Energy and Water Resources of Burkina Faso as Catalyst for Development

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Abstract

This work is dedicated to the research conducted in Burkina Faso. The Research objectives were to study the energy situation, search for sources of water for the power plant and oil refinery. To operate the power plant and oil refinery, large amounts of water would be required. Water from open sources is a scarce resource and is not stable in Burkina Faso due to periods of drought. By average standards, but given the greater volatility, to feed the oil refinery and the power plant water cycle will requires about 0.3 m^3 of water per 1 ton of crude oil per year; that is about 0.8 million m^3 of water per year, or 100 m^3/h. The only source of such water in Burkina Faso is the midstream of Mouhoun River. Information about underground layers of water-bearing capacity in the country is not available. It is therefore necessary to carry out the engineering and hydrological surveys on selected construction sites to power the refinery. The necessity of the construction of the reservoir on the river Mouhoun and the water treatment became inevitable.

Key words: Burkina Faso, energy, water, Mouhoun river

Introduction

The necessity of simultaneous construction of the powerful electrical station and oil refinery for the industrial leap of Burkina Faso's development required comprehensive study of energetic situation, building place choosing, determination of type and capacity of station and refinery, preliminary geodesics and field investigation of Muhun river.

All projects were made in Burkina Faso by agreement with Burkina Faso's government, and General Council in Russia and Commonwealth of Independent States, Beli Biyen, in particular. The main goal of this project is to determine potential resources as well as choice of construction of electrical station with 500 MW capacity and oil refinery with 2 million tons capacity.

Field work and investigation were made in April-August 2012 by Alyoshin A.A. (D.Mendeleev University of Chemical Technology of Russia, Moscow, Russia, Moscow, Russia); Kozlowsky R.A. (D.Mendeleev University of Chemical Technology of Russia, Moscow, Russia); Lunyov E.A. (Azov Sea State Technical University, Mariupol, Ukraine). Expedition supervisor is Prof. Kapustin A.E. (Azov Sea State Technical University, Mariupol, Ukraine).

Lab treatment of samples and analytical researches were made using laboratory equipment of Azov Sea State Technical University.

Socio-economic justification of construction

Fig. 1: Map of Burkina Faso

Burkina-Faso (fig. 1) is one of the worst developed countries of the world due to number of factors, including long distance from the sea (the single railway line to the ocean has a length of 1,300 km, track width – 1 m, 622 km are in Burkina Faso, another 660 km of this road continues in Côte d'Ivoire), infertile soil and a lack of moisture.

The economy is very primitive and based on unproductive agriculture (crops are grown in small quantities, livestock products are mainly used for domestic needs), and the export of labor to Côte d'Ivoire and Ghana for working on the plantations of coffee and cocoa, and as well as unskilled workers in the cities of these countries [1] [2].

Agriculture employs over 80 % of the working population and the share of this sector in national production is 34 %. Livestock is one of the country's major national resource. Meat, milk and skins are sold on the domestic market, while live cattle are exported to neighboring countries. In 2009 Burkina Faso has about 4.2 million heads of cattle and 13 million sheep and goats. Dimensions of livestock are limited due to the lack of water, which determines the size and quality of pastures. Meat and dairy livestock specialization is typical for the eastern regions of Burkina Faso, located outside the range of the tsetse fly. Efforts are being made for the development of animal husbandry in the western regions.

Area of cultivated lands is limited and there may be a severe drought in winter, so it is quite difficult to predict the amount of harvest. The main food crops are sorghum (1.4 million tons) and different types of millet. In addition, corn (0.5 million tons), rice (0.075 million tons), yam (0.01 million tons), cassava, sweet potato and taro are cultivated. Important cash crops are cotton, sugar cane, peanuts, sesame seeds and butyrospermum. The oil, produced from the butyrospermum seeds is used in West Africa for the production of candles, soaps and technical lubricants. In the late 20th century the demand of butyrospermum rose highly due to its use in cosmetics, which led to a significant increase in exports. In the mid 1970s, growing of sugar cane was started on the flooded lands of south-western part of country. Since 1985 industrial production dropped. However it began to rise again in mid of 1990s. Despite the fact that less than 2% of population was employed in industry including mining and building in 1990s it accounted for about 25 % of GDP.

There are handicraft and artisan production in Burkina Faso which to some extent can meet the needs of population in the finished products, embroidery, bronze and leather. There are also over 100 industrial enterprises in the country which specialize in the production of fats, soaps, industrial oils, cotton textiles, beer, soft drinks, cigarettes, cotton and rice production, sugar cane, processing of raw hides. At last, there is production of bicycles and motorcycles for domestic market.

