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Concentrating solar power in Ghana - the sustainable future

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Abstract*— Limited fossil resources and severe environmental problems require new sustainable electricity generation options, which utilize renewable energies and are economical in the meantime. Concentrating Solar Power (CSP) generation is a proven renewable energy technology and has the potential to become cost-effective in the future, for it produces electricity from the solar radiation. In Ghana, the electricity demand is rapidly increasing, while the solar resources and large wasteland areas are widely available in the western and northern part of the country. To change the energy-intensive and environment-burdensome economic development way, Ghana government supports the development of this technology strongly. These factors altogether make Ghana a suitable country for utilizing CSP technology. In this paper, the potential of CSP in Ghana was studied and strategies to promote development of this technology were given.

Keywords- **Ghana, Sustainable, Environment, Development, Concentrated Solar Power, Policy, Energy, Future Prospects.**

I. INTRODUCTION

In today's world, the role of energy generation and consumption cannot be over emphasized. Energy consumption enhances productivity, economic growth, global networking as well as its adverse effects on climatic change. In recent times, the need for additional installed capacity of energy source to meet the potential of a country has continued to be at the forefront of growing economies of many countries. However, these concepts and principles are yet to be fully harnessed in Ghana [1]. In 1975, the world experienced what has been known as the energy shock when the Arab oil suppliers decided to use oil as a weapon and therefore stopped production knowing the effect it will have on the non-oil producing western economies. Prices shot up and there was a general shortage and panic, prompting countries such as Ghana to start learning some lessons. Before 1975 electricity supply in Ghana was in abundance and people were encouraged to freely use electricity, to the point that they were even advised not to switch lights off. The utilities, deliberately as expected at the time, promoted the use of electric boilers, furnaces and kilns in industry so as to promote electricity consumption. Since then things have changed drastically. The population has increased, economic growth rates have increased steadily but the electricity supply base has not caught pace with the growth [2]. Recent analyses on climate sensitivity suggest that a responsible risk management strategy would be to keep emissions levels within the lower end of the probability range associated with a 2^{o}C increase; this means that reducing greenhouse gas (GHG) emissions is a critical imperative for the international community. More than one-third of global CO_2 emission is related to fossil fuel combustion in the power plants [3] energy efficiency and renewable energy sources provide a better promising means of dramatic reductions in greenhouse gas emissions. Climate change has called for great attention worldwide, and has always been one of the major issues in the World Economic Forum Annual Meetings (WEFAM) [4]. Solar radiation is a high-temperature, high-energy source at its origin, the Sun, where its irradiance is about 63 MW/m^2. However, Sun to Earth geometry dramatically decreases the solar energy flow down to around 1 kW/m^2 on the Earth's surface. Nevertheless, under high solar flux, this disadvantage can be overcome by using concentrating solar systems which transform solar energy into another type of energy; usually thermal [5]. Ghana is looking for environment friendly renewable energy sources. As indigenous resources, the renewable energy has additional positive effects of promoting local economy development, mitigating financial burden from energy imports, and improving energy safety of the country. On the other hand, the Concentrating Solar Power (CSP) is a promising option, and this technology represents a sustainable energy source with huge potential for Ghana.

II. ENERGY SITUATION IN GHANA

Ghana is relatively well endowed with a variety of energy resources including biomass, hydrocarbons, hydropower, solar and wind. It also has the capacity to produce modern bio-fuels. The vision of the energy sector is to develop an "Energy Economy" to secure a reliable supply of high quality energy services for all sectors of the Ghanaian economy and also to become a major exporter of power by 2012 and 2015 respectively [6]. Electricity generation in Ghana is currently from three hydro power plants at Akosombo, Kpong, Bui; seven thermal plants and a 2MW solar plant. As at April 2013, the installed capacity of hydro generation was 1,310 MW whilst the installed capacity thermal generation was 1,168 MW as indicated in Table 1. The Volta River Authority (VRA), a publicly owned power utility is the owner and operator of the two hydro plants at Akosombo and Kpong. The Bui Power Authority also manages the Bui hydro plant. The transmission network is owned and operated by the Ghana Grid Company [7]. From the beginning of the year 2014 to date, Ghana has been experiencing power rationing. One of the numerous reasons cited is the inability of the thermal plants to generate at their full capacity because supply of crude oil from Nigeria was not forth coming [8].

