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A GIS-Based Approach for Rural Electrification Planning in Afghanistan with Focus on Renewable Energy

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ABSTRACT

Access to affordable, reliable, sustainable, and clean electricity, goal 7 of SDG, interconnected with five other goals and 125 (out of 169) targets of SDGs, is an essential factor to the success of any economic growth strategy. While 89 percent of households reported having access to any kind of electricity forms in the 2013-2014 (Afghanistan Living Conditions Survey), only 29.7 percent received their power from the grid, which covers only a small portion of electrified rural households. To select the most appropriate options for electrification of rural areas, a multicriteria decision-making approach has been used. The Analytic Hierarchy Process (AHP) is a multicriteria decision-making method used combined with GIS to analyze different options. In this paper, a methodology framework incorporating decision analysis techniques has been presented to evaluate and determine a suitable energy system for rural electrification with a perspective on sustainable development goals. Renewable energy, diesel generator, and national grid expansion have been compared to different options from different views and criteria.

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1. Introduction

The United Nations 2030 Agenda for Sustainable Development was adopted in 2015. It is underpinned by 17 Sustainable Development Goals (SDGs) and 169 targets. All SDGs interact with one another; by design, they are an integrated set of global priorities and objectives that are fundamentally interdependent. The four SDGs goals (goal-2, goal-3, goal-7, and goal-14) are mostly synergistic with the other SDGs [1]. Universal access to electricity by 2030 is one of the key goals of the UN Sustainable Energy for All initiative. Access to affordable, reliable, sustainable, and clean electricity, goal 7 of SDG, interconnected with five other goals (1, 2, 6, 8 &13) and 125 (out of 169) targets of SDGs, is an essential factor to the success of any economic growth strategy. The SDG target 7.1 is to ensure universal access to affordable, reliable, and modern energy services (7.1.1 focuses on the proportion of the population with access to electricity and 7.1.2 on the proportion relying primarily on clean fuels and technologies for cooking). Target 7.2 is to increase the share of renewable energy in the global energy mix substantially. Target 7.3 is to double the global rate of improvement in energy efficiency. SDG target 7.1 calls for universal access to affordable, reliable, and modern energy services. Reliability and affordability remain challenging elements in many countries, even as the number of household connections increases. In 2017, one-third of access-deficit countries faced more than one weekly disruption in electricity supply that lasted over four minutes. A basic, subsistence level of electricity consumption (30 kilowatts/hours per month) was unaffordable for 40% of households in about half of these countries [2]. The energy, which is considered as an important development goal, is the foundation of modern economies and the central need for modern life and a prerequisite for economic growth, improving living conditions and alleviating poverty. Obstacles such as high energy costs, unaffordable energy grid infrastructure, and disperse population make providing access to a majority of the world's population in developing countries a daunting task.

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Afghanistan's power grid is quite complicated. It operates in nine different "islands" that are supplied by different sources, and these are not interconnected or synchronized (Amin, 2015). The quality of power distribution is also poor, with fluctuating voltages and frequent power cuts, forcing industries and commercial customers to maintain a backup in the form of diesel generator sets [3].

The percentage of the population with access to grid electricity in Afghanistan is among the lowest in the world. Per capita consumption averages 186 kilowatts/hours (kWh) per year, significantly less than the South Asia average of 707 kWh and far below the global average of 3,126 kWh (2014 World Bank data). While 89 percent of households reported having access to any kind of electricity forms in the 2013-2014 (Afghanistan Living Conditions Survey), only 29.7 percent received their power from the grid, which covers only a small portion of electrified rural households and accessing the grid remains a serious challenge.

There are growing gaps between the demand for electricity and the supply from the grid, especially outside urban areas. While existing thermal capacity is extremely costly to operate and continued and growing reliance on disparate import sources prolongs the problems associated with lack of grid integration, renewable energy resources are abundant, particularly wind and solar. The costs of exploiting either of these resources have fallen significantly in recent years and compete favorably with the costs of conventional thermal and many hydro projects. To support sustainable rural development in Afghanistan is very important if generation is ensured from reliable and relatively clean and inexpensive sources.