The mining industry focused on the development of major gold deposits (annual production is up to 3 tons). Antimony and marble are mined in small amounts. In the far north-east of the country, near the border with Mali and Niger, deposits of manganese ore has been discovered (14 million tons), which is not mined due to poorly developed transport infrastructure in the area. The country has reserves of zinc, lead, nickel, silver, lime and rock phosphate.

Burkina Faso, along with 15 other countries in West Africa has a common central bank and currency, the CFA franc, fully convertible against the Euro. Working together with the National Banking Committee, the Central Bank adjusts the credit policy of Burkina Faso.

Annual government revenues are very limited, and the budget of the country is usually confined to deficit budget. Most of the public investment is made in part by financial assistance from France and the Development Fund of the European Union. However, taking the path of economic liberalization in the late twentieth century, Burkina Faso became actively involved in a program of structural adjustment of the IMF and the World Bank.

Main export item (600 million of dollars) of Burkina Faso is purified cotton, which provided more than two-thirds of export earnings in 1990s. The country also exports live cattle and meat, gold, hides, vegetables and butyrospermum seeds (shea butter). Major trading partners for export are Singapore (16.76 %), Belgium (12.78 %), China (7.59

%), Ghana (6.89 %), India (6.36 %), Denmark (5.76 %), Niger (5.13 %), Thailand (4.52 %) (2009). Critical import items (1,200 million of dollars) – industrial products, machinery and transport equipment, foodstuffs, chemical products, petroleum and cement are imported from Cote d'Ivoire (24.31%), France (19.48 %), Togo (6.42 %) (2009). Since the cost of imports is four times greater than exports, the country is dependent on foreign aid. Considerable financial help comes vis remittances of Burkina Faso's citizens working abroad.

Despite her poor national economy in general, Burkina Faso has a good transport system as she operates railway line that connects Ouagadougou and Abidjan (Côte d'Ivoire). The total length of paved roads is 15 thousand km and roads, which operates only in the dry season covers only 6 thousand miles. International airports are located in Ouagadougou and Bobo-Dioulasso. There are also 49 small local airports, including 2 paved ones.

A new investment code was enacted in 2004 to attract foreign investment. Due to the gradual but successful privatization of state enterprises and this new code, as well as changes in the law in favor of the mining sector of the country, there was a rise in the gold mining industry and the economy as a whole. This is indicated by the following figures:

GDP at purchasing power parity – $ 18,230 million (2008), $ 18,810 million (2010), $ 17330 million (2012), 126 in the world. GDP at the official exchange rate – $ 8150 million (2012). Growth rate – 6.3 % (2010), 5.5 (2008), 4 % (2007). GDP per capita – $ 1200 (2009-2011). GDP by sector: agriculture – 30.1 %, industry – 20.7 %, services – 49.2 % (2009). The growth rate of industrial production in the last 5 years – about 5 %.

Labor population in the country is put at 6.7 million. Most of the male working population migrates annually to neighboring countries for seasonal work. Unemployment rate is put at 76 % (2011, 199 in the world). The share of the population living below the poverty line is 48.1 %.

Energy situation in Burkina Faso

Information about the availability of the country's energy resources is not very reliable. There is conflicting data from different sources. Unfortunately, even in such an authoritative source of information, as a UN report [3], the data does not correspond to reality. Therefore, to obtain the most complete picture, we used the information contained in the literature and collected on the spot. Sometimes even the highest government officials did not possess this information. In particular, the national power company told us that the present supply of petroleum products by railroad was not possible, since it was destroyed in the recent fighting. Checking out the place we found out that the railway line is not damaged and there is delivery of goods from Côte d'Ivoire.

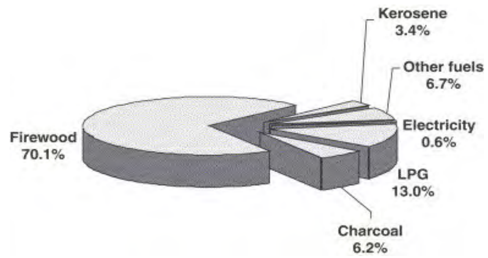

Fig. 2

The total capacity of energy balance is 32 MW – 140th in the world. Electricity production is 611.6 million kW·h, consumption is put at 568.8 million kW·h (2007). Fossil fuel: 71.93 %; hydrofuel: 28.07 %. Oil consumption is 9,000 bbl/day (2009), import – 8283 bbl/day (2007). In 2006, import of hydrocarbons was up to 340,500 tons, that is 104 % of domestic consumption [4] [5].

All petroleum products are imported and the country has no known oil reserves and refining capacity. Import and oil consumption in 2002 was 8,870 barrels per day. As for natural gas, in Burkina Faso, there is neither the gas production, nor proven reserves.

