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ESTIMATION OF ENERGY RECOVERY POTENTIAL AND ENVIRONMENTAL IMPACT OF TIRANA LANDFILL GAS

Due to a very high percentage of organic matter in municipal solid waste (47.36%) and in total percentage of biodegradable matter (62.3%), organic waste disposed is the main source of methane emissions into the air in Albania. Capture, collection and utilization of landfill gas in an energy project leads to economic, health and environmental benefits. Energy recovery potential and methane emissions from Tirana landfill have been studied. This site is scheduled to be closed after 6 or 7 years. The evaluation has been done using LandGEM Colombia Model, version 1.0, as an international LFG Modeling. The model predicted the time of peak production in 2019, one year after assumed site closure. The total annual peak of predicted methane recovery from landfill within the study time frame was estimated to be 2950 m^3/h and a maximum of power plant capacity 8.3 MW.

ABBREVIATIONS USED IN THE TEXT

LFG	– landfill gas
CO_2	– carbon dioxide
FOD	–first order decay
GHGs	– greenhouse gases
LandGEM	– landfill gas emissions model
EPA	– Environment Protection Agency
IPCC	– intergovernmental panel on climate change
MSW	– municipal solid waste
Btu	– British thermal unit
CO_2 eq	– equivalent CO_2

1. INTRODUCTION

Landfills, controlled and uncontrolled are considered a great risk to human and environmental health. According to the Environment Report 2012 [1], landfills are one of

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the largest sources of potential pollution in communities of all types and especially the organic waste disposed of is the main source of methane emissions in the air [1]. This fact is related to typical municipal solid waste composition in Albania since there is a very high percentage of organic matter in national municipal solid waste (47.36%) and in total the percentage of biodegradable matter is about 62.3% [2]. Methane produced at solid waste disposal sites contributes to 3–4% percent to the annual global anthropogenic greenhouse gas emissions [2]. The negative impacts of uncontrolled landfill gas are not only confined to its influence om climate changes, but there are a lot of odorous, toxic and carcinogenic trace components. LFG is potentially flammable and explosive when concentrated in confine spaces. Long term exposure may have harmful health effects and it can damage vegetation [3].

Methane is a potent greenhouse gas. It is about 21 times more potent than CO_2 at trapping heat in the atmosphere over a 100 year time period [4]. The chemical lifetime of methane in atmosphere is approximately 12 years. This relatively short atmosphere lifetime makes it an important candidate for mitigating global warming in the near term. Methane is one of the main components of LFG composed of 50% of methane and 50% of carbon dioxide with less than 1 percent non-methane organic compounds and trace amounts of inorganic compounds [5]. The primary source of CO_2 released from solid waste is its organic material (such as food, paper, wood, and garden trimmings, etc.) But these CO_2 emissions are not included in national total emissions, because carbon is of biogenic origin and net emissions are accounted for under the agriculture forestry and other land use sector.

Once waste is first deposited in a landfill, it undergoes an aerobic decomposition during which carbon dioxide and water is generated. Then less than one year anaerobic conditions, are established and methane bacteria produce methane and carbon dioxide. Methane is generated as a result of degradation of organic material under anaerobic conditions.

In recent years, the Albanian legislation is completed with a series of important regulations and legislative acts about waste management (9010/2003 on environmental management of solid waste, 9537/2006 on dangerous waste management, 8934/2002 on the protection of environment, Law on integrated management of solid waste (2011) and national strategy on solid waste management (2011). According to the national strategy on solid waste management, the integrated solid waste management supports on hierarchy principle as follows: reduction and prevention of waste production, reuse and recovery of generated wastes, separation and selective collection of recycling materials and energy recovery, controlled deposition together with reducing of disposed waste quantity.

But this hierarchy has not been applied in practice, because actually none of methane emitted from landfills and open damps in Albania is captured and utilized as a source of renewable energy [1], while globally methane emissions from landfill are generally considered to represent the major source of climate impact in the waste sector [6]. A gradual decay of the carbon stock in a landfill generates emissions even after disposal has ceased [6]. This is because chemical and biochemical reactions take time to progress and only a small amount of carbon contained in waste is emitted in the year this waste is disposed. Most is emitted gradually over a period of years [6].

