Small hydro in Ecuador: Potential and prospects

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Ecuador has more rivers per square kilometre than any other country in the world and therefore it has a lot of potential for hydropower. However, until a decade ago, the country relied on oil and its by-products for energy generation. Today, 93 per cent of electricity comes from clean renewable hydropower. Ecuador's plan is to reach self-sufficiency through clean energy production, and potentially to export energy to neighbouring countries. Ecuador is one of the countries studied as part of the EU-supported HYPOSO programme (see more details at the end of the article). This article is based on a paper presented in a session on HYPOSO, during HYDRO 2020.

The average annual generation from hydropower between 2006 and 2015 was 10 880 GWh/year, and by 2018, it had risen to 20 696 GWh/year. It is clear that hydropower generation has gained more importance for the country, as the total installed capacity on the Ecuadorian power system almost doubled between 2006 and 2018.

The cost of new hydro capacity under construction is around US$ 2500/kW. The cost of producing a unit of electrical energy is approximately 0.048 US$/kWh in hydropower plants compared with 0.08 US$/kWh for other types of plants. The investment scenarios related to renewable energy projects in Ecuador mainly focus on the construction and operation of hydroelectric plants, because of the great potential of the water resources, which result from the beneficial natural, geographical, hydrological, and climatological conditions. Yet, there are still a number of challenges with regard to the development of small hydropower (SHP) and a need to define a more comprehensive strategy on small hydro project implementation and on encouraging future public-private partnerships.

1. Background

Ecuador has an area of around 283 560 km^2 and a population of about 17.3 million (August 2019 estimate). The country is located on the west coast of South America, and borders Colombia to the north, Peru to the east and south, and the Pacific Ocean is to the west. Ecuador is characterized by three distinct regions: the coast, the highlands, and the eastern interior lowlands. The climate varies with the region, and mean annual precipitation ranges between 200 mm and approximately 5000 mm. Most of the northern coast consists of wet, tropical forest, and an increasingly humid environment. In the central coastal area, there are two seasons: a hot rainy period, lasting from January to May; and, a cooler dry season during the rest of the year, when sea breezes modify the equatorial heat. Quito, the capital, is located at el. 2850, with an average temperature of 13°C and about 1270 mm of rainfall annually. The highlands are cut by numerous deep valleys, which bring subtropical climates to within a few kilometres of the more temperate areas. Cold and wind increase as the slopes surrounding the central plateau ascend to form the paramo. The higher areas rise to peaks above el. 5200, and these are perpetually covered with snow.

The Guayas, in the centre west, and the Esmeraldas, in the northwest, form the principal river systems. The highlands are formed by two parallel ranges of the Andes and divided into 10 basins at elevations from 2400 to 2900, some draining east and some west. It should be noted that a large portion of Ecuador's high mountains are volcanic.

The eastern interior lowlands are part of the upper Amazon basin, beginning at the base of the Andes at about el. 1200. There are at least 2000 rivers and streams throughout the country. The fact that Ecuador has more rivers per square kilometre than any other country in the world, means that it has a great hydro potential. Most rivers have headwaters in the Andes mountain range, and flow either westward toward the Pacific Ocean or eastward toward the Amazon.

Until 1961, the provision of electricity was dominated by private companies and also by the municipalities. Only small thermal electricity generation systems were developed, and installed capacity was insufficient. Therefore electricity could not play a significant role in Ecuador's economic and industrial development. By 1964 there were 1100 powerplants in the country with generation capacity of 190 MW and by 1967 there were 1218 of them (661 private and 557 public). About 35 per cent of the population were supplied with electricity, of which 60 per cent was generated by thermal plants and about 40 per cent by hydro plants. Ecuador ranked in one of the lowest places in Latin America in terms of electrification. The change began after 1961, when the Ecuadorian Electrification Institute (INECEL) was created and the 'decade of development' began throughout Latin America. Between 1971 and 1985, the focus was on using river flows to generate hydropower, developing two types of networks:

- the National Interconnected System, with four large hydroelectric projects (Pisayambo, Paute, Toachi and Montúfar); and,
- the Regional Electric Systems.

