An Assessment of Sectoral Vulnerability to Climate Change on Case Study Level Nuclear Energy – Bulgaria[1]

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Summary: In the long list of potential problems from global warming, the risks to the energy production stand out because energy is a key sector for every economy. The aim of the paper is to evaluate the economic meaning of climate change on nuclear power in Bulgaria. Kozloduy Nuclear Power Plant (KNPP) is a crucial energy source for the country. The impacts of extreme temperature and precipitation conditions under three climate scenarios (A1B REMO, A1B LMDZ and B1 LMDZ) are studied by comparing the mean conditions in the future (2021 to 2050) to those in a reference period (1961 to 1990). The main conclusion is that climate changes will not influence the safety of the KNPP, but will cause the cooling efficiency to diminish and the energy produced in summer to decrease slightly.

The paper is structured as follows: firstly, the past and present of the nuclear energy is presented, namely KNPP, located on the Danube River in North West Bulgaria. Secondly, the future development with and without climate change is described in detail, and the economic meaning of climate changes is assessed by a comparative analysis. Finally, recommendations for policy makers concerning the adaptation to climate change are outlined.

Key words: economic impacts, climate change, nuclear energy, Kozloduy.

JEL: Q54, Q49, O52.

1. Introduction

Most often "energy – climate change" relationship is considered in a one-way direction only and discussions are focused on CO_2 emissions, fossil fuels and thermo-electric plants as a main cause of climate change. In this context, nuclear energy is often considered as a synonym of clean or green energy. However, the impacts of climate change on nuclear energy production, plant design and technologies are rarely

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discussed. Moreover, climate change impacts are studied predominantly from a technical point of view. Therefore, this study is an attempt to fill in these research gaps and to evaluate the economic impacts on nuclear energy production in Bulgaria.

2. Methods applied

In the paper various quantitative and qualitative research methods are applied. The basis of study is a regional climate model REMO version 5.7. Hemispheric synoptic-climatological studies were realised based on the ERA-40 re-analyses data (for the past) and the ECHAM 5 global climate model's results (for the past and the future as well). The scenario simulation (2001 – 2050) is based on IPCC's greenhouse gas emission scenarios A1B and B1 and the following three climate models A1B REMO, A1B LMDZ, B1 LMDZ. Scenarios can be used to quantify climate change signals by comparing it to the control simulation (1951 – 2000) which is based on observed greenhouse gas concentrations. Daily and six hourly mean, minimum, and maximum temperatures, as well as daily precipitation amounts, are error corrected by quantile mapping.

Comparative analysis, scenario analysis and descriptive statistical methods have been applied in economic assessments of the possible climate changes in the future.

The quantitative analysis in paper has been supplemented by qualitative research methods. A number of interviews with representatives of KNPP have been conducted in 2008.

The concept of endogenous regional adaptive capacity (EARC) has been used to evaluate the adaptive capacity of the case study region. The degree of tertiarization and industrialization measured by employment shares and value added, the economic development (the level and growth of GDP per capita), and also touristic capacities and spatial conditions such as the accessibility are main deterinants of ERAC. The classification was performed by utilizing the explorative instruments of factor and cluster analysis.

3. Data and metadata

The source of economic data about energy in Bulgaria as well as the regional economy of Kozloduy municipality and Vratsa district is the National Statistical Institute.

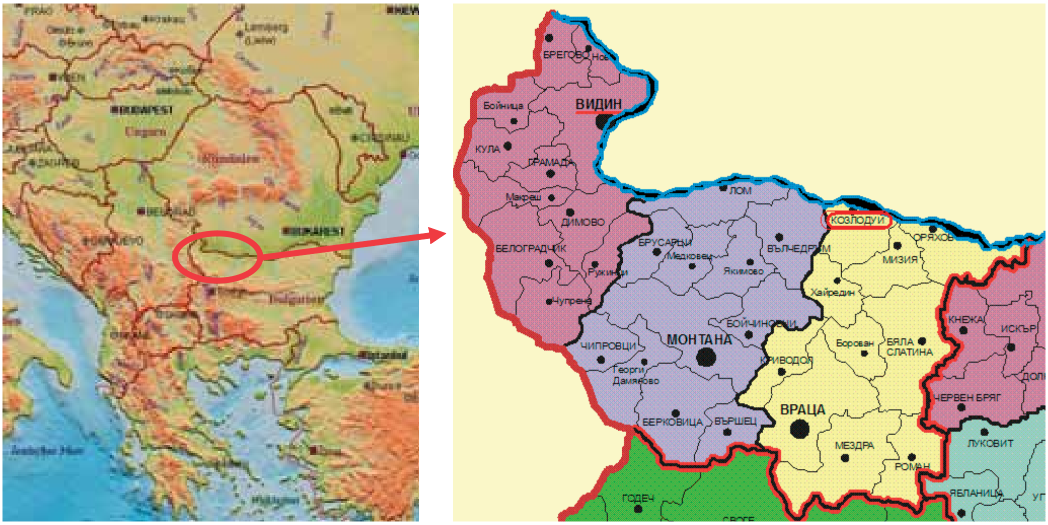
Information about the technical parameters of nuclear units in Kozloduy is provided by the kind assistance of KNPP.

The meteorological data is based on the observational dataset ECA&D which covers Europe with a 0.25° grid. In project CLAVIER uses error corrected daily data from highly resolved regional climate simulations (REMO version 5.7). The main climate parameters including daily mean, minimum, maximum temperature and precipitation amount are error corrected. The hindcast simulation is available from 1961 to 2000 (dataset STAT-CLIMATE-ECA-era40), whereas the scenario run covers the period 1951 to 2050 (dataset STAT-CLIMATE-ECA-A1B). The same principles apply to LMDZ models.

4. Case study

4.1. General description

As a case study is examined the existing nuclear power plant in Bulgaria, which is located on the Danube River near Kozloduy town in Vratsa District (NUTS BG113).



4.2. Importance of the sector

Energy balance of Bulgaria

Bulgaria has very few domestic energy resources. Data in Table 1 indicate the national provision with domestic primary energy source. The country has significant but very low-grade coal reserves. Hydropower potential is also limited since most of Bulgaria's rivers are small and the only large river, the Danube, has a small drop in altitude. Nuclear energy is dominating the primary energy production with 46 % in 2005 (Figuire 1).

Nuclear energy had a share above 40 % in the national electricity generation and the share dropped to 34 % (Figure 2) after shutting down two units of Kozloduy nuclear power plant (KNPP) at the end of 2006.

Nuclear energy plays also an important role in the electricity export of Bulgaria. The foreign trade business of the National Electricity Company (NEK) covers import, export, transit of electricity through Bulgaria in accordance with the Clearing and Settlement Agreement for Cross-Border Trade in the SEE countries, and other services. This activity is carried out on the basis of bilateral contracts concluded following:

Table 1. Energy independence of Bulgaria

Per cent

	2001	2002	2003	2004
Total	54.0	56.0	52.1	54.0
Coal	63.2	68.5	64.0	64.1
Crude oil	0.6	0.7	0.6	0.5
Natural Gas	0.7	0.7	0.5	10.7

Source: NSI

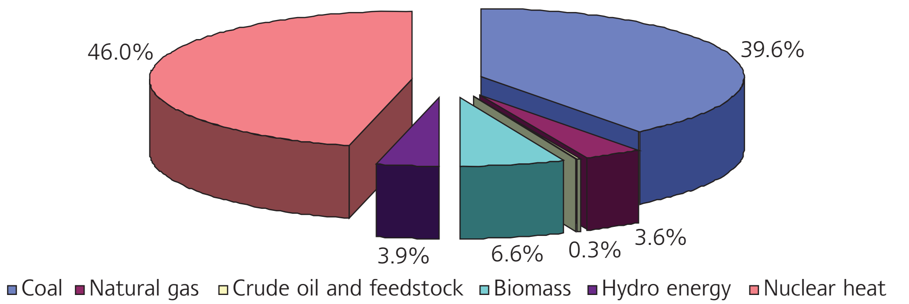


Figure 1. Primary energy production in 2005
Source: NSI.

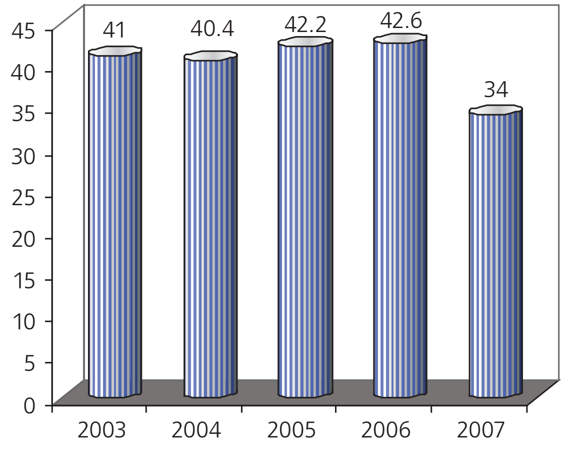


Figure 2. Share of nuclear energy in the national electricity generation (%)
Source: KNPP Report 2007.

- participation in international tenders;
- direct contracting with power utilities;
- direct contracting with electricity traders.