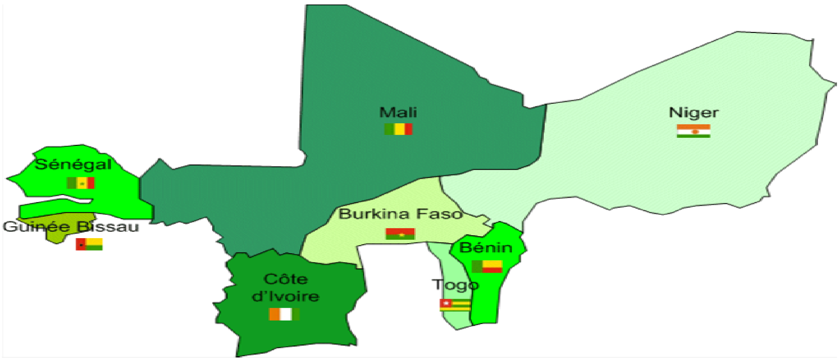

Fig.3 Uemoa

Electrical power capacity in 2001 was put at 121 MW. Production has increased from 42 GW in 1973 to 280 GW in 2001, of which 73.6 % was from thermal power plants and 26.4 % was from hydro power plants. Electricity consumption was 0.26 billion kW·h in 2001. Construction of 15 MW hydroelectric Kompeyna was completed in 1989. In 1999, a grant from the Government of Denmark for 5 months helped to build a new power plant. Production and distribution of electricity and water is controlled by the national power company – SONABEL - established in 1968.

Burkina Faso received a $38 million loan from the African Development Bank for the construction of local networks in order to improve access to electricity for almost 800,000 people. The loan was ear-marking for the energy infrastructure in rural areas.

Demand for electricity in the country is growing at 10 percent annually, while at the same time Burkina Faso tries to develop new sources of energy. In addition, the African Development Bank finances the electric connection of Burkina Faso's networks to the networks of Ghana and Cote d'Ivoire. This two countries border the sea and have easier access to electric power, will be the main source of increased energy supply in Burkina Faso [5] [7].

Project AT-A-Glance, which began in July 2007 and valid until 2013, includes expanding access to electricity in rural and suburban areas.

To facilitate the increased demand for electricity during the summer months, SONABEL plans to build a power plant of 30 MW in Kossodo that will supply power directly to the national network of Burkina Faso in the warmer months. This development will bring additional challenges, especially since the overall energy balance of Burkina Faso is 70% dependent on wood energy (firewood), with limited wood resources in the Sahel and 20 % - on the supply of petroleum products (Fig. 2). Over the past 10 years, the energy dependence on the supply of petroleum products increased by 120-130 %. In addition, hydropower generated in the field, provides a total of 6% of the total consumption and is generated using the water resources that are vulnerable to climate change [7] [8].

The main recommendations for improving the energy supply of Burkina Faso are accentuated by the development of renewable energy sources, especially solar power. These recommendations [9] are: reducing the consumption of firewood; reforestation, development of public transport, the diversification of energy sources, the development of knowledge about the potential of renewable energy sources and their use at a low price.

It also worth to mention the program "Lamp for Africa", funded by the Government of Taiwan. It means the encouraging the development of obtaining solar energy in West Africa, as well as the supplying of low-cost low-power LED lamps and chargers, solar-powered batteries.

A big project related to providing of West Africa countries was presented [10] by Economic Community of West African States (UEMOA - Benin, Burkina Faso, Guinea-Bissau, Côte d'Ivoire, Mali, Niger, Senegal, Togo) (Fig. 3) on March 19th, 2010. This project considers the increasing of energy supply of countries (Burkina Faso – by 144 MW, Guinea-Bissau – by 15 MW, Côte d'Ivoire – by 650 MW, Mali – by 270 MW, Niger – by 93 MW, Senegal – by 543.5 MW, Togo – by 393 MW) by 2020.

It is planned to achieve these parameters by construction of nuclear power station in Niger and oil power station in Benin, Côte d'Ivoire, Mali, Niger, Senegal and Togo. Increasing of power supply of Burkina Faso is planned to achieve with electrical energy from Nigeria through Niger, from Côte d'Ivoire and Senegal.

Notwithstanding, the largest part of energy is planned to obtain using biomass (Benin, Guinea-Bissau, Côte d'Ivoire, Togo) and solar energy (Burkina Faso, Mali, Niger, Senegal) [11-12]. It is assumed to increase the amount of electrical energy by 15000 MW from 2015 to 2030 using solar energy [13-14] and by 1000 MW from 2025 to 2030 using nuclear power station.

Such plan is too ambitious and it is very unlikely to get this plan done, according to the participants of our expedition. It could be proved by several reasons. The growth of generated electrical energy is shown on Fig. 4.