In 2008, to avoid electricity shortages that commonly occurred between 1992 and 2007, the Ecuadorian Government launched the so-called 'Change of the Energy Matrix', based on which large-scale hydro projects were constructed. Within eight years, Ecuador went from 46 per cent of electricity being generated from fossil fuels to 93 per cent generated by hydro, a clean and renewable energy production system. By 2018, access to electricity was estimated to have increased to more than 97 per cent.

1.1 Power sector overview

As mentioned, only a decade ago, Ecuador mostly relied on oil and its by-products for energy generation. Nowadays hydropower generation has gained more

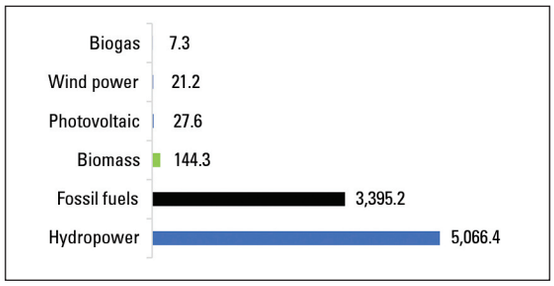

Fig. 1. Effective installed capacities of the Ecuadorian power system in MW [ARCONEL, 2018[13]].

importance, since the Ecuadorian Government committed to developing a cleaner energy system through the development of hydropower plants, biomass, wind power and other renewable source projects. The total installed capacity on the Ecuadorian power system almost doubled between 2006 and 2018.

During this period, the country invested close to US$6 billion in eight flagship projects with a total installed capacity of 2832 MW. Two large-scale projects make up most of this new capacity and both were inaugurated in 2016: Coca Coda Sinclair (1500 MW), a run-of-river facility located in the Coca River (Napo basin) and Sopladora (487 MW), an additional phase to the Paute Integral reservoir hydropower system on the Paute river (Santiago basin). The remaining six projects are already at advanced stages of construction and they were planned to be fully operational by 2020 [Carvajal *et al*., 2019[1]].

The country's total effective installed capacity from all sources was 8662 MW (in 2018), comprising: hydropower (5066 MW); thermal plants based on fossil fuels (3395 MW); thermal biomass plants (144.3 MW); thermal biogas (7.3 MW), solar PV (27.6 MW); and wind power installations (21.2 MW), see also Fig. 1.

In September 2018, three ministries, responsible for hydrocarbons, electricity and renewable energy, and mines, respectively, were merged into the new Ministry of Energy and Non-Renewable Natural Resources (MERNNR). In January 2015, a new law governing the electrical sector had been approved by the National Assembly, which was the Organic Law for the Public Service of Electricity. According to this legislation, ARCONEL (Agencia de Regulation y Control de Electricidad) is the regulatory body for the electricity sector. The National Operator of Electricity (Operador Nacional de Electricidad) CENACE is responsible for administration of the national interconnected grid and the state-owned company, Electrical Corporation of Ecuador (Corporation Electrica del Ecuador) CELEC groups together the main electricity companies. The representative indicator of the hydroelectric potential of Ecuador is estimated to be very high: 0.74 GWh/year/km^2 compared with other countries such as Austria, Norway (0.66) and Brazil (0.15). The installed hydro capacity had reached around 5282 MW and hydro generation 20 671 GWh/year, by 2018 [MERNNR, 2017[2]].

1.2 Renewable electricity policy

The Ecuadorian 2008 Constitution explicitly states that the Government will promote the use of clean and alternative energy sources, in addition to energy efficiency, while providing access to public services, preserving the environment and maintaining food and water security, among other things. Ecuador's plan is to reach self-sufficiency through clean energy production and potentially be able to export energy to neighbouring countries.

The regulatory framework for electricity is the Electric Law of 2015, which explicitly states the objective of promoting renewable energy sources. It points out that the National Electricity Council (CONELEC) will regulate the operation of generation plants using renewable sources. As a result, CONELEC periodically issues regulations (normally every two or three years) for renewable energy plants installed on or after the date of the new law, as well as other regulations covering all renewable plants (including those installed previously).

Between 2000 and 2015, Ecuador had a feed-in tariff system to support renewable electricity deployment, which evolved over time in terms of the duration, rates and technologies included. Ecuador is one of very few Latin American countries to have implemented a feed-in tariff (FIT) scheme for renewable energy [Vargas et al., 2018[3]]. In 2014, Resolution CONELEC 014/14 maintained the feed-in tariff only for biomass and biogas, with differentiated rates for the first time, and for hydro plants smaller than 30 MW.