The electric power system of Bulgaria has been the main exporter within the Balkan region during the recent years. About 75 % of the electricity export in this part of Europe was realized by NEK (NEK, 2008). Besides being the main exporter, NEK also acts as a guarantor of power supply in the event of deviations from the forecasts. The Balkan countries are a traditional market for NEK. In 2007 the company exported 4461 GWh. Although data about producers of this electricity is lacking, it could be concluded from KNPP annual report that most part of the exported electricity is generated by nuclear

Table 2. Bulgarian export and the share of electricity export in 2007

Exports	Million leva	Share of electricity export
SITC 35: Electric current	469.9	
SITC 3: Mineral fuels, materials	3 888.1	12.1 %
Total export	26426.9	1.8 %

Source: NSI, 2008 b, SITC – Standard international trade classification energy, because KNPP electricity was about 95 % of the total supply on the liberalized market.

Concerning the national export, the share of electricity in 2007 amounted to nearly BGN 470 million, which is 12 % of value of the group Mineral fuels and related materials[2] and 2 % of the total export of Bulgaria (Table 2).

In conclusion, nuclear power is a crucial energy source for Bulgarian economy providing for about a quarter of the transformation input of the country and a third of the national electricity generation. In addition to its economic importance, nuclear energy has an important social aspect too, because household and the public sector are the major electricity consumers. Furthermore, Bulgaria is a main electricity exporter in the Balkans. Considering the export group Mineral fuels and other materials, the value of electricity export is the second largest after petroleum related products.

4.3. The climate condition and their significance for the sector

The site of KNPP is located 3.5 km southeast of Kozloduy town and 3 km south of the Danube River and the Romanian border. KNPP is situated entirely on the non-flood plain, single-loess terrace of the Danube river bank at about 3.5 km from the right bank of the river. The elevation of the site 35 m above the sea level is formed on an area considerable in its size. The KNPP was designed in this location to sustain a Danube flood, which occurs once in 10 000 years. Embankments, constructed between the site and the river, are designed for the flow of the 1000 year high wave along the Danube with the required normative reserve. The draining systems in the region are designed to take away the surface waters from intensive rainfalls with different continuity and rain height of probability 0.01 % (once in 10 000 years).

During normal operation of Units 3-6 (average annual power output 2500 – 3000 MW), the water quantity necessary for the cooling system was 110-140 m^3/s or 2.7 – 3.5 % from the river flow. With regard to the average water quantity for many years (5719 m^3/s) this estimation is 3.1 % for continuous work at full power and 1,9 – 2,4 % in normal operation regime.

The climate is moderate continental with cold winter and hot summer. The site is open on the north and northeast and this is conducive to the cold air the pushes in especially in the winter. The observed maximum air temperature is +43.2 °C (August), the minimum air temperature is -26.6° °C (January) and the mean year temperature is 11.5 °C. The annual variation of average monthly temperatures is characterised by a maximum in July (between 23 °C and 24 °C) and minimum in January (between 0 °C and minus 0.5 °C). Average temperatures during the winter season are around 0 °C, and during the summer between 21 °C and 22 °C.

The annual precipitation sum is about 518-558 mm and it is one of the lowest in Bulgaria. It is unevenly distributed during the year – the primary maximum is in May-June and the secondary one – in November. The lowest precipitation is in the autumn and winter, the minimum being in October. In the winter the precipitation is about 110-120 mm, which is 20-24 % of the annual sum, in spring it is 135-150 mm (27-28 %) and in summer – 145-150 mm (28-30 %).

[2] According to the Standard international trade classification SITC, rev. 4, Section 3 is Mineral fuels, lubricants and related materials and includes:
 32 Coal, coke and briquettes;
 33 Petroleum, petroleum products and related materials;
 34 Gas, natural and manufactured;
 35 Electric current.

The strongest wind is observed in spring – up to 25 m/s. Most of strong winds are of west – northwest direction. According to the wind zoning of Bulgaria Kozloduy site is located in a zone where the probable maximum wind speed is 33m/s and the respective pressure of this wind on buildings and equipment is up to 550 N/m^2.

Conclusions regarding the presence of temperature inversion may be drawn from the aero-logical sounding from the period September 1967 – August 1968, performed in the region of the KNPP. The inversions have been observed in 30 % of the cases, this percentage being about 37 % during the cold half-year and about 22 % during the warm half-year. There have been ground-level inversions in 15 % of the cases, their frequency being much lower during the warm half-year – about 7 %, whereas in the cold season it is about 23 %.

The air pollution potential is determined by the frequency of the slight winds (occurrences of calm weather and of winds of speed up to 1 m/s). According to this parameter, there is a regional division of the country. The western part of the Danube hilly plain is characterised by poor conditions for pollution dispersion, where the frequency of slight winds is 60-70 %. The conditions in a narrow strip along the river Danube, which also includes the area around Kozloduy, are little bit more favourable and the frequency of the slight winds is 50-60 %.

In this part of the region along the Danube River, ice formation of ground-level installations may occur when any of the following combinations between meteorological parameters is observed: temperature of the air between 0 °C and -2 °C to -4 °C, wind speed between 0 and 3 to 5 m/s, and relative humidity between 95 and 100 %.

Hailstorms causing damages in north-west Bulgaria have been observed during the period between May 5th and July 31st. In particular in the area of the KNPP it is a random phenomenon. The absolute maximum intensity (mm/min) of pouring rains is up to 3-4 times higher than the average intensity for precipitation with duration up to 30 minutes. Loading induced by wind and snow are estimated as moderate. The probability for snow storms is much lower than that in the north-eastern part of the Danube plain. Fogs occur 45 days per year on average. Their duration is up to one day in 80 % of the occurrences in January. No tornado has been registered in the region. Investigations indicate a negligible probability for this event to happen (of the order of 10-6 cases per year).

Buildings and facilities of KNPP are located on an area of about 1000 dka. KNPP has also its own pumping station on the Danube and canals for technical water supply and the total territory of the power plant covers 4471 dka.

Bulgaria has six nuclear power units at Kozloduy, which started operation between 1974 and 1991. There are four WWER[3] – 440 units, net capacity 408 MW(e) and two WWER – 1000 units, net capacity of 953 MW(e), all imported from the former Soviet Union. Nuclear fuel is imported from Russia too. However nuclear energy is considered a domestic source in the energy mix of Bulgaria.

The first four units were shut down on 31.12.2002 and 31.12.2006 respectively. During the 90s and beginning of 2000s KNPP went through huge modernization programs. The programme for Units 5 and 6 was almost finalized in 2007: 99.1 % of the measures were completed and the last two are in the process of finalization (KNPP, 2007).

[3] WWER - Water cooled, water moderated energy reactor.

According to KNPP report the gross electricity generation for 2007 amounts to 14 643 081 MWh. Compared to 2006, when the two 440 MW Units 3 and 4 were in operation, the generation of Kozloduy NPP is 25 % lower. However, the electricity generated by units 5 and 6 in the last year is 15 % more (almost 2 million MWh) more compared to 2006, and it is the highest generation ever achieved by these units. The record generation of the two 1000 MW Units is a result of their accident-free operation, optimization of equipment operation and maintenance activities, reduced duration of planned outages, minimal downtimes except for the planned outage. In 2007 the load factor of the operating facilities in Kozloduy NPP was 83.58 %, which is higher than the previous years.

In addition to the electricity, KNPP generates also heat. In 2007 the heat generated was 237 166 MWh, that is 50 % more than in 2006. The major part of it was used for the plant-in-house demands including the closed Units 1-4. The amount of heat provided for the households, public and commercial sector of the town of Kozloduy has not been changed – 70 159 MWh. The structure of the heat consumption is as follows – the largest share was used by households (65 %) and industrial and state organizations (27 %) within the town.

The net actual electricity exported by the KNPP for the electricity grid of the country was 13 692 642 MWh. For the regulated market, under a contract with the National Electricity Company (NEK), KNPP supplied 9 603 441 MWh in 2007. This is 70.1 % out of the total net generation of KNPP. The rest was supplied to the liberalized market. The total amount of the active net electricity sold on the liberalized market and supplied by the plant for 2007 was about 95 % of the total on this market[4].

KNPP operates according to the requirements of the Nuclear Regulatory Agency (NRA) at the Council of Ministers of the Republic of Bulgaria, the Ministry of Environment and Water and the Ministry of Health. Is is subjects to permanent control by the International Atomic Energy Agency.

In 2007 for a third successive year there is no reactor scram at Kozloduy NPP units. The criteria accepted by the World Association of Nuclear Operators (WANO) determine one scram per two years as an indicator of high level of safety and reliability of operation (Fig. 10). The total number of operational events recorded during the year is 21 and is lower than the previous years. According to the International Nuclear Events Scale – INES, 2 of the operational events reported were below the scale, and 19 were ranked level "0" (deviation)- below INES scale. No events ranked level "1" (anomaly) or higher were recorded (KNPP, 2007).

The Spent Nuclear Fuel (SNF) is transported from Bulgaria to Russia according to a trilateral agreement between Bulgaria, Russia and the Ukraine. All low and medium radioactive waste, generated in the process of operation of the nuclear power plant was reprocessed by the specialized company "Radioactive wastes-Kozloduy"

[4] Because of the amendments of the Energy Act, since July 2007 the principle for participation of the electricity generating companies on the market has been changed. State Energy and Water Regulation Commission (SEWRC) determines the obligatory generation quotas to satisfy the demand and the consumption on the regulated market with regulated prices of the so called protected consumers, and the rest of the net electricity generation can be sold on the liberalized market. This legal change stimulates more the efforts for optimizing the operation of nuclear facilities and enhancing the effectiveness of the operation of the plant (KNPP, 2007).