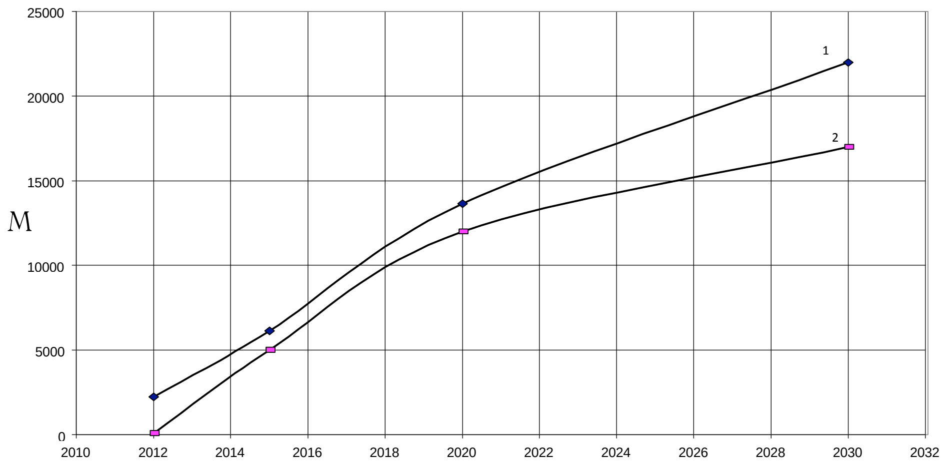

Figure 4. Growth of generated electrical energy: 1 - total, 2 – from renewable sources (solar energy + biomass).

One could see that almost all the amount of energy will be obtained from renewable raw – biomass and solar energy. However, planned 100 MW growth of energy during 2010-2012 was never accomplished.
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Moreover, scheduled trend of changes of ratio energies, obtained from different sources, shown on Figure 5, was not realized by now.

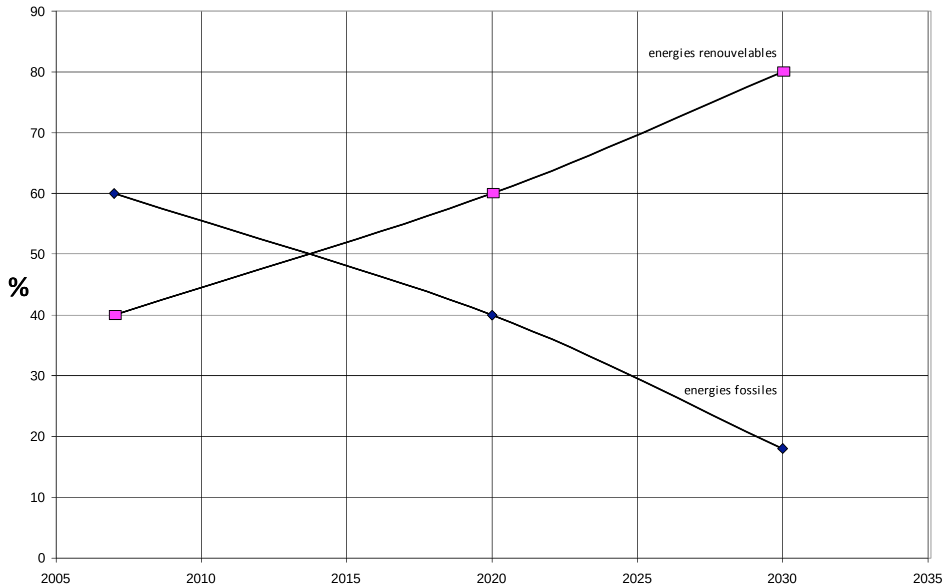

Figure 5. Prospective ratios of generated electricity.

On November, 2012 European Union invested 25 millions euros for the construction of the largest solar electrical station in Africa. French agency of development would invest additional 38 millions euros. New solar station will be located near Ouagadougou, capital of Burkina Faso. 96 thousands solar panels will be installed, which would generate 32 GW·h energy per year. More than 1 billion euros was spent on the improvement of energetic section of Africa in order to expand access to modern energetic service for population. Nowadays only 15 % of population of Burkina Faso has an access to electrical energy, so country depends on import of energy sources. In the future, the European Union promised to provide the electricity for 500 millions people throughout Africa. It is obvious that planned trend will not be accomplished, despite the big difference in cost of generated electrical energy (Table 1).

Table 1. The cost of 1 kW·h electrical energy, obtained from different sources in Burkina Faso, eurocent, 2012

Oil	Gas	Coal	Nuclear station	Hydrostation
15-30	12	4	2*	1

*forecast

Thus, the proposed methods, including the supply of electricity from neighboring countries, the construction of low-power diesel station, using of solar energy and biomass, do not solve the problem of sustainable energy for Burkina Faso's urban and industry use.

This problem is similar to that, which Soviet Union stuck with during first years of existence. It was necessary to construct powerful electrical station, which used mineral fuels. Taking into account the information above, the government of Burkina Faso made a decision about cooperative construction of electrical station together with oil refinery.