Small-scale electricity producers (with capacity smaller than 1 MW) do not require a permit for operation (according to Decree 1581 of 1999). However, to benefit from the feed-in tariffs, they need to be registered with CONELEC. In 2013, Regulation CONELEC 002/13 introduced two payments: a registration guarantee of US$ 7000 for projects smaller than 500 kW and US$ 15 000 for those larger than 500 kW; and, an execution guarantee of 1 per cent of the total project cost [Norton Rose Fulbright, 2017[4]].

The Electrification Master Plan 2013-2022 developed by CONELEC jointly with other relevant entities plans for 26 hydropower projects totalling 4.86 GW of new capacity by 2027, as well as an additional 217 MW of solar, wind and other non-conventional renewables [MERNNR, 2019[5]].

1.3 Hydropower sector and potential

Ecuador has a gross theoretical hydropower potential of 90 970 MW, equivalent to 638 000 GWh/year [Aqua-Media, 2019[6]], while the technically and economically feasible hydro potential figures are 189 300 GWh/year and 156 700 GWh/year, respectively (see Fig. 2). CONELEC [2012[7]] and IDB [2013[8]] indicated different estimations for theoretical and economically feasible hydropower potential, which are 77 000 and 21 520 MW, respectively. So far, about 19.7 per cent of the technically feasible potential has been developed, and by August 2019, Ecuador's total hydro capacity was 5041 MW. The average annual generation from hydropower between 2006 and 2015 was 10 880 GWh/year, about 45 per cent of total generation. In 2018, generation from hydropower was 20 696 GWh (70.2 per cent), a notable increase compared with the years mentioned above.

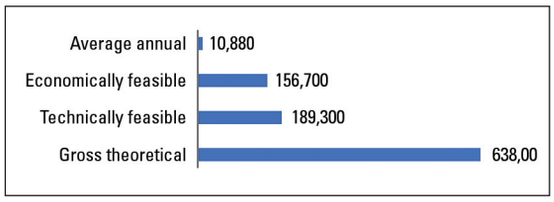

Fig. 2. Hydropower potential in GWh/year in Ecuador, 2006-2015 and average annual generation [data from H&D 2019[6]].

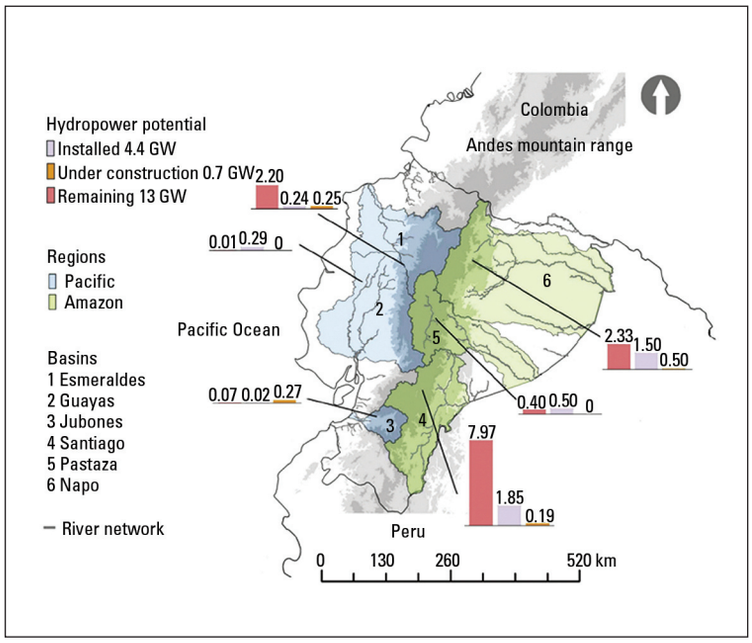

Fig. 3. Ecuador's six major river basins, and geographical distribution of hydropower potential [based on MERNNR, 2017[2]].

Based on the Government's assessment of hydropower potential (GW), Ecuador has six major river basins geographically distributed in two main regions, the Pacific and Amazon (see Fig. 3) [Carvajal *et al*., 2019[1]]. There are 31 large hydro plants (>10 MW) in operation, with a total installed capacity of 4973 MW, while for small, mini or micro hydro plants (<10 MW) a total of 41 plants in operation with a total installed capacity of about 102 MW.