Estimation of methane emissions from landfill are generally made using a first order decay (FOD) model which calculates the rate of methane generation as proportional to waste input. LFG collection typically begins after a portion of the landfill is closed to additional waste placement. The most common method of LFG collection involves vertical wells in the waste. After collection, LFG either can be burnt in flares or can be used in energy recovery system such as internal combustion engines, gas turbines, micro turbines, steam boilers, etc., that use the gas for electricity generation thereby reducing GHGs emissions. However before installation of such systems, it is necessary to determine the methane generation from selected landfill site. To do this estimation, we have to know some information of the landfill site, such as a) amounts of waste disposed at the landfill annually; b) opening and closing years of landfill operation; c) the methane generation rate constant (k); d) the potential methane generation capacity (L_0); e) the collection efficiency of the gas collection system and some other landfill features.

Thus the first step of the LFG recovery project is to determine if the landfill site is likely to produce enough methane to support it. Once it is determined that the energy recovery options is viable, the next step is to estimate gas flow. This article aims at presenting an estimation of potential of LFG energy recovery and methane emissions reduction in Tirana landfill site.

2. DESCRIPTION OF THE STUDY AREA. CASE STUDY

The landfill of Tirana city is considered to estimate the potential of generated and recovered LFG. The landfill, located in Sharra site, is the principal disposal site used by the municipality of Tirana to dispose of municipal solid waste. Sharra Landfill is located about 7 km southwest of Tirana center (Fig. 1) and its total surface is about 55 000 m^2. Tirana's landfill operation started as an open dump in 1995. Firstly it is operated as an uncontrolled open dump with constant open fires and deep fire burning at the site, assuming an average amount of 30 000 t of waste burned per year (20–25% of total amount collected [7]). Moreover, this landfill site being near a great urban center and surrounded during the last few years by many illegal building (about 200–300 m away from landfill), causes sanitary and ambient problems, constituting a high risk for the area population.

Up to about 2008 this site was an open dump and it was considered as one of the main causes of pollution of Tirana [1]. Fires has been present at all times and the odors are been feeling up to some quarters to Tirana. Waste was often exposed to the elements, vectors and scavengers and susceptible to open burning or combustion [8]. Since 2008 the waste field of Sharra has been converting in a landfill, and this process is still going on, meanwhile the process of waste disposing of is going on too. This project is one of the largest ones in the field of solid waste in Albania [1]. Up to 2012, some other landfills were built with a capacity smaller than Sharra landfill: Bushat landfill (Shkodër), landfill of Rrëshen, landfill of Bajram Curri City and the feasibility of some other regional landfills, about 12 over the country have been studied [1], [9].

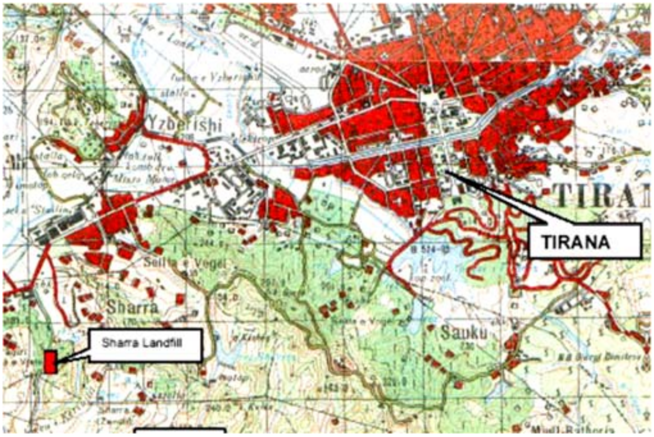

Fig. 1. Location of the Sharra Landfill [7]

The building of these regional landfills will create the possibilities to profit from the economy of scale, since solid waste management is an expensive service if it will be managed according to the EU directives. This implies that if two or more municipalities cooperate, the individual cost of each municipality will be reduced and the possibilities to have higher service standards will increase [10].

Number of families in Albania are expected to grow at the same rate of the last 10 years [11] showing that in the absence of measures to mitigate the growth of the quantity of urban solid waste generated, municipal solid waste can continue to grow with the same rate as in recent years. The solid waste growth rate is estimated to be for the period 2011–2015 approximately 2% [11]. According to report on the state of the environment up to now, none of methane emitted from wastes disposed of damp sites in Albania is captured and utilized as an energy source.