An estimated value of energy deficit, taking into account internal needs of Burkina Faso and export of energy to neighboring countries, was put at 600 MW of total capacity, i.e. 4800 GW·h per year.

Priority energy deficit in Burkina Faso is deficit of electrical energy.

Now Burkina Faso produces around 794 GW·h of electricity per year from liquid fuel. It consumes about 300 000 m^3 of liquid fuels (oil + diesel). The average total capacity of all power stations is about 100 MW. In order to obtain such amount of electrical energy using liquid fuel (mixture of oil and DDO) there is need for additional liquid fuels amounting to 1,620 million tons (1,800 million m^3) per year, assuming that the average specific consumption of nominal fuel is 340 grams of nominal fuel per 1 kW·h.

Water is required for eletrical station and oil refinery. Water from open sources is deficient and non-stable (during droughts) in Burkina Faso. Using the average standards and taking into account that evaporability in Burkina Faso is 3 times larger than average oil refinery required is 0.3 m^3 of water per 1 ton of raw oil, or about 0.8 million m^3 per year, or 100 m^3/h for feeding of water cycle. The only source of such amount of water in Burkina Faso is midstream of Muhun river. There is no information about capacity of underground water layers in the country, so additional engineering and hydrological surveys are required.

Exploring the Muhun basin and proposed place of construction.

Field investigations were carried out in order to find out the possibility of using the water of Muhun river (Fig. 6).

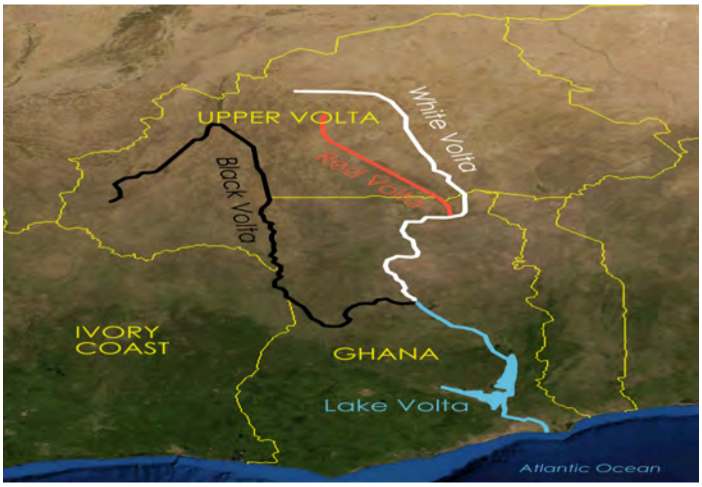

Figure 6. Rivers in West Africa countries

The basin of Muhun river (former Black Volta) is located on territory of six West Africa countries, 80 % of its square in Burkina Faso and Ghana in particular. Agriculture on irrigated land in the basin is the main source of life for people in these countries. The growth rate of the population, as of 2012, is about 3 %, which increasing dependence on land and water resources.

Development of agriculture in Burkina Faso expands steadily, which in turn depends on access to surface water. Increasing of water consumption significantly affects on the availability of water downstream, in particular, at the Akosombo dam, the main source of electricity in Ghana. Low water levels at the dam lead to serious energy crisis in Ghana. While many accuse Burkina Faso in this effect, most often it caused by unstable amount of rains in the region. A permanent decreasing in rainfall last years has aggravated water shortages and competition of its consumption in the region.

Misunderstanding between two countries currently prevents adequate cooperation in joint management of this shared resource, which may have a significant impact on peaceful resolution of any further conflicts between countries.

Continuous dialogue and coordination between two neighboring countries is needed, since the development of Ghana is determined by the amount of energy, obtained from river, while development of Burkina-Faso's agriculture requires more water [15].

Hydrographic basin Muhun river covers about 414,000 km^2 or six West African countries: Benin, Burkina Faso, Ivory Coast, Mali, Ghana and Togo. The total population of this basin is currently estimated around 14 million people, moreover, the region is under high population pressure with a growth rate of about 3 % per year. Extremely low incomes much of the population as a result of over-exploitation of natural resources in the basin have a serious impact on the sustainable development of the region.

Annual amount of precipitation in basin of river varies from 400 mm in the north of Burkina Faso to 1800 mm in the coastal zone. Annual average evaporation ranges from 2500 mm in the north to 1800 mm in the coastal zone. The main waterways of the basin are: Muhun, Nakambe (White Volta), Nazinon (Red Volta), Sura, Sissy, Ooty and Pendjari. The most significant water consumption is in cities Bobo-Dioulasso and Ouagadougou in Burkina Faso, Bolgatanga , Tamale and Coomassie in Ghana; Natitingou in Benin; Sokode in Togo. Wateri) is provided by a combination of surface and groundwater resources of these cities [16].