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Meanwhile, the adverse impact of the crisis has continued to be dreadful and unrelenting, escalating the operating costs of businesses and limiting production and hence growth output, particularly in energy-sensitive sectors of mining and manufacturing all of which have serious implications for profits and employment as well as for government revenue targets [9].

Table 1: Installed Electricity Generation Capacity as of April 2013 [7]

Plant	Fuel Type	Capacity (MW)	
		Installed	**Dependable**
Hydro Generation			
Akosombo	Water	1,020	960
Kpong	Water	160	140
Bui	Water	130	100
Sub-Total		1,310	1,200
Thermal Generation			
Takoradi Power Company (TAPCO)	Light Crude Oil(LCO)/ Diesel/Natural Gas	330	300
Takoradi International Company (TICO)	Light Crude Oil/Diesel/ Natural Gas	220	200
Sunon Asogli Power (Ghana) Limited	Natural Gas	200	180
Tema Thermal 1 Power Plant (TT1PP)	Light Crude Oil /Diesel/Natural Gas	110	100
Tema Thermal 2 Power Plant (TT2PP)	Diesel/Natural Gas	50	45
Takoradi 3 (T3)	Light Crude Oil/Diesel/ Natural Gas	132	120
CENIT Energy Ltd (CEL)	Light Crude Oil/Natural Gas	126	120
Sub-Total		1,168	1,065
Solar Power Plants			
VRA Solar grid-inter-tied		2	2
Sub-Total		2	2
Total		**2,480**	**2,267**

Table 1 shows that Ghana's electricity generating capacity is almost virtually based (99.9%) on hydropower plants and thermal power plant however, natural gas and oil (diesel, LCO) are the imported most important fuel for power generation in these thermal power plants. In the coming years, Ghana is expected to continue to depend mainly on natural gas, diesel and light crude oil as an energy source in the thermal power sector. But the importance of these energy sources will increase in the future and solar and wind power generation will probably play important role in the Ghanaian power sector. However, as already mentioned above, the use of non-renewable energy sources (natural gas and crude oil) as the primary energy source causes numerous environmental problems, that is contribute to climate changes through increased CO_2 emission [4]. It has been projected that Ghana will need more than seven times its present electric power capacity by 2020 if we are to succeed in developing Ghana's economy into a middle income economy [2]. Ghana is well endowed with Renewable Energy Resources particularly biomass, solar, wind energy resources, and to a limited extent mini-hydro. The development and use of renewable energy resources have the potential to ensure Ghana's energy security and also mitigate the negative climate change impact of energy production and use; as well as solve sanitation problems [7]. Electricity consumption in Ghana is estimated to be increasing by 10% per annum due to the demand from the growing population and the advent of oil and gas with its associated industries. However, current baseline production sources generate only 66% of the current demand. From this, an estimated 65% is used in the industrial and service sectors while the residential sector accounts for about 47% of total electricity consumed in the country [1].

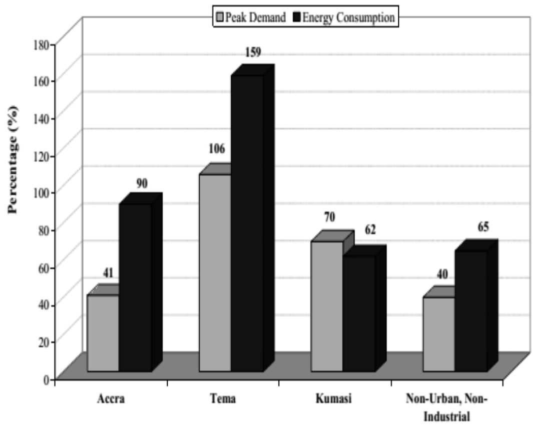

Fig. 1 Peak Demand and Energy Consumption for key urban areas 2010 [1].