The definition of small hydropower (SHP) in Ecuador is up to 10 MW [WSHPDR, 2019[9]]. In practice, installations of slightly higher capacity are sometimes classified as small. The main features of Ecuadorian small hydro sector are presented in Table 1. Note that the small hydropower potential shown in Table 1 (296.6 MW) is underestimated, taking into account the fact that total hydropower potential is high (economically feasible is 25 550 MW). A preliminary assessment carried out by the HYPOSO project estimates an SHP potential at least 5 to10 times larger than that given in the report of WSHPDR [2019[9]].

2. SHP policy and market analysis

It is difficult to separate clearly small and large hydro policy and other related issues in the electric sector, as there is no specific legalisation related to the sizes of hydro plants in the country. A contact list of the main stakeholders involved within the hydropower sector were identified [HYPOSO D3.1, 2019[10]].

Table 1: Ecuador - Small hydro (<10 MW) characteristics according to different sources

References	Potential, MW	Installed capacity, MW	Number of operating SHPs	Comments
WSHPDR, 2019	296.6	98.2	37	Data at the end of 2016
H&D, 2019			31	Capacity limit for SHP is unknown
HYPOSO, 2020		102	41	

2.1 SHP policy

Key documents making up the legal framework to which hydropower must comply include: Legal Legislation of Ecuador; Organic Law on Public Service of Electric Energy; Organic Law on Popular and Solidarity Economy; Environmental Organic Code; and, Organic Law on Water Resources Uses and Water Development.

The main permits/rights granted to develop small hydro are:

- Authorization for Hydroelectric Development, issued by the MERNNR, which takes about six months to obtain;
- Productive Water Use Authorization for Power Generation, issued by the National Water Secretary (SENAGUA), which takes one year to obtain and is valid for 10 years;
- Environmental Licence for projects, works and activities that produce medium to high impact and environmental risks, issued by the Ministry of Environment (MAE), which remains valid during the project´s life;
- Construction Licence for 1st and 2nd category installations, issued by the MERNNR, which is valid during construction work; and,
- Operation and Maintenance licence.

Hydro plants smaller than 1 MW do not need environmental licence, but only an environmental plan.

For more detail on these legal documents regulating renewable energy and hydropower, as well as the regulations for granting concessions and permits please refer to the HYPOSO deliverables [HYPOSO D3.2, 2020[11]]. Small hydropower is integrated within the whole energy and hydropower sector.

2.2 Industrial and economic overview

There are at least 11 companies in the country which are working to some extent in SHP consultancy, design and construction, or operation and maintenance. A few examples are: Sedemi, ASTEC, Ingeconsul, ICA, Macroconsult, PANAVIAL, CVA, Constructora Villacreces Andrade SA, Acotecnic, EPMAPS, Geincosolution, Hidrosierra. Hydraulic machinery manufacture has not been well developed. Some preliminary economic estimates for hydropower are shown in Table 2.

The cost of new hydro capacity under construction is around US$ 2500/kW. The cost of producing a unit of electrical energy is approximately US$ 0.048/kWh at hydropower plants and US$ 0.08/kWh at other types of plants [Aqua-Media International, 2019[6]]. The Ecuadorian Government implemented a feed-in tariff (FIT) scheme for renewable energy [Vargas *et al*. 2018[3]] that was approved in 2013 and since then it has been awarded for a period of 15 years. For small hydro plants of up to 10 MW, the FIT rate is 0.0781 US$/kWh. Since 2011, it has been mandatory for FIT-sponsored renewable energy projects to contribute part of income from each kWh generated to social and community projects (0.0189 US$/kWh for hydropower < 30 MW).

In mid-2019, the Government began launching auctions for renewable energy projects, including small hydro installations, through which it intended to allocate around 500 MW of power generation capacity. Developers ware to be granted a 25-year power purchase agreement (PPA), and the sole off-taker of the

generated energy will be the state-owned utility Corporacion Electrica de Ecuador, SA (CELEC).

3. SHP financing opportunities

The investment scenarios relating to renewable energy projects in Ecuador are mainly focussed on the construction and operation of hydro plants, because of the great potential of the water resources, which result from the beneficial natural, geographical, hydrological, and climatological conditions.