4.4. Influence of climate in the past

The meteorological and hydrological conditions which are important for the KNPP have been clarified in interviews and a questionnaire and literature reviews (IAEA 2003a, b). The ordinary (normal) climate-related conditions do not have any influence on electricity production and definitely have no influence on the safety of the nuclear units and nuclear waste.

Literature review shows that impacts on nuclear energy are usually studied as a part of the effects on thermo-electrical plants in general (CCSP, 2007). Most of the direct climate impacts are related to power plant cooling and water availability.

The International Atomic Energy Agency (IAEA) maintains a database of external events in the operation of nuclear power plans (NPP) all over the world. External events are only a minor part (2 %) of all causes of recorded events (over 3000 since 1980). The nature of external events is shown on Figure 3 (IAEA, 2003 a).

These events are both human and nature-induced, and it is difficult to differentiate between climate and non-climate related events. In the IAEA report there are examples of the following events that might be related to climate: floods from rivers, floods from precipitation (due to poor drainage on site), leakage from groundwater, other water-related events – ice in water intake, salt contaminations, biological fouling (mussels, fish, clams, shrimps, jellyfish, etc.). According to IAEA (2003b) extremely low temperature has been the root cause of many malfunctions in nuclear power plants (moisture condensation, hindrance of proper operation of the air ventilation system). Heat waves in summer have also caused problems, although none of the safety-related operating limits in the installations was reached or exceeded. However, the regulations governing warm

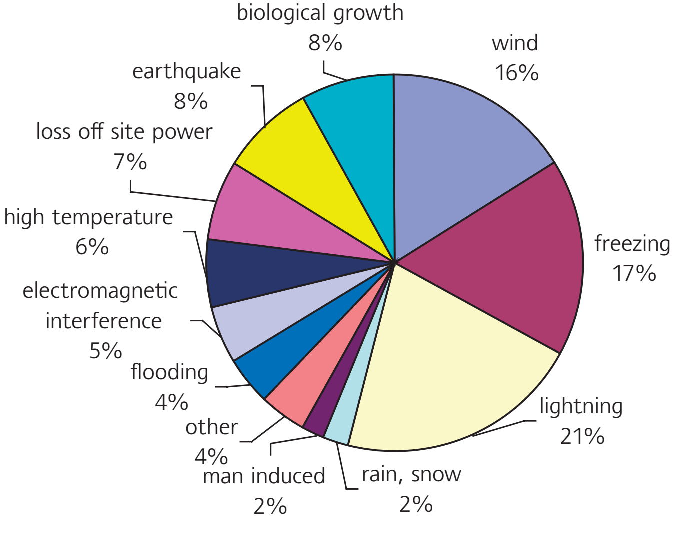


Figure 3. Structure of external events affecting NPP
Source: IAEA, 2003a, p. 20.

water discharge into rivers from nuclear power stations had to be temporary disregarded.

On the base of the literature review, a questionnaire and interview were prepared. The engineers interviewees were asked to explain how extreme weather conditions might inpact KNPP, including each of the above listed events, as well as if there was any such events in the past.

According to the reports about the operating experience of KNPP (IAEA, 2007) the climate in the past has not caused full outages[5]. Considering outages caused by environmental conditions (flood, storm, lightning, lack of cooling water due to dry weather, cooling water temperature limits etc.) KNPP reports less than one hour of such outages. Only one event of such type has occurred so far. The interviewees explained that in 2005 there was power reduction in Unit 5 for 40 minutes caused by biological fouling of the canal grating. The plant growth in the river was stimulated by the high temperatures and increased level of the Danube.

Unit shutdowns caused by extreme weather conditions (temperature, wind, precipitation), very low or high levels of the Danube and natural disasters have never happened so far. The level of the Danube at Kozloduy depends on the natural climatic conditions but also on the operation of Iron Gate Hydro Complex in Serbia.

The water temperature of the Danube river, which is used for cooling, has no influence of the KNPP safety, but high temperatures in summer (above 28-30°C) reduce the cooling efficiency and thus, the energy produced by about 50 MW per hour.

According to the KNPP engineers the meteorological and hydrological conditions in the past were carefully studied in the course of the plant design in the 1960s of the last century. The facilities are designed to sustain an extreme event with probability 10^{-6}. Currently the external conditions and exploitation characteristics are regularly monitored and compared to the design characteristics. This analysis is part of the periodic safety reviews that KNPP is required to conduct and submit to the Bulgaria Nuclear Regulating Agency in order to have its licence renewed.

Since 1997 three automatic meteorological stations have been functioning in KNPP, before that there was one station. The stations measure every hour a number of parameters: air temperature, relative humidity, precipitation, wind speed. They are used to calculate the so called Atmospheric stability class as required by the safety regulations[6]. The Danube level and the water temperature are monitored too. The information is gathered and processed according to the requirements of the International Atomic Energy Agency (IAEA). Experts at KNPP do not make weather and hydrological forecasts. They receive daily forecasts about the water level from the Executive Agency for Exploration and Maintenance of the Danube River. KNPP experts are informed about the weather forecast from the forecasts of the National Meteorological and Hydrological Institute that are publicly available in the media (TV, radio). KNPP does not receive any special forecasts about the extreme meteorological events.

5 According to IAEA the outage is defined as any status of a reactor unit, when its actual output power is lower than the reference unit power for a period of time. By this definition, the outage includes both power reduction and unit shutdown. The outage is considered significant, if the loss in the energy production corresponds to at least ten hours of continuous operation at the reference unit power or if it has been caused by an unplanned reactor scram (even if the unit had been shut down for less than 10 hours).

6 It is used to forecast the spread of radioactive contamination in case of an accident.

5. Future developments

5.1. Framework for the future development of the sector irrespective of climate changes

The Energy Strategy of the Republic of Bulgaria (2002) aims at achieving a competitive economy through a competitive energy sector and more specifically: continuing the market reforms in the sector, privatization, security of energy supply, energy efficiency, social security, environmental protection, opening of the system towards the European energy market, etc. The strategy outlines the major role of the nuclear power in the energy balance in the country and points out that Bulgaria will continue to develop it in accordance with the contemporary safety requirements, international conventions and EU legislation. Bulgaria must apply the EU directives on energy security, nuclear safety, Internal Energy Market (IEM) and the Emissions Trading Scheme (ETS).

A new Energy Strategy is expected to be adopted in 2010. According to the Concept for the new strategy (MEE, 2008a) nuclear energy plays an important role in the energy balance of Bulgaria and South East Europe. The priorities of the strategy are sustainable development, competitiveness, energy security. The national objectives till 2020 are in line with the European objectives – reducing green house gas emissions, increasing the share of renewable energy in the energy mix, enhancing energy efficiency. According to the Concept the development of nuclear energy is in compliance with the energy security priority and it has the advantage of a source of secure and emission free electric energy. A number of objectives (a low-carbon energy mix, stable prices and expansion of export) are planned to be achieved by:

- building a new nuclear power plant – Belene NPP;
- enlarging the capacity of Kozloduy NPP.

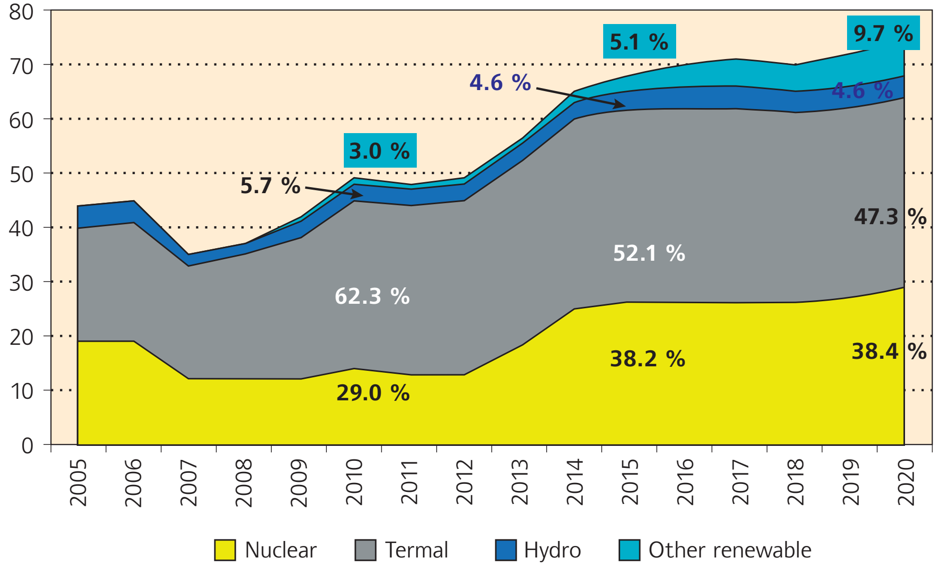


Figure 4. Forecast energy balance (TWh)
Source: NEK 2007a.

According to the Concept, as well as the strategic plans and forecasts of NEK nuclear energy is going to be the second major energy source after the coal and is planned to be an important factor in the energy balance of Bulgaria and the Balkan region (Figure 4).

Bulgaria's gross power demand is going to increase in the future. NEK has developed two scenarios – minimum and maximum (NEK 2007 b). The forecasts are characterized by smaller annual growths in power demand in the beginning and gradual increase until 2020. In view of the future electricity demand and replacement of decommissioned capacities, new generation plants are planned to be constructed.