Potential total irrigated area in the region is: Benin – 30,000 hectares, Burkina Faso – 142,000 hectares, Cote d'Ivoire – 25,000 hectares, Ghana – 1,2 million hectares, Togo – 90,000 hectares. Total – 1,487,000 hectares (data on Mali is not defined due toii) difficult political situation) [16].

Available potential hydro accumulated sources for electricity generation have next parameters: Suru dam – 0.3 km^3, Ziga dam – 0.2 km^3, Kompeyna dam – 2 km^3, Bagri dam – 1.7 km^3 (all – Burkina Faso).

Akosombo dam (150 km^3) in Ghana is by far the largest in the region, its construction has led to the creation of a huge artificial Volta lake, which completely changed the natural course of the river and caused many environmental and social problems, many of which have not solved.

Burkina Faso, being less developed than Ghana economically and industrially chose the direction of building more dams for irrigation. This is the source of big conflict since Ghana refuses any plans regarding the reduction of water volume, which comes to Akosombo dam, which in turn is important for energetic potential of Ghana.

It is very important to coordinate all future projects in transparent and equitable manner between countries prior to construction, and that these countries agree with the principles and determining factors that will serve as a basis for the future development of water resources. Since the population increases as well as needs in water, these agreements will be important for prevention of future conflicts.

Projected reduction of rainfalls will lead to lost of 100 mm at 2025-2050 year with simultaneous increasing of average temperature by 2-4 °C [17-18].

The main problems, related to water sources in river basin, are:

Quantitative decrease in water resources due to lack of rainfall occurring in the past three decades, which also have implications for optimal filling of the reservoirs in the basin and that would jeopardize the goal originally assigned to these activities (production of electricity, drinking water, irrigation, etc.);

Changes in the hydrological regime of waterways pool after construction of large infrastructure projects, which may be the source of flooding, waterlogging and water-borne diseases;

iii) Spread of aquatic plants that affect all waterways basin;

iv) Water pollution with household waste, mainly due to rapid and uncontrolled urban development of the basin;

v) Absense of appropriate legal agreements for the management of shared water resources and water-related conflicts.

Muhun river flowing through Burkina Faso, Ghana and Côte d'Ivoire, is the main water stream in West Africa (Fig. 7). Its source is in the low hills of the Baule in southwestern Burkina Faso, near the city of Bobo-Dioulasso, and at the end of its course it flows into Lake Volta in Ghana, which is a large artificial pond created on the river above the former Muhun several places the confluence of the White Volta and Muhun

Fig. 7. The water flow of Muhun river in April (low water level).

From its source in Burkina Faso Muhun flows in a northeasterly direction for approximately 320 km, and then turns south and flows in a southerly direction 550 km, forming a natural border between Ghana and Burkina Faso, and then between Ghana and Côte d'Ivoire. Near the town of Bamboo in Ghana, the river turns again, first to the north, and then to the east, and after about 130 km it flows into Lake Volta. The total length of the river is 1160 km. Slope gradient of the river is relatively flat – 40 cm per 1 km. Rainfall is low and at the peak of the dry season flow of the river may stop. However, from the Bamboo and the border of Côte d'Ivoire for the river is already supported by a dam.

We planned a place for the construction of refinery and power plants to be located to the west of the capital between the Siby and Zamo railway stations.

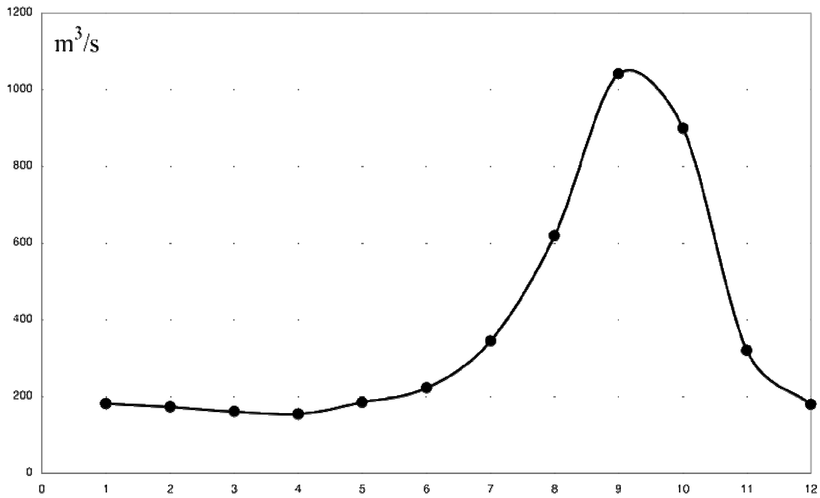

Figure 8. Changes in the water flow in the river Muhun depending on season.