Benefits from landfill gas energy projects are: reduced emissions of GHGs, improved air quality, reduced environmental compliance costs, increased economic benefits through job creation and market development, conserve land, etc. [12]. Combusting captured methane to generate electricity produces two by products: water and carbon dioxide. Carbon dioxide that is emitted from LFG energy projects does not considerably contribute to global climate change because the carbon was contained in recently living biomass and would have been emitted through the natural decomposition process [12].

3. SELECTED ESTIMATING MODEL AND ITS INPUT VARIABLES

The landfill gas emissions model (LandGEM) is an automated estimation tool with a Microsoft Excel interface that can be used to estimate emission rates for total landfill gas (LFG), methane, carbon dioxide, non methane organic compounds, and individual air pollutants from municipal solid waste landfills [5]. The Colombia Model version 1.0 (2010), estimates the LFG generation rate in a given year using the following first-order exponential equation, which was modified from the U.S.EPA's landfill emission model (LandGEM) version 3.02 (EPA, 2005):

$$Q_{LFG} = \sum_{t=1}^{n} \sum_{j=0,1}^{1} 2kL_0 \left[\frac{M_i}{10} \right] \mathrm{MCF}\, F \mathrm{e}^{-kt_{ij}} \tag{1}$$

where: Q_{LFG} is the maximum expected LFG generation flow rate (m^3/year), i – 1 year time increment, n – (year of calculation) – (initial year of waste acceptance), j – 0.1-year time increment, k – methane generation rate (1/year), L_0 – potential methane generation capacity (m^3/Mg), M_i – mass of solid waste disposed in the ith year (Mg), t_{ij} – age of the jth section of waste mass M_i disposed in the ith year (decimal years), MCF – methane correction factor, F – fire adjustment factor.

This model incorporated the structure of the Mexico model and IPCC model, with revised input assumptions to reflect local climate and conditions at disposal sites. According to the model, the total LFG generation is equal to two times the calculated methane generation [5]. The exponential decay function assumes that LFG generation is at its peak following a time lag representing the period prior to methane generation [5]. The model assumes a six month time lag between placement of waste and LFG generation [5]. After six months, for each unit of waste, the model assumes that LFG generation decreases exponentially as the organic waste is consumed. The year of maximum LFG generation normally occurs in the closure year or the year following closure (depending on the disposal rate in the final years) [5]. Then the landfill biogas recovery rate is calculated by multiplying the calculated amount of biogas generation by collection efficiency estimating.

This model, as an international LFG one, gives to the other countries, except Colombia for which it is projected, the possibility to input manually information provided from a specific landfill site, reflecting the specific site conditions and features. It can be used to estimate landfill gas generation from landfills and potential landfill gas recovery rates for landfills that plan to have gas collection and control systems. This is why we have chosen this LFG model to apply for this particular case. The model automatically assigns values for k and L_0 based on climate and waste composition data [5]. The k values vary depending on climate and waste group. The L_0 values vary depending on waste group [5]. The model applies separate equations to calculate LFG generation from each of the four organic waste categories, explained in the following.

Total LFG generation for all wastes is calculated as the sum of the amounts of LFG generated by each of the four organic waste categories. The model's calculation of LFG generation also includes an adjustment to account for the degree to which waste decays aerobically, known as the methane correction factor (MCF), and an adjustment to account for the extent to which the site has been impacted by fires (fire adjustment factor, *F*).

According to the model, the user has to input site-specific data for the landfill opening and closure year, refuse disposal rate, and landfill location and to answer several questions regarding the past and current physical conditions of the landfill. The landfill has been operated since 1995. Its capacity is enough for about 6–8 years [11]. The climate of Tirana is classified as plain Mediterranean, by a dry summer and a wet, relatively cold winter. The average rainfall is around 1247 mm/year with most rain during the period October–February (about 70–75%) [13]. The total surface of the landfill is about 55 000 m^2. Due to active surface erosion in this area, both slopes of the valley are very steep with angles of about 40° [7].

The year of disposal is estimated at 1997 and the projected closure year is 2018 [11]. Table 1 presents the annual MSW rates disposed of up to 2012 and the estimated disposal rates for 2013–2018, assuming the annual solid waste growth rate 2% [1].