The development of the power system until 2012 is predetermined. It covers completion of existing projects and new projects for hydro and thermal power plants. The need for a new nuclear capacity emerges in 2013 under the minimum scenario or 2015 under the maximum scenario. The second nuclear unit is scheduled for 2016 (maximum scenario) or 2018 (minimum scenario).

There are similar forecasts in the Concept for a new energy strategy (Figure 5) The Ministry of Economy and Energy of Bulgaria and the National Electric Company respectively have an ambition to strengthen the position of the country as a powerful energy centre on the Balkans by accelerated construction of new electric plants. New capacities 7000 MW are going to be launched until 2020 (MEE, 2008 a, p. 20).

NEK has declared its intention to enlarge its markets in the future (Fig. 6). The company as a public provider is buying and selling electrical energy in Bulgaria at regulated prices determined by the State Energy and Water Regulatory Commission and at non-regulated prices at the electricity market.

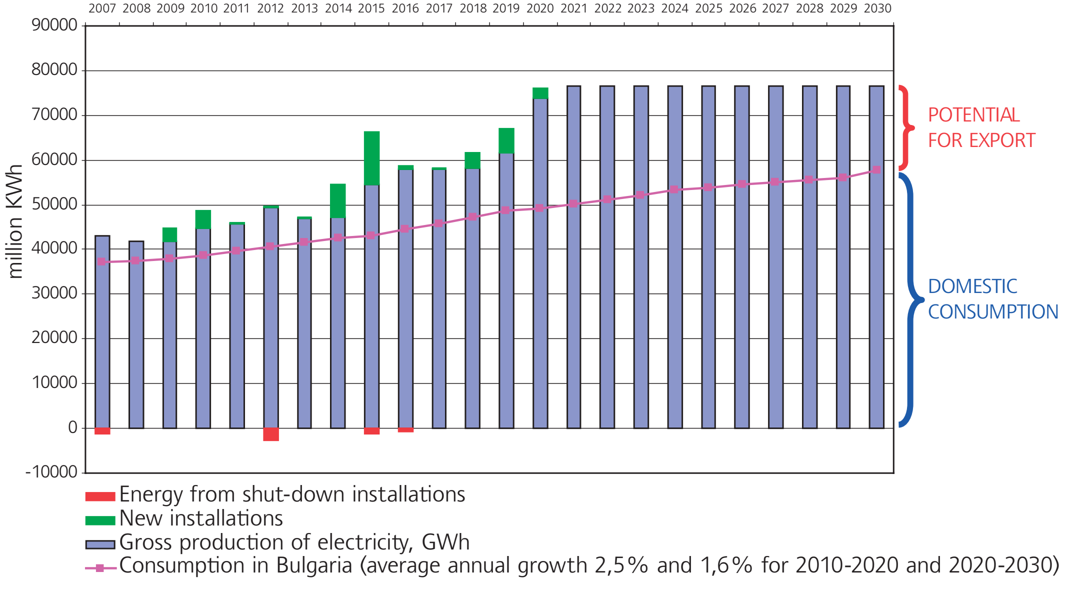


Figure 5. Security of electricity supply
Source: MEE, 2008 b.

In 2007 in addition to 1-year contracts, NEK started to use monthly and weekly export contracts as a result of which it succeeded in achieving maximum utilisation of capacities and reduction in costs. According to NEK, the forecasts for the next 3-5 years show that the power deficit on the Balkans would increase due to the limited capacity of the company to cover it. A clear indication of that is the structure of the contracts NEK enters into where the percentage of emergency supply contracts is higher. NEK aims to maintain and increase its presence on the regional power market.

Concerning the projected expansion of nuclear capacities there are specific plans and government decisions only about Belene plant. According to the Concept for a new strategy two units of Belene NPP (1000 MW each) are planned to be launched in 2014 and 2015 respectively. During the 1970's, a site for the construction of a second nuclear power plant was selected near the town of Belene. In 1980, the Ministry of Energy started its construction. Initially the construction of 4 units with WWER-1000/V320 reactors was envisaged with a possibility for exceeding this capacity with additional new facilities. The engineering works on the site and the construction of the infrastructure started at the end of 1980. The construction of unit 1 started in 1987. In 1991 the Belene NPP construction was stopped by the Council of Ministers. At that time the first unit was 40 % complete.

In 2003 the Government announced its intention to restart the construction at the Belene site. In February 2007 the Bulgarian authorities announced construction plans to the European Commission, as they are required to do under the Euratom Treaty. A Belene construction project has been established in which the State utility NEK will retain overall control, with 51 %, but the remaining shares have been put to tender. On 3 Oct. 2008 it was announced that RWE Power was selected for a strategic partner of NEK. It is expected that in 2009 the contraction works at Belene are going to start. Belene is a priority investment project for Bulgarian authorities.

Concerning the future development of the nuclear energy sector irrespective of climate change, two conclusions can be drawn from the above analysis of the strategic plans of the Bulgarian government:

2007
Electricity:
4.5 billion kWh export
+
2.8 billion kWh transit
Capacity of the grid:
9 billion kWh

2030
Electricity:
18 billion kWh possible export
(or 33 billion kWh if new units are constructed in Kozloduy, units 7&8 – 2 x 1000 MW)

Capacity of the grid:
15 billion kWh

Figure 6. Bulgaria – the energy hub of the Balkans
Source: Adapted from MEE, 2008 a, p. 25.

- Belene NPP is an ongoing priority investment project for Bulgaria. However, financing has not been secured yet;
- the development of the nuclear energy is a clear priority for Bulgaria, it is going to be second largest source of electricity (with about 37-38 %) after thermal electric power plants in 2020. The government rely on nuclear power to achieve energy security and a low-carbon energy mix, as well as for export. NEK has declared its intention to enlarge its markets on the Balkans and Bulgaria to be become the largest energy centre in the region.

5.2. Expected climate change of the relevant parameters in the region

Climate scenarios describe the mean conditions over a longer period. Hence, comparing the mean conditions in future periods (e.g., 2021 to 2050) to those in a reference period (e.g., 1961 to 1990) allows deducing the influence of climate change. As explained above analyses have been focused on extreme events in the three climate models under consideration A1B REMO, A1B LMDZ and B1 LMDZ[7].

The first two are based on one and the same scenario[8] for the CO_2 emissions in the future (the so called A1B), the difference are the climate models[9] applied (developed by MPI Germany and LMDZ France respectively). The third one is based on the emission scenario B1 and climate model LMDZ. The Emission Scenarios have been developed by the Intergovernmental Panel of Climate Change (IPCC).

The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into different groups that describe alternative directions of technological change in the energy system. A1B scenario is a balance across all energy sources: fossil intensive and non-fossil energy sources.

The B1 storyline and scenario family describes a convergent world with the same global

Table 3. Differences in the climate parameters in the future 2021-2030 as compared to the past climate 1961-1990 in Bulgaria

Scenario/model	Yearly mean of the mean daily temperature (°C)	Yearly mean of the daily precipitation amount (mm)
A1B – REMO	+ 1.0	0.0
A1B – LMDZ	+ 2.3	-0.2
B1 – LMDZ	+ 1.8	-0.5

Source: own calculations based on CLAVIER database

7 The source of all data and figures in this section is CLAVIER project database.
8 Emission scenario: a plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g., greenhouse gases, aerosols), based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development, technological change) and their key relationships.
9 Climate model (hierarchy): a numerical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties.

population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

The changes expected in the future 2021-2030 as compared to the past climate 1961-1990 over the territory of Bulgaria under the three scenarios are presented in the table below.

None of the climate models shows extreme values in the future that are above the critical meteorological parameters for the safe operation of the KNPP. That is why, only the first model A1B REMO is described in this paper in details in order to illustrate the nature of expected extreme events. The LMDZ A1B and LMDZ B1 models have been analysed briefly in parallel to compare the differences between the two different emission scenarios A1B and B1.

I. Scenario REMO A1B at Kozloduy

Mean climatic conditions

The climatic situation under A1B in the Kozloduy[10] region is similar to the expected average changes over the territory of Bulgaria. The average yearly temperature is expected to raise by 1.6 °C, the increase in the mean monthly temperature is relatively significant in February, September and October (+ 2.8 °C), as well as in summer (+ 1.6 ÷ 1.7 °C). Changes in precipitation sums are negligible. The mean yearly precipitation will decease by 0.1 mm in 2021 – 2050 as compared to 1961 – 1990. A decrease in the mean monthly precipitation will be observed during most months of the year and especially in June and July (-0.32 mm on average), an increase is expected only in December (+ 0.23 mm).

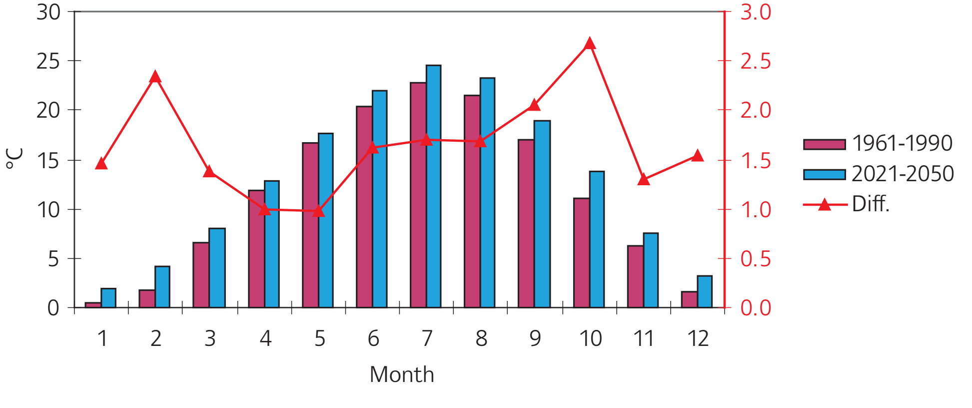


Figure 7. Monlthly mean temperature
Source: Own calculations based on CLAVIER database.