Our studies have shown that the amount of water in the river is dependent on the season (Figure 8). The lowest level is observed in late April, just before the beginning of the rainy season, while the flow rate exceeds 150 m^3 per second, which enables selection of 100 m^3 of water per hour. It should be noted that at the same period we studied White and Red Volta rivers and the water flows in river were absent. (Figure 9-10).

Figure 9. The absence of water flow in Red Volta river in April.

Figure 10. The absence of water flow in White Volta River near Ouagadougou in May.

Despite the large fluctuations in water level of Muhun river, it would be very effective to use a continuous water withdrawal for refinery and power station, carrying out proper water treatment. Because of that, additional studies of Muhun river water were carried out.

Temporary hardness of water in the river – is about 0, total hardness – is 0.0028 meq/l. Total suspended solids in the river water is 2.497 g/l. More than 90 % of suspended solids in the river have a size less than 50 microns, indicating that they belong to a class of clay, not loess. Suspended matter is a mixture of kaolinite and hematite, but with high concentration of Ca > 10000 mg/kg. Content of other elements is shown in Tab. 2.

Table 2. The content of different elements in suspended particles in the water, mg / kg

Mg	Ba	Mn	Cu	Zn	Co	Pb	Ni	Sn	Ga	Cd	B	Ag	Au
1800	95	85	75	75	12,5	9,2	7,5	7,5	7,5	6,4	4,5	0,1	0,01

The deposition rate of suspended particles from water is shown in Fig.11. Thus, the water is soft and the total mineralization is minimal, however, it is required considerable time for the deposition of suspended particles. Based on the given water needs with a margin of 1 million m^3 per hour, a required deposition time is 10 days, the minimum volume of the reservoir will be 240 million m^3.

For reservoir with an average depth of 10 m, the size of the water table will be 5x5 km. The value of deposited suspend matter is $20*10^6$ tons per year, and, therefore, there should be a permanent removal of the resulting precipitate and supply of reservoir volume

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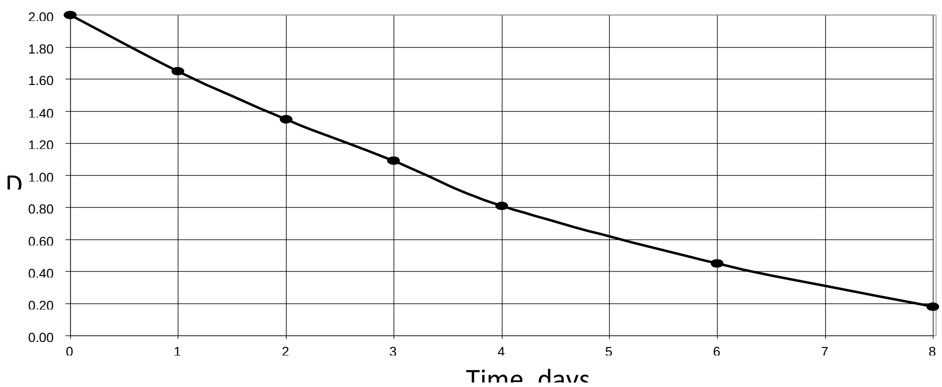

Figure. 11. The rate of deposition of suspended particles (D – optical density).

Taking into account the high evaporability of water from the reservoir (average annual evaporation ranges from 2500 mm in the north to 1800 mm in the south of Burkina Faso) and the projected increase in temperature by 2-4 degrees by 2040, there should be a light reflecting surface of the insulation, and we suggest to use white foam balls floating on the surface of the reservoir. Increasing of light reflectance will also reduce the overgrowth of aquatic vegetation reservoir.

We also investigated prevailing flora in river in order to estimate overgrowing of the pond with vegetation. In the upper region of the river, in the arid zone, the vegetation of the river presented by typical West African plants, namely *Nymphaea lotus, Aeschynomene crassicaulis, Aponogeton subconjugatus, Centrostachys aquatica, Ipomoea aquatica, Limnophyton obtusifolium, Nymphoides indica, Vossia cuspidata* [19]. In the average region of the flow of the river, in the area of future construction, as shown by our study, the main water plant is *Heteranthera* from the family of hyacinth. Prevention of overgrowth the reservoir with water plants requires additional special studies.

In general, from Bobo Dioulasso to Ouagadougou Muhun river and its inflows flow through sparsely populated areas, so coasts of streams are relatively clean. Cluttering of floodplain is observed only in communities with individual dwellings. In these cases, the waste storage is frequently observed. Basically debris accumulations are fragmented, thereby cleaning cluttered areas must be carried out manually.

Approximate ratio of household and construction waste is following:

- Household waste (80 %). Content: polyethylene and other plastics, glass cullet.
- Construction and other waste (no more than 15 %).
- Food waste (no more than 5 %).