Poor electricity supply not only hampers the essential activities of rural households but also has a negative impact on health, education, farming, and related livelihood activities [4]. The most important livelihood activities are related to access to clean fuels for cooking. The share of the global population with access to clean fuels and technologies for cooking increased from 57% in 2010 to 61% in 2017. To reach universal clean cooking targets by 2030 and outpace population growth, the annual average increase in access must rise to 3 percentage points, from the rate of 0.5 percentage points observed between 2010 and 2017 [2]. According to the Ministry of Energy and Water, Renewable Energy Department (MEW-RED, 2016) more than 60% of the people across the country live in dark homes, without access to a reliable form of electricity with no connections to power grids or large-scale energy in remote rural village communities." The sources of energy for most people are the burning of wood and diesel generators at high costs for fuel, which contribute to air pollution and deforestation. Many people in rural areas rely on kerosene and dried cakes of animal dung [4]. The ground reality of unstable economy of Afghanistan has descriptively recorded availability and affordability of fuel as a predictor in the choice of cooking fuel in the rural areas, which might not be representative to explore the current need of energy transition and determinants of household cooking energy (a large part of national energy use) choice among rural and urban Afghanistan. While the cooking covers the highest proportion of total energy consumption in Afghanistan, the most commonly used cooking fuels are firewood, LPG, straw/grass, and animal dung, among which firewood is the major source of rural subsistence and low-income people in the country.

The residents outside cities obtain firewood from the agricultural areas, and those cities generally purchase firewood from markets, while LPG is imported from neighboring countries. LPG is commonly used by high income and middle-income families, whereas firewood, straw/grass, and animal dung are mostly used by low-income families. 79.9% of Afghan residences use solid fuels for cooking, while this number is 97.4% for space heating [5].

Apart from education, households with more possessions (and electrical appliances) as the wealth index based on a principal component analysis of quintiles are "wealthy" [6]. According to the WHO, about 3 billion people are cooking and heating their living places with simple stoves and open fires, burning biomass (crop waste, wood, and animal dung), and coal. More than 4 million people die prematurely because of illness due to the air pollution arising from cooking with solid fuel. More than 50% of premature deaths as a result of respiratory disease among under-five children are caused by the material (soot) breathed in from household air pollution (WHO, 2016) [7].

It is estimated that household air pollution causes over 27000 deaths per year, whereas Ambient air pollution (outdoor) causes over 11000 deaths annually in Afghanistan. An estimated 3000 Afghans die due to second-hand smoke every year (EMRO/WHO, 2016). Women and children are at particular risk of exposure to household air pollution as they stay at home more than men (WHO, 2016). Progressive population growth, as well as increasing the energy demand rate, is a big issue and needs a practical solution. Net demand was projected to increase from approximately 2,800 GWh in 2012 to 15,909 GWh in 2032, representing an average annual growth rate of 9.8 percent. Peak demand was forecast to increase from approximately 600 MW at the beginning of the forecast period (2012) to a projected 3,502 MW in 2032, approximately 8.6 percent per year. It is this demand projection that the GoA is proposing to meet at least in part with RE (Word Bank, 2018) [4].

2. Previous plans for Afghanistan electrification

The Afghanistan Power Sector Master Plan developed in 2013 by Fichtner company utilized optimization models to create an electricity supply plan to meet projected demand growth [8]. This plan includes an assessment of the potential role of large hydropower plants (HPP) in the optimal generation mix but did not address possible grid-based roles for other renewable energy resources such as solar PV and wind power plants [4]. Fichtner recommends developing distributed hybrid wind, solar, and diesel power plants and off-grid solar home systems to meet the demand mainly in rural areas [9].

For the rural electrification, the Ministry of Rural Rehabilitation and Development (MRRD) has implemented a program "Energy for Rural Development in Afghanistan" (ERDA) with the support of UNDP and other donors. Presently, ERDA is supporting the implementation of microhydro schemes in different provinces of Afghanistan and has also mandated to implement the use of other rural energy technologies such as solar and wind power. ERDA has installed 746 kW of microhydro projects in the last four years. National Solidarity Program (NSP) is another important program implemented by the Ministry of Rural Rehabilitation and Development (MRRD) and it is supported by the World Bank. In this program, community development councils are being created which implement various projects including many rural energy projects. NSP has electrified 600 villages (i.e., about 72,000 households) with solar PV across Afghanistan.