[10] The information about Kozloduy point is extracted from a grid dataset 25/25 km and thus, analysis of data about an individual point should be used with caution.

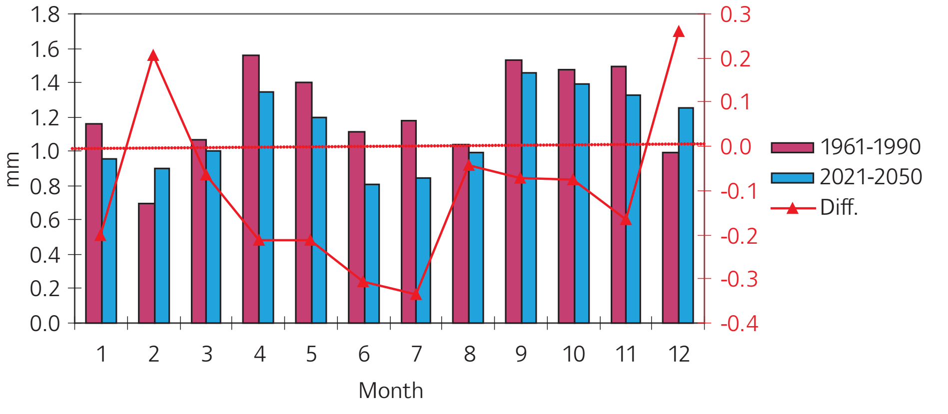
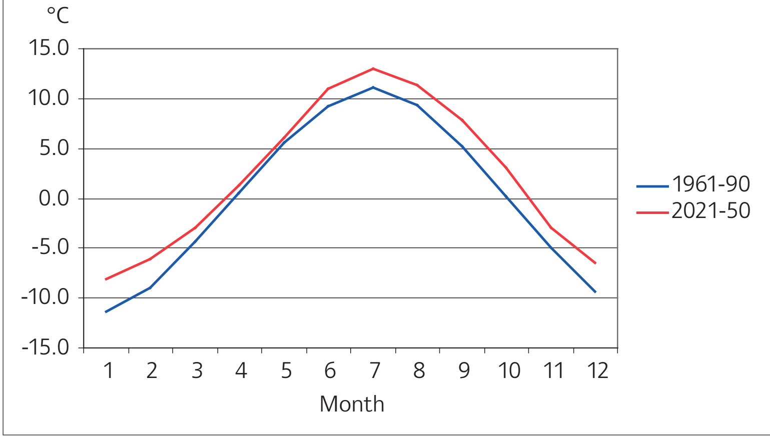


Figure 8. Monthly mean precipitation
Source: Own calculations based on CLAVIER database.

II. A1B REMO – Description of extreme values

Monthly minimum of daily minimum temperature[11]

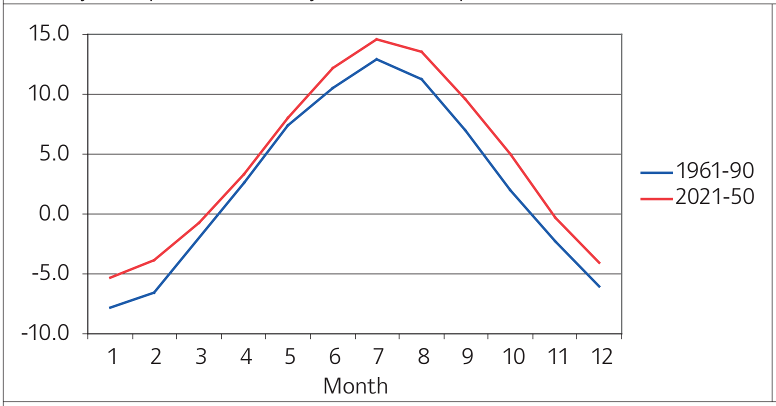


The comparison of the minimum values per month of the daily minimum temperatures during the periods 1961-1990 and 2021-2050 shows that in general an increase is expected in the future. The change is most significant in the period December – February and in September – October. The lowest daily minimum temperatures in the future are expected in December and January.

Figure 9-a. Temperature

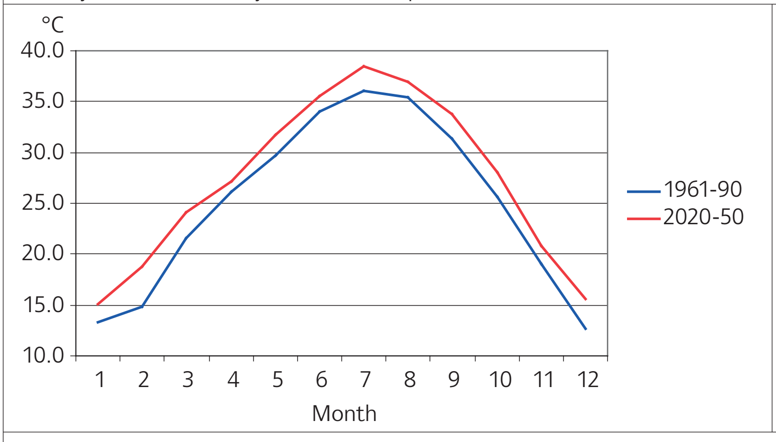
[11] The original data about temperature is in Kelvin.
The data has been recalculated in degrees as follows Celsius 0 °K = - 273.15 °C

Monthly 10th percentile of daily minimum temperature



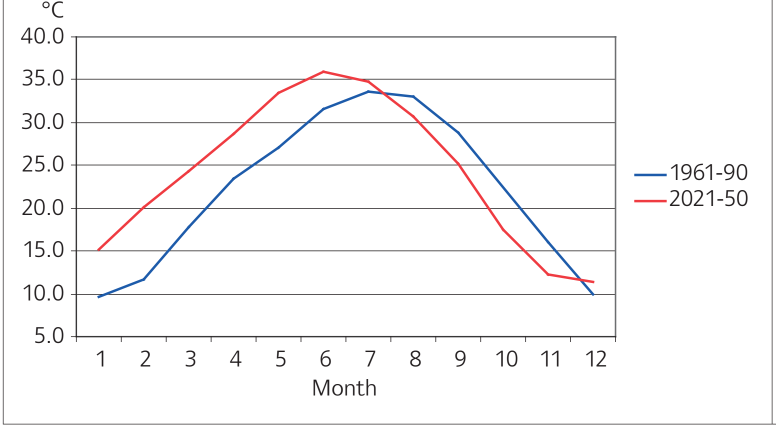
The figure shows the average values per month of monthly 10th percentile of daily minimum temperature. It is expected to increase by about 2°C in the period 2021-50 as compared to 1961-1990.

Monthly maximum of daily maximum temperature



The comparison of the averages of the daily maximum temperatures during the periods 1961-1990 and 2021-2050 shows that an increase is expected in the future. The most significant changes are in winter. In summer an average difference in maximum daily temperatures of + 1.8 °C is expected, however in June it is + 2.4 °C.

Monthly 90th percentile of daily maximum temperature



The figure shows the average values of the 90th percentile of daily maximum temperature per month. A clear shift of the 2012 – 2050 curve to the left and upwards could be observed as compared to the average curve in the past 1961-1990. Thus, the monthly 90th percentile of the daily maximum temperature is expected to increase by around 5°C during most time of the year except August, September, October and November.

Figure 9-b. Temperature

Yearly 90th percentile of heat wave duration index of daily maximum temperature (in days)