Table 1

MSW generated in Tirana in 1997–2018 [MT]

	1997	1998	1999	2000	2001	2002
MSW	87 140	96 869	140 097	170 077	186 907	169 180
Year	2003	2004	2005	2006	2007	2008
MSW	217 650	282 518	250 606	300 979	373 685	380 000
Year	2009	2010	2011	2012	2013	2014
MSW	337 237	340 506	414 377	383 138	390 800	398 620
Year	2015	2016	2017	2018		
MSW	406 590	414 720	423 010	431 470		

The total annual waste generated in Albania is about 825 000 t or about 266 kg/capita/year, from which the organic matter in national municipal solid waste constitutes 47.36% and in total the percentage of biodegradable matter is about 62.3% [1]. While for Tirana city these percentages are respectively: organic waste 45.2% and biodegradable waste: 64.1% [11] (Table 2). The ability of gas collection system to capture the generated LFG is expressed by collection efficiency as a measure of it. It estimates the amount of LFG that can be captured for flaring or beneficial use. The rates of LFG capture can be measured, but the rates of LFG generation in a landfill cannot be measured. This is why a model is used to estimate LFG generation. Due to considerable uncertainty regarding actual collection efficiency at the landfill, EPA suggests that collection efficiencies at landfill typically range from 60% to 85%, with an average of 75%.

Table 2

Waste composition for Tirana city [wt.%] based on [11]

Waste componet	Content [%]
Organics	45.2
Wood	1.6
Paper	6.7
Cardboard	10.6
Biodegradable waste	64.1
Plastics	13.1
Glass	5.0
Textile	6.0
Metals	1.2
Hospital waste	0.2
Rubber waste	0.2
Inert waste	5.3
Sanitary waste	3.5
Electrical and electronic waste	0.3
Animal waste	0.8
Total	100

The values for some of model input variables for LFG projections for Tirana (Sharra) landfill are:

Annual precipitation moderately wet	1247 mm/year
Estimated growth in annual disposal	2%
Average landfill depth	10 m
Landfill area impacted by fire	30%
Waste area to be covered with wells	100%
Waste area with final cover	80%
Waste area with intermediate cover	0%
Waste area with daily cover	0%
Waste area with no cover	20%
Waste area with clay cover	50%
Is waste compacted on a regular basis?	yes
Methane volume content	50%
Collection efficiency estimate	74%
(estimated by the model with the data listed above)	
MSW in total for period 1997–2018	6 596 176 MT

In Table 3, the values for L_0 and k parameters are presented, calculated for four waste groups.

Table 3

L_0 and k parameters

Parameter	Decay			
	fast	moderate	moderately slow	slow
CH_4 generation rate constant k	0.26	0.120	0.048	0.024
CH_4 generation potential L_0, m^3/Mg	56	99	129	160

Gas engines were considered for energy recovery purpose, which are designed for robust performance in challenging conditions and difficult fuel gases. The LFG energy recovery by means of gas engines is a quite wide spread practice in modern landfills. The gas engines have also proved to be highly reliable and durable in all types of applications, particularly when are used for natural gas and biological gas applications and to be able to constantly generate the rated output even with variable gas conditions.

4. ESTIMATION OF LFG GENERATION AND RECOVERY

The projected LFG generation and recovery for Sharra Landfill site is given in Fig. 2.