In addition, the Afghanistan Clean Energy Program, a USAID initiative, is also promoting clean energy. In line with these efforts and the challenges ahead, the pathways that Afghanistan is taking towards rural electrification are worth evaluating [10].

3. Methodology

3.1. Study area

The scope of the study is nationwide, but the focus is on finding the best option for rural electrification. In this study, those provinces with no access to the national grid are focused on. Because of the lack of data of rural areas, districts as a much wider area rather than villages have been targeted. Afghanistan enjoys an abundance of renewable energy resources, whose exploitation could help to alleviate future supply gaps at cost levels that are both economically and financially attractive. Afghanistan is located between 33°56'2.5"N and 67°42'12.35"E with about 300 sunny days, good potential for solar PV utilization.

Average Global Horizontal Irradiance in Afghanistan is 6.5 kWh per m^2 per day. Although the southern areas such as Kandahar, Helmand, Farah, and Herat provinces have the highest radiation, in the Northern provinces with irradiance averages of 4.5 kWh per m^2 per day, electricity generation is technically feasible [4]. This corresponds to an average annual Global Horizontal Irradiance (GHI) of 1935 kWh/m^2. National average seasonal maximum and minimum GHI are 7.84 kWh/m^2/day and 2.38 kWh/m^2/day. Annual GHI for Herat and Balkh provinces are 1726 kWh/m^2 and 1967 kWh/m^2, respectively [9]. The total estimated national capacity based on solar radiation and the feasible area is 222,000 MW.

Total hydroelectric capacity (recoverable) is estimated at 23,000 MW, of which 87 percent (20,000 MW) is in the northeast on the Amu Darya, Panj, and Kokcha Rivers. A further 8 percent (1,900 MW) is located to the east of Kabul, with over half of this on the Kunar River near the border with Pakistan. Figure 1 shows the solar and hydroelectric potential comparing with population density.

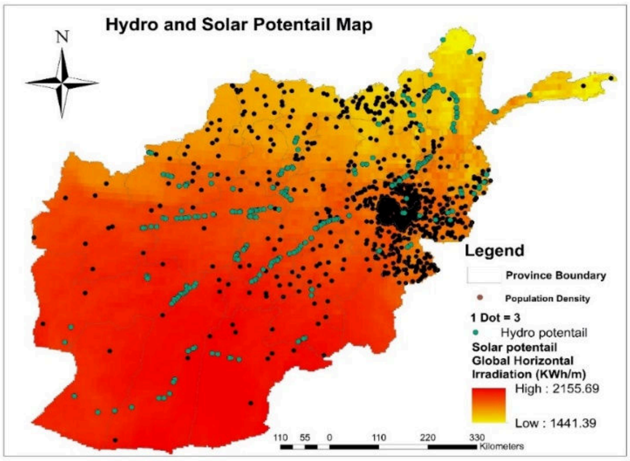

Figure 1. Solar and hydroelectric potential and population density.

Afghanistan's wind resources are also substantial but highly localized with the areas of maximum potential located in the southwest near the Iranian border. The country's total capacity is approximately 150,000 MW, while exploitable capacity (i.e., that is not constrained by accessibility or terrain) is estimated to be roughly 66,700 MW [4,9]. Figure 2 depicts Afghanistan wind potential.

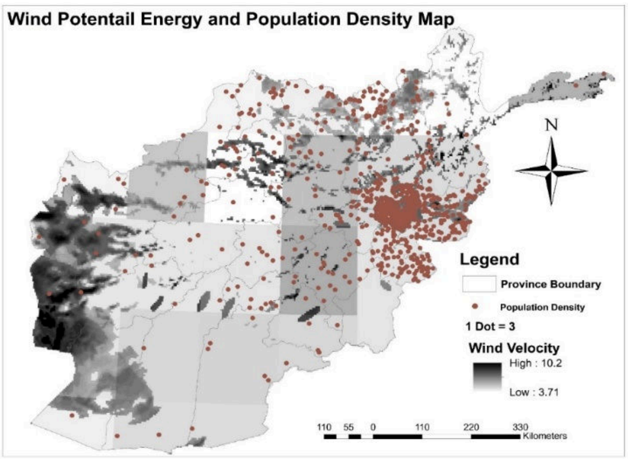

Figure 2. Wind potential and population density.