Many organizations currently finance, or have financed, small hydro schemes. These are national and foreign banks, and some other organizations, for example:

- governmental entities: for example, BIESS and MERNNR;
- local government: EPMAPS, GADs (gobiernos autonomos descentralizados), and municipalities in each province;
- private investment: Grupo Noboa, Caminosca (currently out of the market), and Grupo Supermaxi;
- regional institutions: Corporación Iberoamericana de Inversiones (CII) and Corporación Andina de Fomento (CAF);
- various foreign companies: Banco Nacional de Desarrollo Económico y Social de Brazil, Société Générale de France, Deutsche Bank, Chinese Bank (Eximbank), Agence Française de Developpement (AFD);
- national investors: Fondo Ecuatoriano de Inversión en los Sectores Estratégicos e Hidrocarburífero (FEISEH), Constructora Nacional; and,
- Others: entities with cooperation agreements.

4. Environment

The provision of basic services such as water and electricity supply are the responsibility of the Government, through the various public companies; however, it is possible for private companies to invest in renewable energy projects. The institution responsible for water management is the National Secretariat of Water (Secretaría Nacional de Agua, SENAGUA). The Ecuadorian Constitution has placed special emphasis on the environmental protection in all fields of development, but in particular those related to water resources development. Environmental legislation relating to hydro projects is set out in the Estudios de Impacto Ambiental Preliminar y Definitivo (Preliminary and Final Studies on Environmental Impact).

The participation of local people in new power projects is actively encouraged. In fact state policy dictates that communities and neighbouring towns must be able to participate in, and benefit from, new projects. However, some community opposition remains, particularly regarding private and large hydro projects. The Ministry of Energy and Non-Renewable Natural Resources (MERNNR) is working with ARCONEL to raise awareness of the importance of dams and hydro plants, and the benefits they can bring to communities and the country as a whole.

5. Barriers to SHP development

While the Ecuadorian Ministry of Electricity and Renewable Energy is making considerable efforts to ensure higher reliability and resilience of the energy sector, there are still a number of challenges with regard to the use of SHP, as outlined below [WSHP-DR, 2019[9]]:

- Lack of detailed data regarding to economic and technical potential of SHP affects investment decisions and policies in the sector;
- Lack of technical capabilities and knowledge to ensure effective integration of small hydropower technology into the power system;
- Dependency on large hydropower makes larger projects a priority for the Government and limits the interest in small hydropower investment;
- Lack of reliable information for the private sector and for international investors due to most data available being based on theoretical predictions, increases uncertainty in the planning process.

There is a need to define a more comprehensive strategy for implementing small hydropower and to encourage future public-private partnerships. Progress regarding environmental awareness, social acceptance, and cultural justice, is still needed to ensure the rural electrification sustainability efforts in small indigenous communities in the Amazon basin [Feron *et al*., 2016[12]].

Table 2: Ecuador - Key economic estimates for hydropower

Year: 2015-2019 (average)	Small Hydro (<10 MW)		Medium (10-50 MW)	Large Hydro (>50 MW)
	Low head (<20 m)	Medium and high head*		
Average Investment Cost (€/kW)	3 017	2 907	2 068	1 481
Average O&M Cost (as % of total investment cost)	3	3	2.50	2
Average lifetime of the mechanical equipment (number of years)	25	25	20	20
Average Civil Works Cost (as a % of total investment cost)	40	50	68	64
Internal Rate of Return (Average in %)	20	20	16	26

** head in the range of 20 to 100 m and above 100 m, respectively*

6. Future prospects

As of 2019, the following SHP projects were under construction, or preparations were being made for them to go ahead soon [Aqua-Media, 2019[6]], with various forms of financing, as listed.

Under construction

- Mazar Dudas San Antonio (7.2 MW), CELEC EP - Hidroazogues, public funds, nearing completion.
- San Jose de Minas (6 MW), Hidroelectrica San Jose de Minas SA, private funds, nearing completion.
- Chorrillos (4 MW), Hidrozamora EP, public funds, expected to begin operation in 2022.