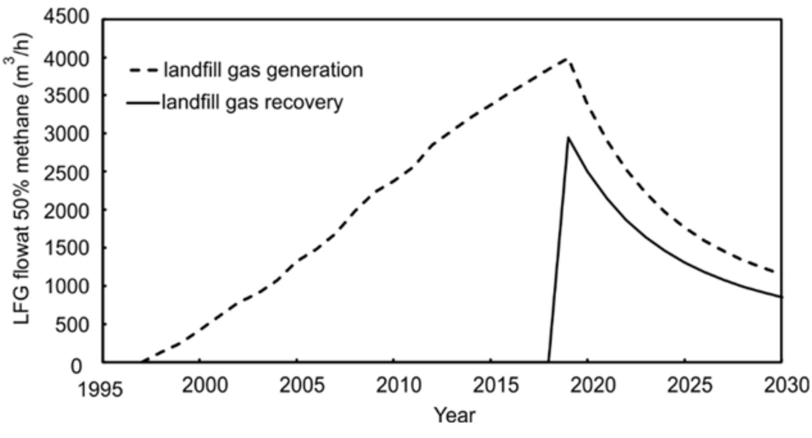

Fig. 2. Projected LFG generation and recovery for Tirana landfill site

The detailed calculation of predicted LFG recovery biogas quantity and power generation are presented in Table 4. Maximum power plant capacity assumes a gross heat rate of 10 800 Btu per kWh. The total hours of plant operation are supposed 7200 h/year (by the model) [5]. This estimation does not consider the constraint of using the gas engines, arranging a configuration for maximum LFG exploitation since 2018 (non--constrained scenario). The peaking value of LFG that can be recovered is 2950 m^3/h, in the second assumed year after closure an installation of collecting system.

Table 4

Predicted LFG recovery and power generation for Tirana landfill site

Year	Predicted LFG recovery biogas [m³/h]	Power generation [GWh/year]	Year	Predicted LFG recovery biogas [m³/h]	Power generation [GWh/year]
2018	2842	57.60	2028	995	20.16
2019	2950	59.76	2029	921	18.72
2020	2506	50.40	2030	856	17.28
2021	2153	43.92	2031	801	16.56
2022	1871	38.16	2031	751	15.12
2023	1644	33.12	2033	707	14.40
2024	1460	29.52	2034	668	13.68
2025	1310	26.64	2035	632	12.96
2026	1186	23.76	2036	599	12.24
2027	1082	21.60			

In Figure 3, the maximum power plant capacity is shown.

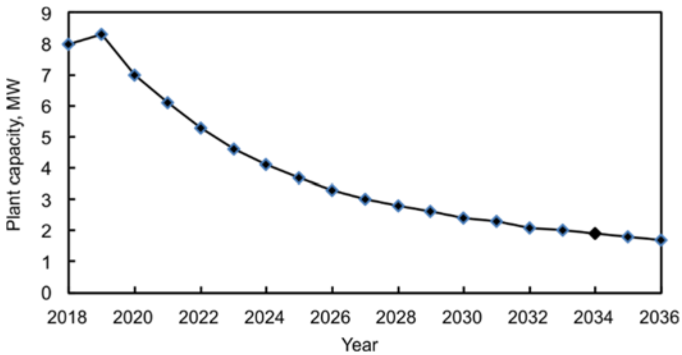

Fig. 3. Maximum power plant capacity

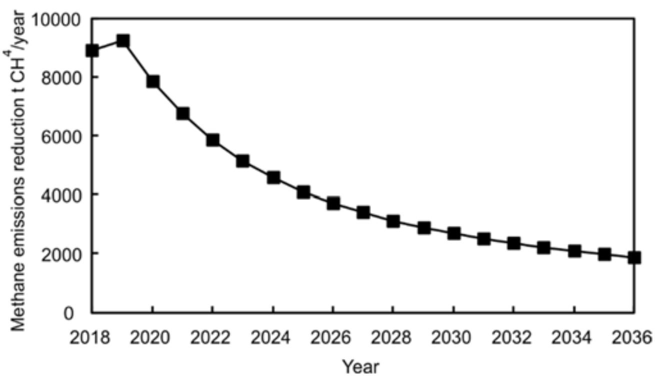

Fig. 4. CH_4 emissions' reduction in t CH_4/year

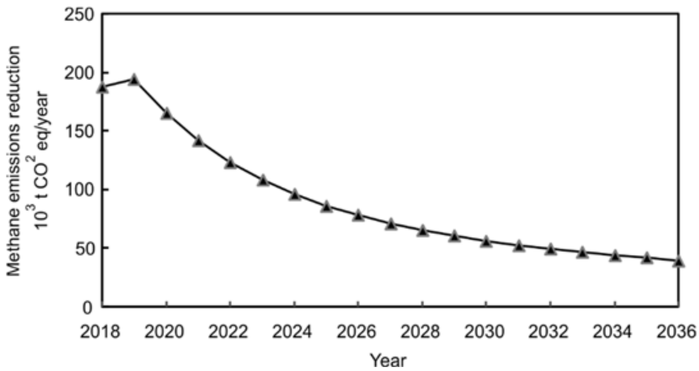

Fig. 5. CH_4 emissions reduction in t CO_2 eq/year

Reductions of emissions do not account for electricity generation or project emissions and are calculated using the methane density (at standard temperature and pressure) of 0.0007168 Mg/m^3 [5]. In Figure 4, the estimation of methane emissions reduction in t CH_4/year, and in the next Fig. 5 in t CO_2 eq/year for the time period 2018–2036.