3.2. Model

Effective GIS-based electrification planning requires reliable geospatial information. Spatial information has been created using Arc-GIS tool. Applied required primary input data are fuel cost, existing power plants, planned power plants, existing transmission lines, planned transmission lines, population density, roads, rivers map, solar radiation, wind energy potential, and land use map. The selection of suitable energy solutions for rural electrification seems complicated, requiring multiple and simultaneous technical, social, economic, and environmental traits addressing. In Afghanistan, adequate energy-related data is not accessible; thus, some simplifications needed to be applied. To select the most appropriate options for rural electrification areas, a multicriteria decision-making approach has been used. The Analytic Hierarchy Process (AHP) is a multicriteria decision-making method used combined with GIS to analyze different options. In this paper, a methodology framework incorporating decision analysis techniques has been presented to evaluate and determine a suitable energy system for rural electrification with a perspective on sustainable development goals. Renewable energy, diesel generator, and national grid expansion have been compared to different options from different views and criteria.

3.3. Options and criteria

Options for rural electrification are the diesel generator, grid connectivity, and renewable energy like solar, MHP, and wind. Some options have already been used with respect to the economy of end-users. Hybrid systems and mini-grids have not been taken into account as an option in this stage, and they can be discussed after determining option priorities. Some provinces are located in the route of transmission lines, which mostly supply from neighboring countries and are supplemented by electricity from domestic hydropower plants (HPPs). Now 29 percent of Afghanistan population receive their power from the grid; thus, to simplify, all districts which are connected to the grid have been excluded, and those districts with no connectivity to transmission network have been selected.

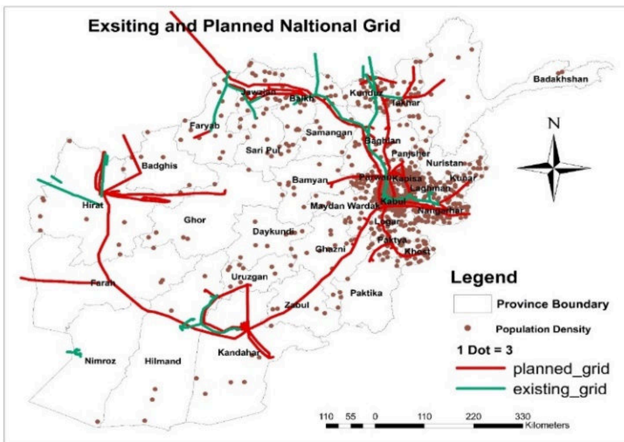

Figure 3. Existing and planned transmission lines.

Each district's priority of each option has been determined regarding the following factors.

3.4. Cost factors

Cost as the first important factor has been considered for option prioritization. Renewable options might impose constraints on the transmission network that will be needed to deliver the electricity to markets, which leads to further variations in their unit cost, so apart from Levelized Cost of Generating Electricity (LCOE), cost differences related to location distance from existing or planned transmission network and roads have been considered which is defined as Levelized Cost of Interconnection Electricity and Levelized Cost of Road Construction Electricity. LCOE for interconnection includes the cost of building a transmission line from the project site to the closest electrical grid point, as well as the cost of two substations.

In this paper, the cost of transmission was assumed to be a function of its length only, and therefore some assumptions used to simplify. Voltage, the capacity of the line, type of conductor, the structure of the poles, terrain, and right-of-way, as well as location or region-specific factors such as financing and material costs, are not included. LCOE for road construction estimated using a fixed capital cost per km of additional road needed and assumed independent of the size of the project. Globally, LCOEs for solar average in the order of US$0.10/kWh, excluding storage, but solar costs are expected to continue to decline and several planned projects are purported to be much more attractive financially. Unit costs range is from a low of US$ 0.097 per kWh in the southern and southeastern parts of the country to a high of US$ 0.137 per kWh, mainly in the northwest. Feasibility studies for the exploitation of hydropower resources are incomplete and out of date but notionally indicate Levelized Costs of Energy (LCOEs) in the order of US$0.045 to over US$0.10 per kWh. However, if storage or backup capacity was included (flows are highly seasonal and peak in the summer while demand peaks in the winter), the true costs would be considerably higher. For wind energy, looking at international experience, the average LCOE for land-based wind energy is in the order of US$0.065/kWh in OECD countries and slightly higher elsewhere. For wind energy, the costs of generation range are from a low of US$0.050 per kWh to a high of US$0.197 per kWh [4,7].