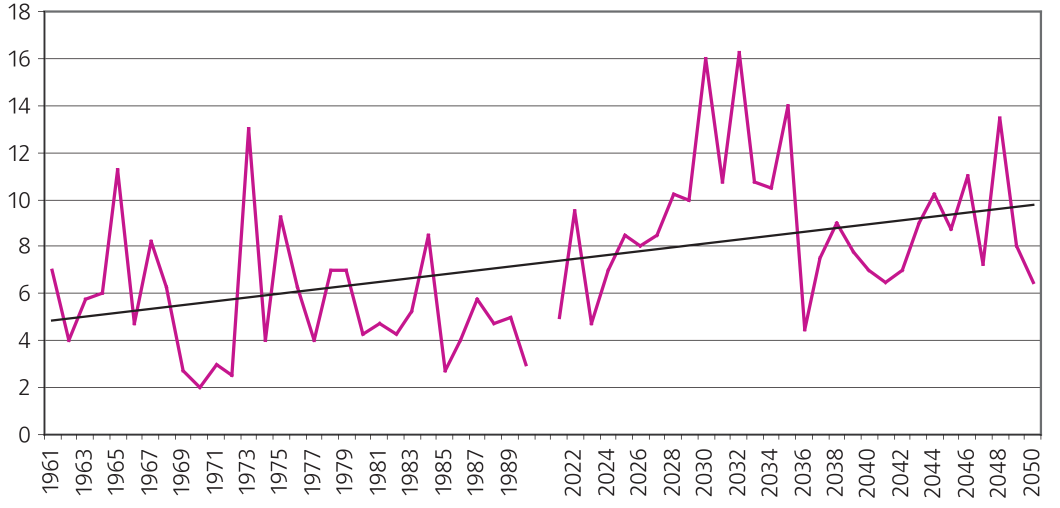
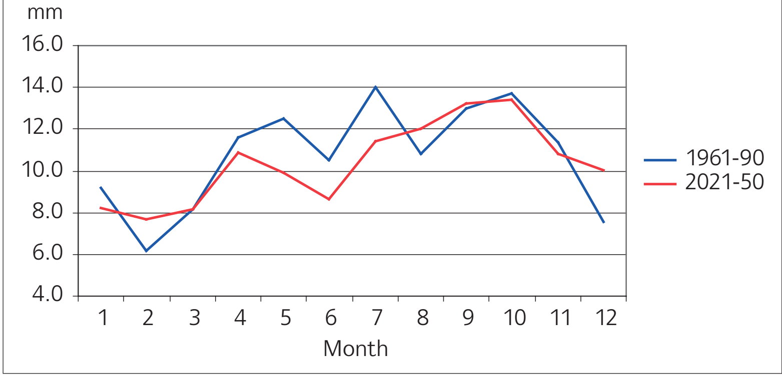


Figure 9-c. Temperature

The duration of heat waves is expected to increase in the future under the A1B scenario. In 1961-1990 the average value of yearly 90th percentile of heat wave duration index is 5.5 days, whereas during the period 2021-2050 it is 9.1 days. A clear upward liner trend could be observed on the figure above.

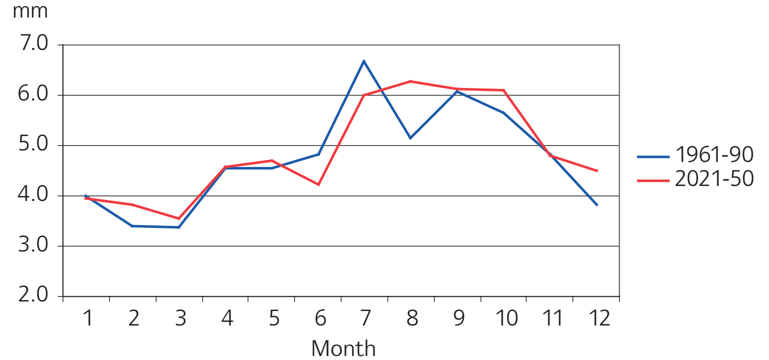
Monthly maximum of daily precipitation amount



The figure shows the average values each month of monthly maximum of daily pre-cipitation amount. Two major differences could be observed in the future period under review: a relatively significant decrease in maximum daily precipitation during the period May – July and an increase in Febru-ary and December.

Figure 10-a. Precipitation

Monthly maximum of daily maximum temperature

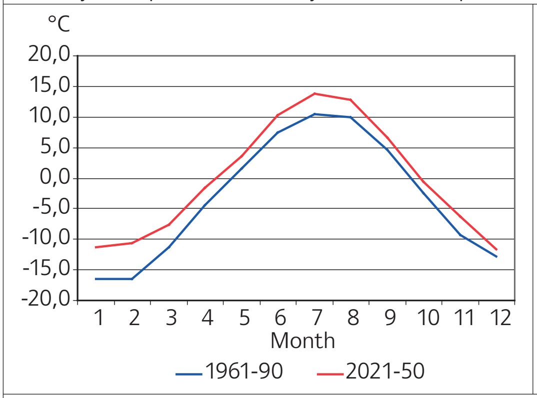


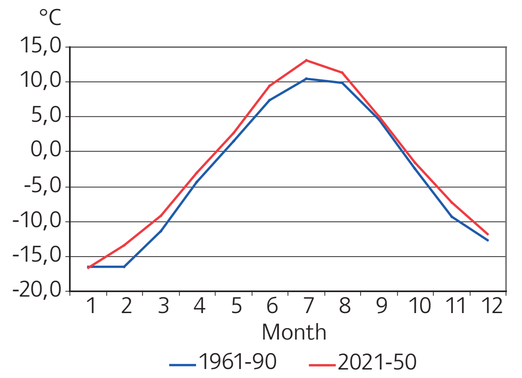
Monthly precipitation intensity index of daily precipitation amount (in mm)

Figure 10-b. Precipitation

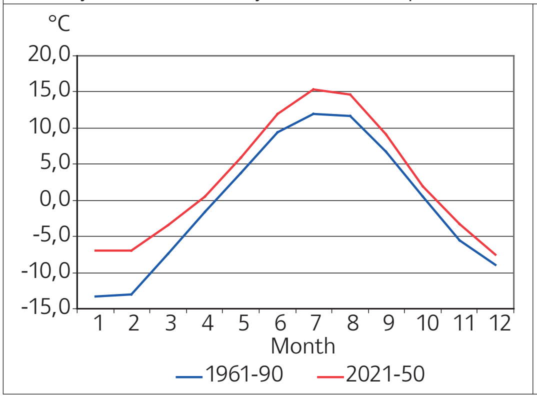
A1B	B1

Monthly 10th percentile of daily minimum temperature





Monthly maximum of daily maximum temperature[12]



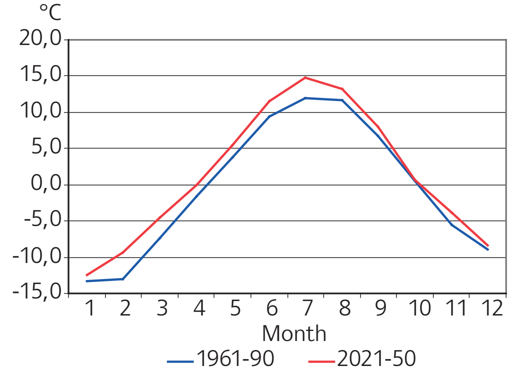
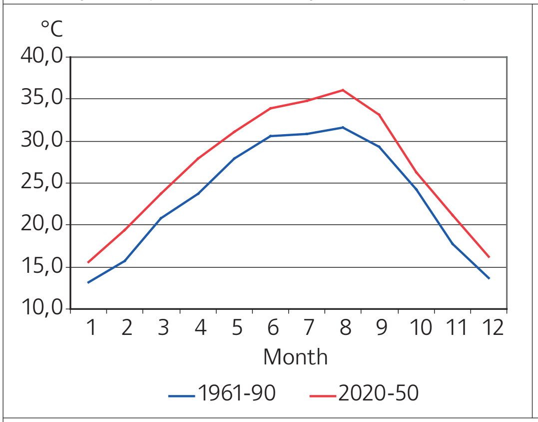


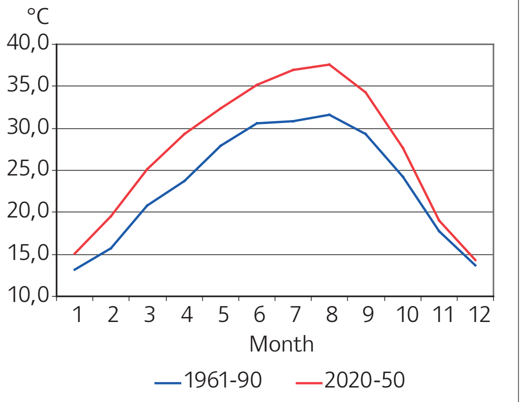
Figure 11-a. III. LMDZ climate models – extreme values temperature

12 See the definitions in the annex.

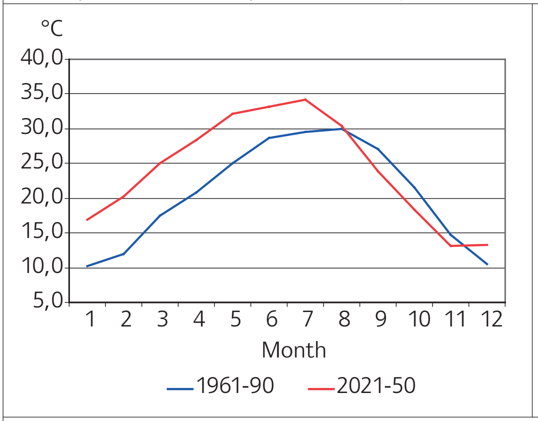
A1B	B1

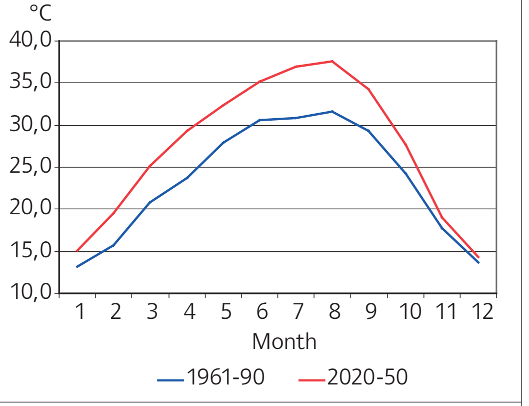
Monthly 90th percentile of daily maximum temperature



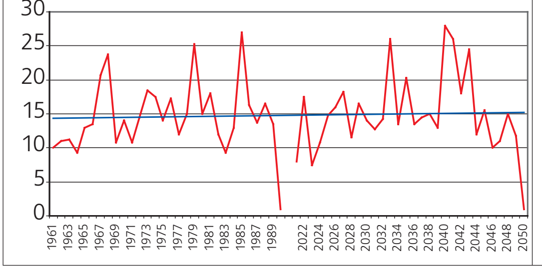


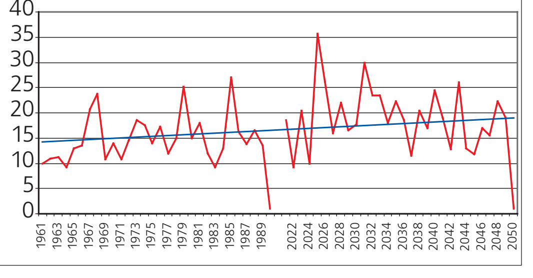
Monthly maximum of daily maximum temperature





Yearly 90th percentile of heat wave duration index of daily maximum temperature (in days)





Heat wave duration increases significantly under B1 LMDZ scenario as compared to A1B LMDZ.