5. RESULTS AND DISCUSSION

The use of LandGEM model has been widely documented in literature. However, the accuracy of LFG energy recovery and emission estimates can be significantly affected by limitations due to the structure of the LandGEM, such as changes in k or L_0 in a model run as well as changing landfill conditions and waste composition over time which cannot be modeled. Therefore it requires the LFG modeler to be careful in the selection of various parameters to represent as best as possible the site specific conditions. This has led to development of specific LFG models for various countries under the U.S. EPA's Landfill Methane Outreach Program [5].

LFG is a valuable energy source since its total chemical energy is sufficient to sustain the operation of an electric power generation as a supplementary or primary fuel contributing to the total electric power generation [14]. The carbon dioxide released from burning landfill gas is considered to be a part of natural carbon cycle of the earth [15]. Producing electricity from landfill gas avoids the need to use nonrenewable resources to produce the same amount of electricity. In addition, burning LFG prevent the release of methane, a potent greenhouse gas into the atmosphere.

Biogas at a constant concentration of 50% CH_4 and 50% CO_2 is flammable when its concentration in air is between 9% and 20% and it will not burn using conventional gas combustion if the CO_2 concentration is higher than 75% [16]. The results show LFG generation and recovery, and also that reduction of methane emissions as estimated by the LFG model are strongly influenced by the waste disposal rate and waste composition. The model parameters are highly depending on prevailing site conditions and LFG capture efficiency and therefore are difficult to quantify.

The success of a LFG recovery project is dependent on an accurate and timely estimation of the produced LFG, as an overestimation could lead to its failure. The estimation depends of the selected model, the quality of the available data and the selection of the correct coefficients. It is recommended that data from more landfill site is used in the landfill model before implementation at national level [16].

The development and implementation of LFG energy recovery project can generate socioeconomic and environmental impacts despite reduction of GHGs. It is now time to consider acceptance and adoption of LFG recovery technologies as a key strategy for deriving environmental, regulatory monetary and socio benefits.

6. CONCLUSIONS

The aim of this study was a theoretical estimation of the potential of LFG energy recovery and methane gas emissions from Tirana landfill site using the first order decay models namely LandGEM. The model predicted the time as peak production as occurring in 2019. The total peak annual methane recovery was estimated to be 2950 m^3/h. It was also determined that the predicted peak production of plant power capacity and power generation was 8.3 MW and 59.76 GWh/year, respectively .

We notice that biogas production and electric power generation of the landfill examined in this study increases only for one year. This happens due to the fact that LFG collection and utilization system is supposed to establish after almost 20 years of operation. But this increment is only for a short time interval and based on other LFG projects in other countries. Power production is predicted to be considerable not only for covering biogas plant's consumption, but for flowing enough power to the grid as well. Under normal conditions, the rate of decomposition reaches a peak within the first 3–6 years of waste deposited. Then it slowly decreases for a period of 30 years or even more. Taking under consideration these results it is better the collection and utilization system must to be installed in the open year of the landfill to achieve the best results with increasing peak rates and to avoid at the same time the eventually reduction.

Landfill biogas can be used as a fuel for electrical power generation and methane emissions reduction. Energy recovery from waste is an area of a great interest since it is a clean, viable and internationally established technology of waste management. This technology option reduces not only GHGs emission but reliance on other fuel sources as well. The reduction of methane emissions predicted by model is, in total, ca. 1 707 768 t CO_2 eq, during the time period 2018–2036. Energy production from LFG can avoid the need to use non-renewable resources to produce the same amount of energy, can avoid gas end user and power plant emissions of CO_2 and some other pollutants.

Success of the LFG recovery project is dependent on an accurate and timely estimation of the produced LFG, while an overestimation could lead to its failure. The estimation depends on the accuracy of the selected model, the available data quality and the selection of the correct coefficients.

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