3.5. Quality factors

Quality related aspects such as life duration, annual energy generation, and operation and maintenance of each option have been considered in comparison matrixes in the AHP model.

3.6. Stability factors

Renewables energies such as wind and solar cannot meet all daily demand continuously. Regarding selected areas, and its renewable potential, this factor has been considered in comparison matrixes as well.

4. Results and discussion

After eliminating those areas which have access to the transmission network, the remaining area has been selected from the central and southeast area. Provinces with no connectivity to transmission networks are Paktika, Ghor, and Daikundi. These are high prior provinces for the electrification plan. In Paktika and Ghor, some districts are in the route of the planned transmission network. Ashtarlay, Barmal, and Lal-wa-Sarejangal have been studied from Daikundi, Paktika, and Ghor, respectively.

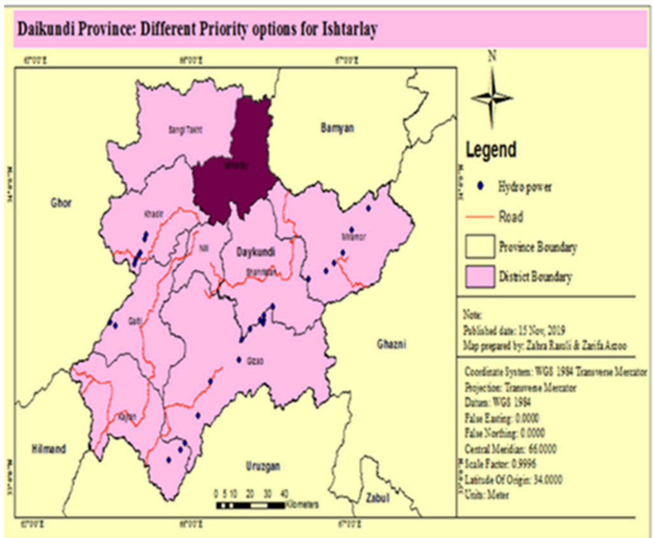

Figure 4. Ashtarlay-Daikundi Province.

Daikundi province, unfortunately, is not located in the route of any planned transmission line. The following tables show the comparison matrixes of criteria and options.

Table 1: Criteria comparison matrix for Ashtarlay-Daikundiprovince.

	Cost	Quality	Stability	Average Weight
Cost	0.1	0.1	0.1	0.1
Quality	0.6	0.7	0.7	0.6
Stability	0.3	0.2	0.2	0.3

Table 2: Comparison Matrix for different options regarding different criteria for Barmal-Paktika province.

	Cost	Quality	Stability	Weight
Solar	0.4	0.5	0.1	0.3617
Hydropower	0.2	0.3	0.3	0.2773
Wind	0.0	0.1	0.1	0.0896
Diesel Generator	0.0	0.0	0.1	0.0560
Grid	0.2	0.1	0.5	0.2153
Solar	0.4	0.5	0.1	0.3617

Regarding existing potential and criteria considerations, the result has been shown in Figure 7.

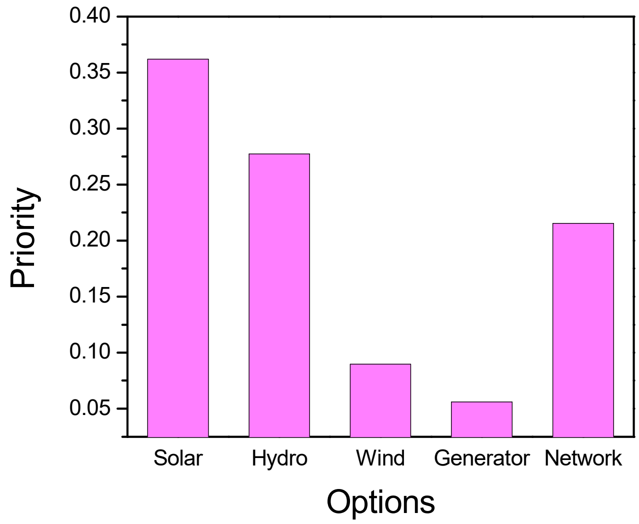

Figure 5. Option priority for electrification Barml- Paktika province.

