WOIMA

CORPORATION

CASE STUDY

DECENTRALIZED
WtE POWER GENERATION
NAIROBI KENYA


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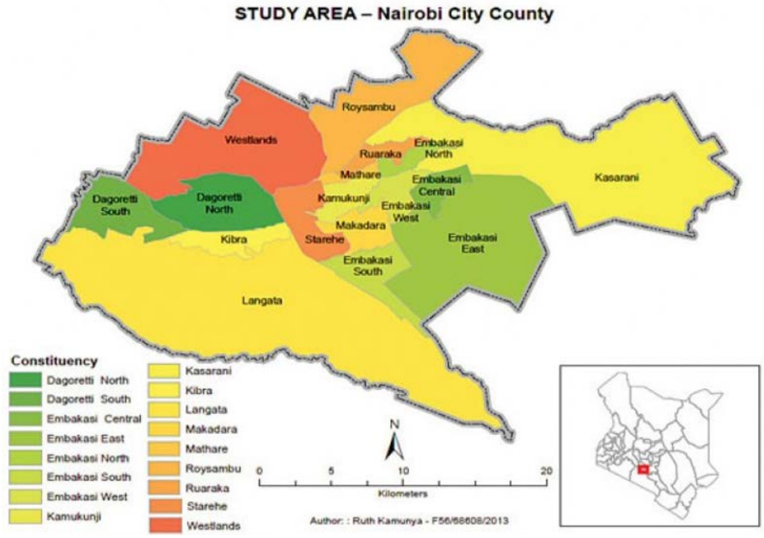
Background

The City of Nairobi is the capital of the Republic of Kenya and the largest administrative, commercial and industrial center of the country. Nairobi has been experiencing rapid population growth largely due to rural-urban migration and natural rate of increase, and the population of the city is presently estimated at 3.5 million, which is expected to grow to 6.0 million by 2030. Current waste generation rate is 2,500 tons per day, which will increase to 4,000 tons per day by 2030. The main drivers behind the rise in waste generation are

- population growth
- improved living standards
- rapid urbanization
- lack of implementation of the 3R concept (reduce, reuse, recycle)



Nairobi is divided into 17 sub-counties of different size, each of which generates roughly the same amount of waste (130 to 170 tons per day). About half of the present solid waste generation is left uncollected or illegally dumped inside the city limits and the remaining waste is delivered to the over-flowing Dandora dump site, which at 42 ha is close to full capacity.

Dandora is an open unsanitary landfill right next to the Nairobi River, which has a major detrimental effect on the hygienic, environmental as well as aesthetic conditions for the people of Nairobi City. There are plans to close down the site and open a new sanitary landfill in the outskirts of the city in the next few years.

The Kenya Vision 2030 states in its strategy that Kenya is to become a clean, secure and sustainable environment by the year 2030. To realize this, improvement of pollution and waste management are paramount.

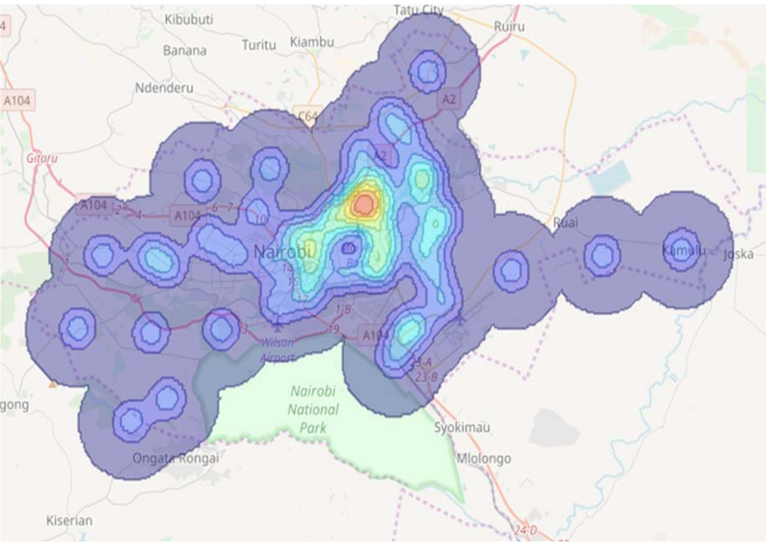
The objective of this case study is to demonstrate, how a decentralized waste management and power generation solution could enable Nairobi to reach its strategic goal at minimal cost. It would also eventually eliminate the need for a new landfill altogether and yield significant side benefits towards public health, the environment and climate change.