Figure 11-b. III. LMDZ climate models – extreme values temperature

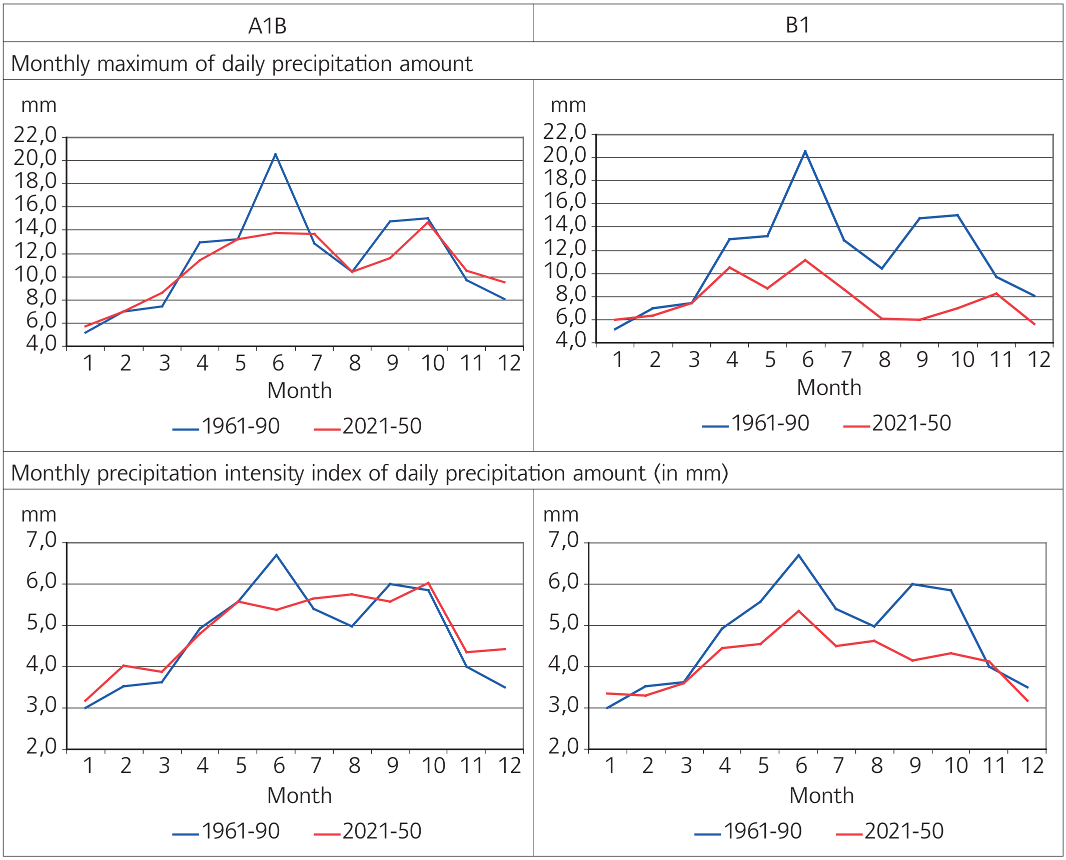


Figure 12. LMDZ climate models – extreme values precipitation

In addition to the parameters analysed above, it has been checked specially if there are days in the future when the precipitation is above 210 l/ha/s, which is the absorption capacity for heavy rain of the KNPP site. In all three climate models, there no such day in the future when the precipitation could exceed the limit of 210 l/ha/s.

In conclusion, under the three climate models A1B REMO, A1B LMDZ and B1 LMDZ no drastic changes in climate parameters can be expected until the mid of 21st century. Definitely, there will no extreme values of the maximum and minimum daily temperatures, the heat wave duration index, the maximum precipitation and the precipitation intensity index. Therefore, these parameters will remain within the limits of the design characteristics of the KNPP. They are not expected to influence the safety of the plant.

Another important aspect of climate impact studies is the ***efficiency of cooling process*** at KNPP, which depends directly on water temperature of the Danube River and indirectly on the air temperature. It does not concern the safety of the KNPP, but influences the quantity of the electricity produced and thus, it has economic implications. Therefore, the number of days with daily maximum temperature above 30 °C is analysed. Long-term averages of 30 years are considered by extracting the total number of unfavourable days and calculating the average number of such days per year. Climate changes are determined by comparing the average number of unfavourable days in the periods 1961-1990 and 2021-2050 (Table 4).

According to the three climate models the number of unfavourable days per year (days with low cooling efficiency of the energy production at KNPP) will definitely increase at least 1.6 times in the period 2021-2050 as compared to the past 1961-1990 (Table 6). The worst situation is expected under LMDZ B1 model when the number of these days will increase more than five times and such days will occur not only in summer, but in spring and in autumn as well (Table 7).

Table 4. Average number of days per year with T > 30 °C

Scenario	REMO-A1B	LMDZ-A1B-L	LMDZ-B1-L
1961-1990	33	14	14
2021-2050	52	53	72
Difference	+ 159 %	+ 381 %	+ 519 %

Source: own calculations based on CLAVIER database

Table 5. Average number of days per month with T > 30 °C in the future 2021-2050

Month	REMO-A1B	LMDZ-A1B-L	LMDZ-B1-L
1	0.0	0.0	0.0
2	0.0	0.0	0.0
3	0.0	0.0	0.1
4	0.3	0.8	0.8
5	2.7	2.5	3.7
6	11.1	10.0	15.1
7	17.7	15.8	21.9
8	14.7	18.4	21.5
9	4.9	5.4	8.8
10	0.3	0.2	0.6
11	0.0	0.0	0.0
12	0.0	0.0	0.0

Source: own calculations based on CLAVIER database

A conclusion could be drawn that projected climate changes in the future will not influence the safety of the KNPP, but will definitely cause the cooling efficiency to diminish and the energy produced in summer to decrease.

6. Economic meaning of climate changes

T*he first aspect* of the possible economic impacts is related to the safety of the KNPP. Analyses of climate scenarios and future extreme events have shown that projected climate parameters are within the limits of the design capacity of the power plant. As already mentioned the meteorological and hydrological conditions in the past were carefully studies in the course of the KNPP design and the facilities are designed to sustain an extreme event with probability 10^{-6}.

According to the experts, gathering and analysing meteorological and hydrological data, there are no changes in the average conditions as compared to conditions in the past. KNPP operates in accordance to the IAEA safety requirements and guidelines related to extreme external event. Therefore, the opinion of the KNPP experts is that no special adaptation measures to climate change are required at this moment. However, they are strongly interested in the results of the climate change modelling. In case in the future such models show indications of drastic changes in weather conditions which are different to the plant design parameters, the necessary measures will be taken, irrespective of the costs/ investments. During the interview the engineers emphasized on the fact that in such cases cost benefit analyses are not conducted because safety of KNPP is the only priority in its operation and maintenance.

The second aspect of the impact analysis is related to the cooling efficiently of the KNPP in summer and the possible economic losses caused by the decreased energy production. According to the experts, interviewed at KNPP, they have not done special measurements how much the production decreases by 1 degree increase in air temperature. They have provided some approximate information that in the hottest days in summer the production decreases by 5 %. Therefore, this number has been used to calculate approximately the production losses. The maximum possible production per month has been taken from the real production data from the latest publication of the IAEA (IAEA, 2008). Year 2007 has been chosen because in 2007 both reactors registered the biggest production of electricity and 7 and 11 years operation without reactor scrams at unit 5 and 6 respectively. The maximum production was registered in December:

Unit 5 – 720.8 GW.h = 23.3 GW.h per day

Unit 6 – 726.3 GW.h = 23.4 GW.h per day

Total for the KNPP 46.7 GW.h per day maximum electricity production.

The average export price of the electricity:
1 kW = BGN 0.1053.

Expected decrease of 5 % per day:
2.3 GW.h = BGN 245 774 per day

Total production in 2007 of KNPP:
6669.9 (Unit 5) + 7024.8 (Unit 6) = 13694.7 GW.h

In order to analyse the range of possible economic losses, the results of the two extreme scenarios are applied – REMO A1B and LMDZ B1. Only the unfavourable days in the summer months (June – August) are taken into account. It is assumed that hot days in spring and autumn occur rarely and probably will not warm too much the water of the Danube and will not decrease the cooling efficiency. It is assumed also that all extra electricity produced by the KNPP in summer is exported.