Significantly, Ghana's three largest cities; Accra, Tema, and Kumasi, have been the key drivers in increased urban electricity usage, because of the impact of urbanization. The total peak electricity demand for these cities rose from 48% in 2000 to 52% in 2009 with a corresponding steady growth of electricity consumption at just over 50%. The most significant growth was in Tema, where peak demand grew more than 106% over the 10 year period and energy consumption grew more than 159% as shown in Fig. 1. To sustain this growth, significant development of additional infrastructure is required [1]. Renewable energy in general and solar energy

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in particular can make an important contribution to electricity supply in rural areas which do not currently have access to the national grid if the nation gears itself up to overcome the challenge of policy implementation [2]. The total electricity consumption in Ghana increased from 782 GWh in 1970 to about 1,328 GWh in 1980 at an average annual growth rate of 5.50%. Average annual GDP growth rate for this period was 0.2%. As a result of a drought in 1983, electricity consumption decreased from 1,361 GWh in 1981 to 1,007 GWh in 1984 at an average annual rate of minus 6.5%. During this period, the average annual GDP Growth rate was minus 2.0%.

Table 2. Electricity consumption by customer class in 2011[1]

Class	Consumption (GWh)	Percentage consumption (%)
Residential	2,761	34.6
Non-Residential	1,040	13.0
Industrial	3,900	48.9
Street lighting	279	3.4
Total	7,976	100

Thereafter, total electricity consumption increased from 1,251 GWh in 1985 to 5,286 GWh in 2004 at a steady average annual growth rate of 8.86% compared to an average annual GDP growth rate of 4.46% [2]. In 2012, the total grid electricity generated (thus electricity generated by the state utilities and the Independent Power Producers and pumped into the grid) in the country was 12,164 Gigawatt-hours (GWh) (thus million units of electricity) [10]. Figure 2 depicts the shares of final energy consumption in 1970, 2004, 2009 whilst Fig. 3 shows the sectoral shares of total energy consumed in the country for the years 2004 and 2009.

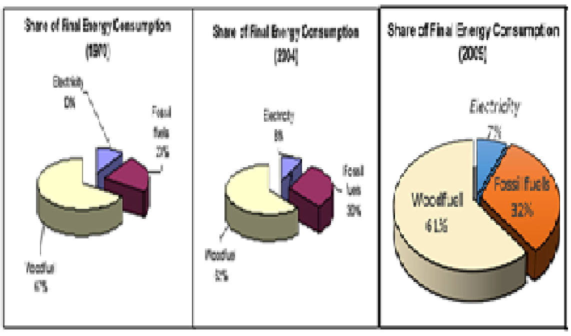

Fig. 2 Share of Final Energy Consumption for 1970, 2004 and 2009 [11].

In 2004 the residential sector accounted for 59% of total energy consumption whiles in 2009 the residential accounted 51% of the total energy consumption. This refers to electricity, petroleum fuel and wood fuel which make about 88% of the total residential sector final energy consumption. Transport in Ghana is mostly petroleum based and that accounted for 16% and 21% of total energy consumed in the year 2004 and 2009 respectively. Agriculture took some firewood and petroleum, whilst energy consumed in industry is made up of electricity, petroleum and wood fuel. This has been the trend since the year 2000. In 2004 the total energy consumption was 6.16 million tons of oil equivalent. The breakdown in terms of electricity, petroleum and wood fuel is shown in Fig. 3. Wood fuel is by far the largest contributor to energy in this country. Taking 2004 alone and breaking it into actual figures, electricity constituted only 8% of total energy consumption as shown in Fig. 2.

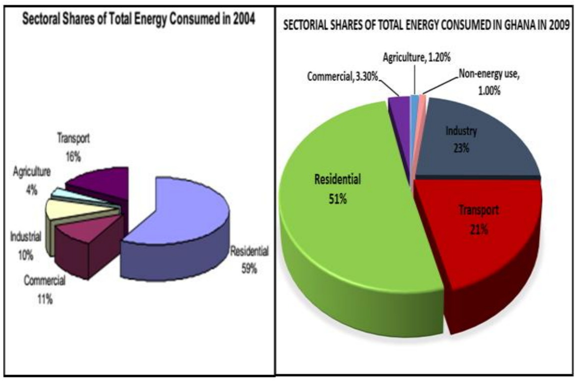

Fig. 3 Sectoral shares of total energy consumed in Ghana in 2004 and 2009 [2].