Ghor province is one of the central provinces with no connectivity to the grid. Regarding the planned transmission line and population density, Lal-wa-Sarejangal has been selected for this study. Figure 8 shows the location of this district in Ghor province.

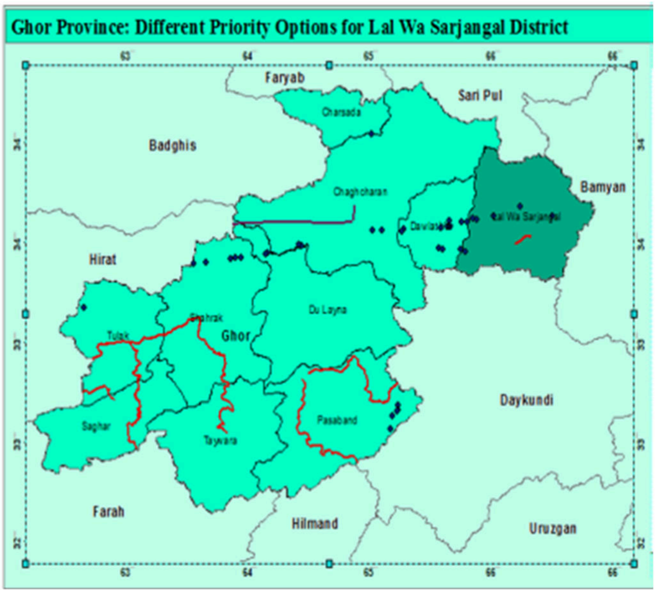

Figure 6. Lal-wa-sarejangal-Ghor province.

The following tables show the comparison matrixes for criteria and potions for Lal-wa-Sarejangal.

Table 3: Criteria comparison matrix for Lal-wa-sare jangal -Ghor province.

	Cost	Quality	Stability	Average Weight
Cost	0.1	0.1	0.1	0.1
Quality	0.6	0.7	0.7	0.6
Stability	0.3	0.2	0.2	0.3

Table 4: Comparison matrix for different options regarding different criteria for Lal-wa-sarejangal-Ghor province.

	Cost	Quality	Stability	Weight
Solar	0.2	0.1	0.0	0.1167
Hydropower	0.3	0.2	0.2	0.2187
Wind	0.0	0.1	0.0	0.0706
Diesel Generator	0.1	0.1	0.3	0.1106
Grid	0.4	0.5	0.5	0.4835
Solar	0.2	0.1	0.0	0.1167

Regarding the existing potential and criteria considerations, the result has been shown in Figure 9.

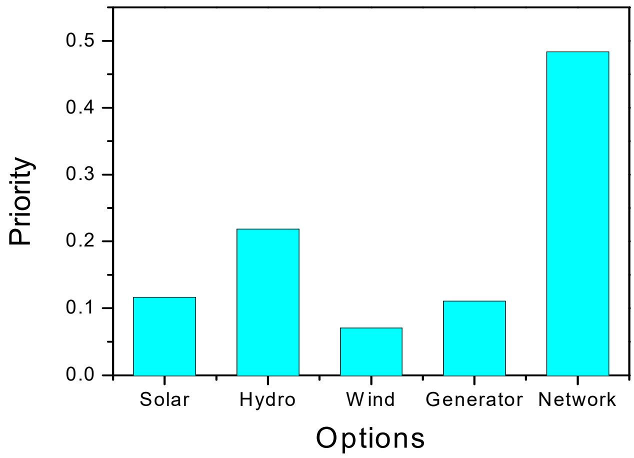

Figure 7. Option priority for electrification Lal-wa-sare-jangal -Ghor province.

5. Conclusion

Using geospatializing data, different collected data have been digitized and classified in the ArcMap environment. After providing all required data in the form of digitized maps, and integrating them, some areas which are not connected to the transmission network has been selected. Using the AHP model integrated with GIS, the best options have been determined for the electrification of these selected districts. Results show that the solar system and grid connectivity are high priorities.

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