduced in EU-CIRCLE Taxonomy [9], according which *vulnerability* refers to essential properties of the system, parts of the system, assets, community and the environment which make them susceptible to adverse effects of natural hazards and other threats.

Nowadays, maintaining reliable and resilient power systems is an important challenge. According to International Energy Agency (IEA) [23], demand for electricity is set to rise faster than any other final form of energy, expanding by more than two-thirds over the period from 2011 to 2035. According to Pursiainen [33], the electricity system can be even more vulnerable to extreme weather in the future. In this context, new initiatives to improve energy efficiency and ensure electricity security have to be created. The IEA consider four key strategic areas to assess electricity security [23]:

– electricity sector unbundling,
– generation adequacy,
– regional market integration,
– variable renewable generation.

One of concepts to face these goals are demand response programs. *Demand response programs* are incentive-based programs that encourage electric power customers to temporarily reduce their demand for power at certain times in exchange for a reduction in their electricity bills. Some demand response programs allow electric power system operators to directly reduce load, while in others, customers retain control. Customer-controlled reductions in demand may involve actions such as curtailing load, operating onsite generation, or shifting electricity use to another time period. Demand response programs are one type of demand-side management, which also covers broad, less immediate programs such as the promotion of energy-efficient equipment in residential and commercial sectors [38].

Other terms, such as stability of an electric system or electric industry restructuring**,** also applies to electricity security. *Stability* can be defined as the ability of an electric system to maintain a state of equilibrium during normal and abnormal conditions or disturbances. *Electric industry restructuring* is the process of replacing a monopolistic system of electric utility suppliers with competing sellers, allowing individual retail customers to choose their supplier but still receive delivery over the power lines of the local utility. It includes the reconfiguration of vertically-integrated electric utilities [38].

Ongoing geo-political instability in some producing regions and increasing demand on energy highlight the vulnerability of energy supply chains. Therefore, an important issue is supply chain management. By the APICS Dictionary, *supply chain management* is defined as design, planning, execution, control, and monitoring of energy supply chain activities with the objective of uninterrupted, sustainable, competitive and secure energy supply, building a competitive infrastructure, leveraging worldwide logistics, synchronizing supply with demand and measuring performance globally [1].

5. Conclusion

In the paper the basic terminology and taxonomy that refers to energy sector and particularly to the Baltic Electric Cable Critical Infrastructure Network (BECCIN) is given. The BECCIN is an element of the Global Baltic Network of Critical Infrastructure Networks (GBNCIN) and is widely described in [5]. Considering critical infrastructures located in the Baltic Sea Region, we focus on climate change influence on their operation and strengthening their resilience to climate change. Further steps of this research are described in [11]. They are concerned among the others with particular critical infrastructures safety modelling, prediction and optimization. Further, tasks will be related with assessment of the critical infrastructure operating environment threats and weather extreme hazards impacts and modelling critical infrastructure accident consequences. Finally, the critical infrastructure resilience, business continuity under climate pressures analysis and Cost-Effectiveness Analysis will be performed.

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