The electricity consumption by customer class (GWh) in the year 2011 is shown in the Table 2.

III. CONCENTRATING SOLAR POWER (CSP)

In this section, a description and assessment of the CSP systems is given, which incorporate three different design alternatives: parabolic trough, power tower and dish/stirling. These systems are solar thermal concentrating devices: Direct Normal Insolation (DNI) is reflected and concentrated onto a receiver/absorber where it is converted to heat, and then the heat is used to produce steam to drive a traditional Rankine power cycle [4]. Fig. 4 has the performance data for various CSP technologies. The function principle and the main system parameters of these power plants are described.

Fig. 4 Performance data for various concentrating solar power technologies [4]

CSP systems	Capacity range (MW)	Concentration	Demonstrated annual solar efficiency (%)	Thermal cycle efficiency (%)	Land use m^2/(MW h a)
Parabolic trough	10–200	70–80	10–15	30–40	6–8
Power tower	10–150	30–1000	8–10	30–40	8–12
Dish-stirling	0.01–0.4	1000–3000	16–18	30–40	8–12

A. Parabolic trough system

Parabolic trough system is line-focusing, and it uses the mirrored surface of a linear parabolic concentrator to focus direct solar radiation to an absorber pipe running along the focal line of the parabola. The Heat Transfer Fluid (HTF) or water (in case of Direct Steam Generation, DSG) inside the absorber pipe is heated and pumped to the steam generator, which in turn is connected to a steam turbine to produce

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electricity. Normally a natural gas burner is used to produce steam at the time of insufficient radiation. Parabolic trough technology has demonstrated its ability to operate in a commercialized environment by the nine solar power plants in California, the United States, which was developed by Luz International Limited between 1984 and 1990. The accumulated 154years' operation experiences of these plants indicate the low technical and financial risk in developing near-term plants [4]. During the long term's operation of the plants in California, electricity generation has been improved significantly by improving operation and maintenance procedures. The Kramer Junction, one of the three sites locating the nine plants, has achieved a 30% reduction in operation and maintenance costs during the last 5 years. Besides many detailed modifications, several major improvement works have been proceeding on, including DSG and Integrated Solar Combined Cycle System (ISCCS). Using direct solar steam generation, the HTF/water heat exchanger will no longer be required. Thus, by reducing investment costs and at the same time increasing system efficiency, a significant reduction of electricity generation cost is expected; ISCCS is a new design concept that integrates a parabolic trough plant with a gas turbine combined-cycle plant. The ISCCS has called much attention because it offers an innovative way to reduce cost and improve the overall solar-to-electric efficiency [5].

B. Power tower system

Power tower system is characterized by the centrally located large tower. A field of two axis tracking mirrors (heliostats) reflects the solar radiation onto a receiver that is mounted on the top of the tower, where the solar energy is absorbed by a working fluid, then used to generate steam to power a conventional turbine. To maintain constant steam parameters at fluctuant solar irradiation or even at the time of no shining, the system can be integrated with a fossil back-up burner or a thermal storage unit [4].

C. Dish/stirling system

Dish/stirling system uses a parabolic dish concentrator to focus direct solar radiation to a thermal receiver, and a heat engine/generator unit located at the focus of the dish generates power. Typically, a Stirling engine is used; other designs use gas (Brayton) turbines. A hybrid operation using natural gas is also possible [5].

D. Comparison of the systems

With a capacity of 10–400 kW, the dish/stirling is rather small. It does not enjoy the same economy of scale as the other two systems, so it is doubtful whether dish/stirling will ever form the backbone of multi-GW grid connected systems. However, this system could play an important role in the decentralized part of the solar economy. Parabolic trough and power tower are both centralized systems, and they are candidates for applications with grid connection. The tower is still immature and the large scale utilization of parabolic trough could be realized in near and mid-term [4].

IV. POTENTIAL OF CSP IN GHANA

The section focuses on the siting parameters of centralized CSP systems and an investigation of the potential of such plants in Ghana. There are many technical and economic issues related to sitting of the CSP plants, the main factors are discussed.