Under the above assumptions and other things equal, the expected economic losses are between 10 600 and 14 500 thousand BGN. The expected decrease in electricity production is a small part of the total production in 2007 – about 1 %.

Under all scenarios the expected physical impacts on nuclear energy production is low. Hence, the expected economic impacts are insignificant both on a regional and a national level.

Table 6 . Expected yearly losses at KNPP caused by climate change in 2021-2050

Scenario	Average number of days per year with T > 30 °C in summer months (days)	Decreased electricity production (GW.h)	Economic losses (thousand BGN)
REMO-A1B	43	100.4	10 568.26
Share of total production in 2007		0.7 %	
LMDZ-B1	59	137.7	14 500.64
Share of total production in 2007		1 %	

7. Relative regional vulnerability

7.1. Adaptive capacity

According to the analysis of the endogenous regional adaptive capacity (ERAC) in CLAVIER project the North-West planning region is predominately a rural service region. The three districts of the North-West planning region are part of the following clusters:

- rural service cluster: 2 districts (Vidin and Montana);
- depopulated cluster: 1 district (Vratsa).

In the rural service cluster the mean employment (34.3 %) and value added share (21.1 %) of the agricultural sector are still slightly above the average values in all the Clavier regions. With an employment share of 25 % and a value added share of 22.8 %, the secondary sector is less productive compared to the whole Clavier region, where the average value added share of the industry sector (32.3 %) slightly exceeds its employment share (30.9 %). As the service sector contributes 40.8 % to total employment and generates 56.2 % of the value added it more or less goes along with the average values resulting from all the Clavier regions. The rural service regions are sparsely populated, but show good accessibility. The regional GDP per inhabitant is inferior to the national average and in addition the regions under consideration show a lower growth rate of the regional GDP than the average. As the population projections for the area under consideration are found to be below the average, the rural service regions show a depopulating tendency. With an HHI of 0.11 the sectoral concentration is diverse.

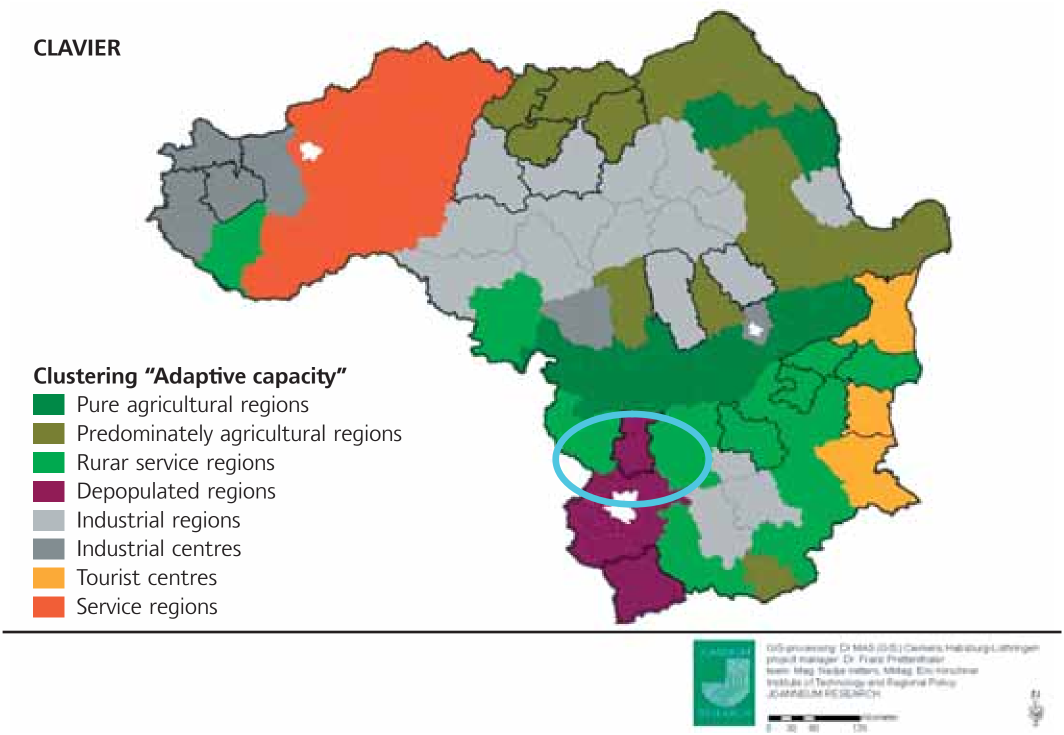


Figure 13. Adaptive capacity of CLAVIER regions – map of clusters

The depopulating cluster type includes five regions all of them are located in Bulgaria and Vratsa is one of them. Whereas the average of the population projections for all the Clavier regions amounts to 84.9, the forecast for the Depopulating Regions only amounts to a mean of 66.5. Therefore there is an above-average depopulating tendency in the regions under consideration.

With an agricultural proportion of 31.1 %, an industry share of 31.6 % and a service proportion of 37.4 % the mean sectoral employment shares of the regions under consideration are largely consistent with the averages of all the Clavier regions. More significant differences to the average are found regarding the sectoral value added shares. Whereas the mean value added shares of the agricultural (14 %) and the service sector (44.8 %) lie below the average resulting from the Clavier regions, the value added share of the secondary sector (41.2 %) is higher. The sectoral productivity indicators show that,

Table 7. Assessment scheme for evaluating economic vulnerability on case study level

Scope (level of investigation)	Sectoral Level	Case Study Level	All regions	Sector specific Case Study
	Potential economic Impact		ERAC (+)	Estimated Economic Vulnerability
	Economic Sensitivity (-)	Exposure (-)		
	extent to which the economy depends on a certain sector	areas whose economies are closely linked with climate-sensitive resources	potential of responses that go beyond normal adaptations	= f (Economic Sensitivity, Exposure; ERAC) [estimated by assuming average exposure for the whole sample]
Pure Agricultural Regions	high (agriculture)	Depends on the level of climate change and on the system's location whereas according to the definition single climate variables, specific weather events or long-term processes are to be integrated into the definition. Physical Climate Changes and their impact on the region have to be analysed. Analysis has to be undertaken on regional level and serve as the basis for the impact assessment on case study level.	limited	high
Predominantly Agricultural Regions	presumably high (agriculture)		limited	presumably high
Rural Service Regions	high (agriculture, unstable population)		below average	average
Depopulating Regions	low (already severe structural problems)		inferior	presumably low
Industrial Regions	average (industry)		average	average
Industrial Centres	low		high	Low
Tourist Centres	high (tourism)		slightly above average	high
Service Regions	low		high	Low

Source: JR-InTeReg.

Table 8. Assessment scheme for evaluating potential economic impacts on regional level

	Pure Agricultural Regions	Rural Service Regions	Tourist Centres	Predominantly Agricultural Regions	Industrial Regions	Service Regions	Depopulating Regions	Industrial Centres
sensitivity (regional)	high	high	high	presumably high	average	low	low (already severe structural problems)	very low
exposure (sectoral)	agriculture	agriculture, tourism, unstable population	tourism	agriculture	agriculture, tourism, old industry	agriculture, tourism	N.A	agriculture, tourism
potential impact (regional)	high	high	high	presumably high	average	average to low	N.A	low

Source: JR-InTeReg.

compared to the other sectors, the agricultural one is highly unproductive (45.3).

Besides the depopulating future trend, the regions under consideration are already characterised by sparse population. Furthermore the regions show low participation rates. In addition the region in this cluster can be described as non-accessible and they exhibit a low regional GDP compared to the national level.

In conclusion, the adaptive capacity of the North West region is rather low as compared to other CLAVIER regions.

7.2. Economic vulnerability

The economic vulnerability to climate change is a function of the adaptive capacity of a region and the expected economic impact. The ERAC of the North West region is rather low. However, taking into account the insignificant economic impact of climate change on the KNPP, expected under scenarios REMO A1B, LMDZ A1B and LMDZ B1 a conclusion could be made that economic vulnerability of region concerning the nuclear energy is low or insignificant.

8. Recommendation for policy makers

The history of incidents has shown that all types of energy supply are affected by weather related events and thus, all of them may suffer from climate change impacts in the future. There are many uncertainties concerning weather and long-term climatic processes. Many of the possible consequences of climate change on nature and society, as well as the impacts on energy supply have not being studied in depth yet. The fact that climate phenomena are exceptional or rare in the past of NPP operations, should make us caution and vigilant on the issue. The scale, frequency and nature of climate-related problems concern the existing plants, as well as the design of new reactors and the selection of new sites for NPPs. Hazards related to extreme events for reactors and nuclear waste sites should be reassessed, such as extreme high and low air and water temperatures, floods and droughts, storms, snow, tornado, lighting, freezing of rivers, etc. The resistance of plants to these hazards has to be reviewed, and the new technologies being currently developed, should address them accordingly. The literature, referred to above, describes single events. However, climate change will have complex consequences. Therefore, it is very important to consider also the combined effects of several extreme events occurring simultaneously.

Moreover, studies should be made about the combined effects of climate change on all types of energy supplies and national and European energy systems. Also, both the direct and indirect impacts on energy supply should be taken into account.

The economic relevance of climate change for energy will crucially depend on adaptation strategies. This calls also for detailed studies of the costs of adaptations on a local and national level, as well as for developing new policy frameworks at a European level and regional level.

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