Going ahead (as reported in 2019)

- Maravilla (9 MW), Hidroequinoccio EP, public funds, expected to begin operation next year.
- Chalpi Grande (7.6 MW), EPMAPS EP, public funds, expected to begin operation next year.
- Mazar Duda Dudas (7.4 MW), CELEC EP - Hidroazogues, public funds, expected to begin operation next year.

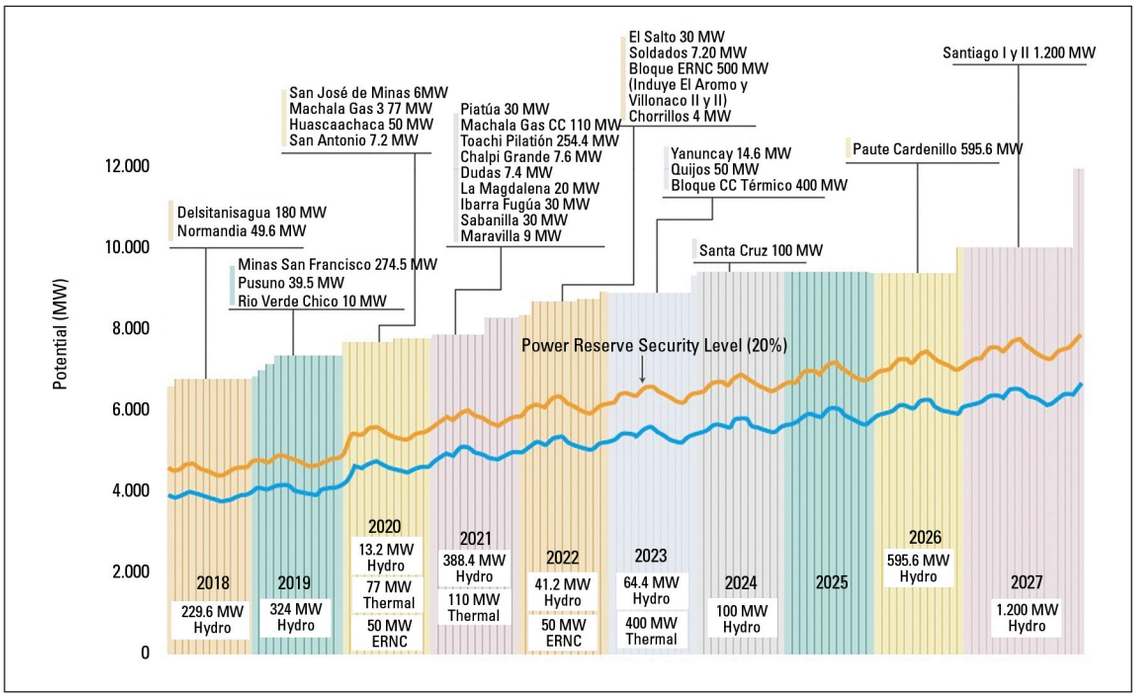

Fig. 4. Sequence of projects that will be implemented up to 2027 in Ecuador.

• El Laurel (1 MW), CBS Energy SA, private funds, expected to begin operation next year.
• Ulba (1 MW), Hidroulba SA, private funds, expected to begin operation next year.
• Others: Soldados (7.20 MW), Chorrillos (4 MW), expected to begin operation in 2022.

Around 40 small hydro projects, with a total capacity of 225 MW, already have the final design completed, and are ready to go ahead for construction (see Fig. 4). A number of pilot pico hydro projects have also been developed. The experience acquired in applying this technology will be used in the future, which will help rural communities to gain access to electricity. ◊

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About HYPOSO

The overall objective of the HYPOSO project is to support the market uptake of European hydropower technologies to foster more clean and reliable energy in selected target countries in Africa (namely in Cameroon and Uganda) and Latin America (namely in Bolivia, Colombia, and Ecuador). It is expected that beside the promotion of the European hydropower industry in the developing and emerging regions the realisation of the HYPOSO objectives will pave the way for better investment conditions (legal, political, financial, social) in target regions and increase the share of renewable energy there, especially small and medium-sized hydropower by helping relevant governments, authorities and local stakeholders to create better framework conditions for renewables (eg, faster permits and shorter planning periods, energy cooperatives and communities, easier and faster funding, etc).
This article summarizes the main findings on the analysis for Ecuador. A report on all five countries can be found at:
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