A. Assessment of solar energy resources in Ghana

The Republic of Ghana has a land area of 238,500 sq km, made up of two broad ecological zones - a High Forest Zone (HFZ) covering much of the southern 30% of the country, and a savanna zone over the considerably drier northern 70% [13]. It belongs to those so-called Sun Belt countries. Fig. 5 shows the solar map of Ghana.

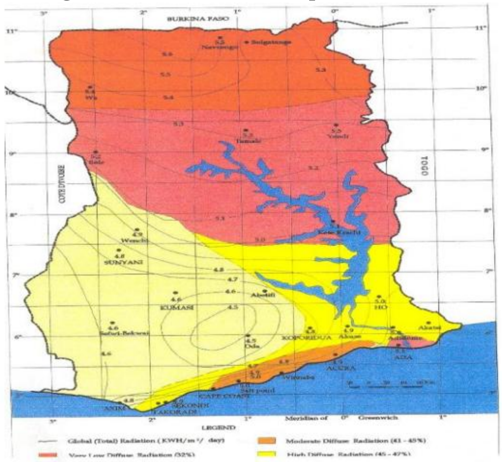

Fig 5: Solar map of Ghana [14]

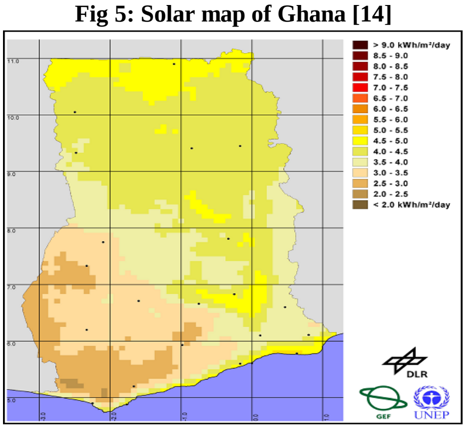

Fig 6: Direct Normal Solar Radiation of Ghana [11]

Generally speaking, the solar resource is abundant in Ghana, but greatly diverse in various areas. The direct normal solar radiation ranges from less than 2 kWh/m^2/day in part of the south-east to more than 9 kWh/m^2/day (Fig. 6) in part of the west. CSP systems require high DNI for cost-effective operation. Sites with excellent solar radiation can offer more attractive levelized electricity prices, and this single factor normally has the most significant impact on solar system costs [4]. It is generally assumed that CSP systems are economical only for locations with DNI above 1800 kW h/ (m^2day) (circa 5 kW h/ (m^2day) (Mills, 2004). As can be seen from Fig. 5, most of the northern and the western parts of Ghana land area can satisfy this requirement. The country receives an average solar radiation of about 4-6 kWh/m^2/day and sunshine duration of 1800 hours to 3000 hours per annum. Solar radiation in Ghana shows strong geographical variations with the highest level of solar radiation found in the northern regions of the country.

B. Assessment of the land use and land cover

Land is a very important asset and a means to sustain livelihood. It is the key and finite resource for most human activities including agriculture, industry, forestry, energy production, settlement, recreation, and water catchments and storage. Land is a fundamental factor of production, and through much of the course of human history, it has been tightly linked to economic growth. Except for the solar radiation, CSP plants require a large area for their solar field, approximately a land area of 20,234 m^2 is required per megawatt of electricity produced in a solar thermal power plant [4]. With the population dynamics (including growth and urbanization) in Ghana, the agricultural land and forest which is needed for crop and biomass production for the growing population should not be considered for siting power plants. Thus, only wasteland which is unsuitable for agriculture and residential use can be considered as construction sites. Most of the wasteland is located in northern Ghana where the solar radiation is among the highest [15].

C. Other factors

Except for solar energy resources, land use and land cover, the other siting factors are not much different compared with those of the traditional steam power plant. Land slope is an important characteristic during the siting investigation of a CSP plant. An overall slope of less than 1% is preferable; higher slope up to 3% is also acceptable, but will elevate the cost. For comparison, a thermal fired plant requires a land slope of 1–3% [4]. Another siting issue is the water availability. The water used at a Rankine steam CSP plant is for the steam cycle, mirror washing, and mostly the cooling tower. If sufficient water is not available at the site, dry cooling system is the other choice. However, the plant electricity cost can be raised by 10% in this case (Mills, 2004). Access to transmission line and natural gas pipeline are also important factors for selecting the sites. Transmission line costs can be very high, so proximity of potential CSP plant to the grid is very important. With fossil fuel, preferably natural gas, as supplement for the solar energy resource, the solar thermal power plants have the capacity to provide firm power in a hybrid configuration. However, the last issue is significant, but not determinant [4]. Therefore a feasibility study involving all these factors must be implemented before the location is determined for a CSP plant.