Dumping in the streams at the time of the survey was not observed. In general, the water in a river is substantially pure and doesn't have characteristic indicators of contamination. Investigation of soil in the area showed that most of the future construction area has common lateritic soils, characterized by red-brown tones. Reddish soils is due to accumulation of iron oxide and aluminum in the weathering zone. These soils are extremely susceptible to erosion and flat areas are easily washed rainfall in the rainy season. There are areas with bare, almost barren horizons of weathered rocks. Granite massif is located at a depth of 6 m below ground level.

Soil is gravel with sandy and sandy loam filler. Gravel and pebble are rounded. Analysis of samples taken at the place of future construction, showed the following results. Content: Al – 12,5 %, Si – 19,9, Fe – 8,3 %, K – 0,5 %, Ti – 0,3; rest– oxygen. Phase composition showed approximately equal presence of quartz, kaolinite and hematite $Al_2Si_2O_5(OH)_4$. Sampling from the rocky shallows of the river discovered an unusual composition, the analysis of which is given in Tab. 3.

Table 3. Elemental analysis of a sample from the river, %

Sn	Si	Fe	Ti	Nb	Al	Y	Mn
26,12	5,41	5,33	3,02	2,72	2,71	0,83	0,22

Chemical and phase analysis showed that ponds to the cassiterite. Besides, during reconnaissance studies we found the source of the release of flammable gas. Analysis showed that this gas contains no sulfur and has a density higher than the density of air.

Conclusions

Priority energy shortage in Burkina Faso is a shortage of electricity. Burkina Faso produces around 794 GW·h of electricity per year from liquid fuel. It consumes about 300,000 m^3 of liquid fuels (oil + diesel fraction). The average total capacity of all power stations is about 100 MW.

Taking into account Burkina Faso's needs and export to neighboring countries, the value of estimated energy deficit is around 600 MW, i.e. 4800 GW·h per year. In order to produce such amount of electricity, the demand in additional liquid fuel (a mixture of oil and diesel fraction) will be about 1,620 tons or 1,800 million m^3 per year based on average fuel consumption at 340 toe/KW·h. Today, Burkina Faso imports all kinds of oil products. The total import is about 600,000 m^3 per year. The percentage of liquid fuel for power stations is 50%, and the rest is gasoline and diesel for transport.

We propose the next solution. Due to the lack of natural gas sources in the country the planned power station should be equipped with steam turbine. The fuel oil and even heavier fractions can be used as the fuel for boilers, which generate steam. The latter is even more preferable economically.

A construction can be carried out in the following phases:

i) condensing power unit without producing of energy

ii) power unit with producing of energy

iii) refinery (the break between ii an iii should be about one year).

It is necessary to increase the volume of storage as well as carrying capacity of road system (railroad, tanks) of Burkina Faso should be increased 4 times in case of import of required value of liquid fuel. However if needed amount of liquid fuel is planned to produce at own refinery (an atmosphere oil rectification with desalination installation), it is required to process more than 2,5 million tons of crude oil pre year (depends on its quality).

Simultaneously with producing of 1,620 million tons of liquid fuel per year, there will be concomitants, namely, 260,000 tons of virgin gas (octane number is about 46), 210,000 tons of petrol and 520,000 tons of diesel.

The water is needed for power station and desalination installation. The water from open sources is deficit and not stable resource in Burkina Faso due to droughts. Using the average standards and taking into account that evaporability in Burkina Faso is 3 times larger than average oil refinery required 0.3 m^3 of water per 1 ton of crude oil, or about 0.8 million m^3 per year, or 100 m^3/h for feeding of water cycle. The only source of such amount of water in Burkina Faso is midstream of Muhun river. There is no information about capacity of underground water layers in country, so additional engineering and hydrological surveys are required.

The minimal expenses of construction of refinery (2.6 million crude oil per year) are 220 million dollars. The cost of power station with steam generation in boilers is 630 million dollars. However, taking into account the specific price-formation in Burkina Faso, the cost will be larger.

The construction place. The only convenient place is around the intersection of River Muhun with the railroad (between Siby and Zamo stations). There are unloaded railroad as well as high-voltage line, a source of water, the road to the construction place (a missing part is about 2 km), flat terrain and rocky base (need additional geological surveys) in this place.

Most efficient way is to use Nigerian oil delivered through the port of Abidjan and further by railroad, which is in an agreement with the Government of Nigeria. There is a lack of developed construction industry (concrete structures, steel structures). Most of the territory in the basin of Muhun refers to natural and wildlife reserves. Also there is a lack of skilled labor, both during construction and operation.

Thus, it is preferable to build a power station and refinery based on Nigerian oil in that area. The accurate information about the cost of construction and time of pay off will be obtained by developing technical specifications and feasibility study, taking into account poor infrastructure, lack of skilled human resources, lack of construction machinery, complex geographical and climatic conditions as well as other related factors.

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