V. ENERGY SECTOR POLICY TARGETS AND STRATEGIES IN GHANA

Ghana's Strategic National Energy Plan (SNEP) reechoes the Energy Ministries vision which is to develop an 'Energy Economy' that will ensure sustainable production, supply and distribution of high quality energy services to all sectors of the economy in an environmentally friendly manner for Ghana's future while making significant contribution to the country's export earnings. In 2010, wood fuel accounted for 66% of the total energy consumption of the country whiles LPG accounted for 1%. The policy target indicates that by 2020 the wood fuel consumption would be reduced to 30% and LPG consumption increased to about 25%. Electricity consumption is also to be increased to 20% by 2020 as indicated in Fig. 7.

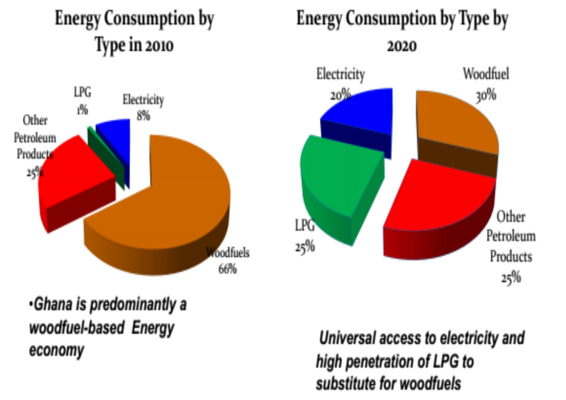

Fig. 7 Universal access to modern energy forms by 2020 [11]

Ghana's Energy Sector Policy Targets include among others to achieve an increase in power generation from the current level of 2,000MW to 5,000MW by 2020 and to develop a non-constrained transmission network by 2015. The national goal is to achieve 100% universal electrification by 2020. Achieve 10% contribution of modern Renewable Energy in the electricity mix by 2020 and 10% of renewable in terms of petroleum fuels supply by 2020. The renewable for electricity is expected to come from solar, wind, small and medium sized hydros, biomass and municipal solid waste. Renewable to supplement petroleum supplies is expected to come from bio-fuels. Ghana is expected to reduce demand on wood fuel from current 66% to 30% by 2020 and increase LPG use to 25% in that same year [7]. Table 3 presents the strategies to attain a 10% renewable energy in the electricity generation mix of the country by 2020.

Table 3 Strategies to attain 10% renewable energy in the electricity generation mix by 2020 [7]

Energy Source	**Exploitable Potential (MW)**	**Investment Requirement US$(million)**
Wind	200-300	250-400
Solar	20	100-150
Medium-small Hydro	150	200-300
Modern Biomass/Waste to energy	90	90-150
TOTAL	**500MW**	**640-900**

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To develop the Renewable Energy (RE) industry of the country, the Government of Ghana developed the Renewable Energy Act 2011 (Act 832), which was passed and accented on 31st December, 2011 to provide for the development, management, utilization, sustainability and adequate supply of RE for generation of heat and power in an efficient and environmentally friendly manner. The Act provides the enabling legal framework for Government to institute a licensing regime for RE producers, a feed-in tariff scheme for electricity and the RE development fund.

VI. CONCLUSION

Energy consumption of the country is increasing by 10% per annum as a result of the demand of the growing population, resulting in the growing environmental problems emanating from the use of fossil fuel. Consequently, a CSP technology provides a most promising opportunity for the Country. However, in the development of the Strategic National Energy Plan and Energy Policy for Ghana (2006 – 2020), CSP technology was not mentioned. To be able to bring CSP technology to a market-ready position in Ghana, much more efforts will be necessary and the government's support and strategies is highly anticipated. CSP technology can easily be adapted to the northern and western part of Ghana due to the abundant solar radiation and the large wasteland.

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