Sub-County	Daily Waste Generation (kg)
Kamukunji	169 000
Embakasi South	160 000
Kasarani	159 000
Ruarake	155 000
Mathare	154 000
Roysambu	153 000
Embakasi Central	148 000
Langata	148 000
Dagoretti North	146 000
Embakasi North	145 000
Dagoretti South	144 000
Embakasi West	144 000
Kibra	142 000
Westlands	141 000
Starehe	132 000
Embakasi East	131 000
Makadara	128 000

Methodology

The study compares two waste-to-energy scenarios in Nairobi City

1. One centralized waste-to-energy facility
2. Decentralized model, where smaller WtE facilities are built in six locations close to where the solid waste is generated



The key questions in the study are

1. What are the waste transportation savings?
2. What are the power transmission savings?
3. What are the carbon emission savings?

Two points in time (2018 and 2030) are selected to emphasize the significance of growth in population and energy demand. It is assumed that all the solid waste can be collected and delivered to the facilities.

The study considers both CAPEX and OPEX impacts in each scenario.

In each sub-county, three logical collection points are chosen close to the main roads as shown in the above heat map. It is assumed that each collection point receives an equal amount of waste within the sub-county.

The centralized waste-to-energy facility is located at the current dump site in Dandora. Out of the six decentralized WtE facilities, one is located in Dandora and the remaining five locations are optimized around the city based on land availability, power transmission network routes and waste generation patterns.

Transportation savings are calculated using Open Door Logistics, a Vehicle Routing and Scheduling Program (VRSP) calculating

- fuel costs
- labor costs
- service and maintenance costs
- administrative costs
- depreciation of transport vehicles

Power transmission savings are calculated using the estimated cost of new transmission lines and substations for both models. The net power generation capacity is estimated as 40 MW_e in 2018 and as 65 MW_e in 2030.

Carbon emissions from the waste transportation are derived using annual waste collection and transportation distances, estimated vehicle fuel consumption and the fuel-specific emission factor. The carbon emission savings arising from the shorter construction time of the smaller decentralized facilities, and thus faster carbon emission abatement are also calculated.

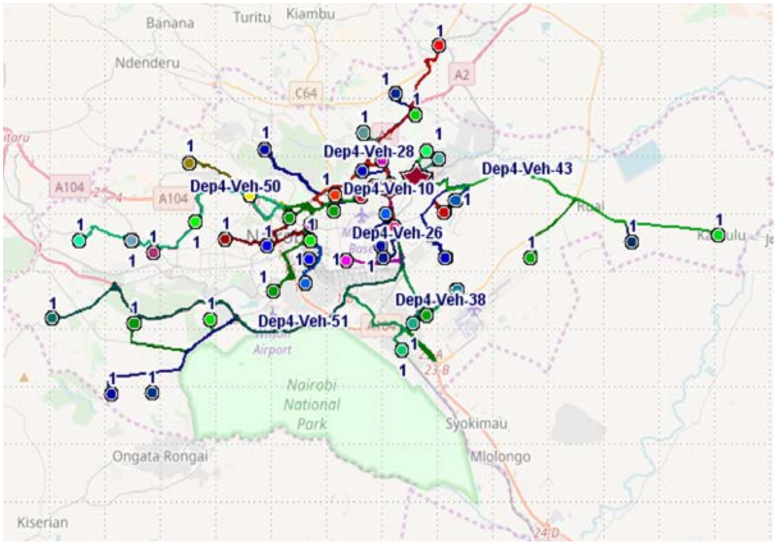
Monte Carlo simulation is used to tackle the effect of uncertainty of future events, namely oil price and labor cost, in the year 2030 results. It will deliver the probability of different outcomes based on historical data.

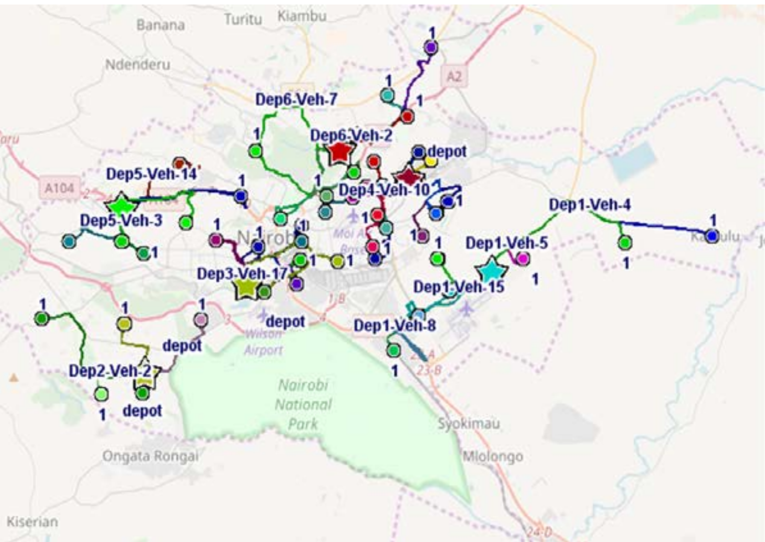
Results - Transportation

In the centralized solution (right hand picture), the total distance for the solid waste transportation to Dandora (purple star) is 2,845,000 km annually in 2018. This translates to $6,350,000 in total costs per year. This consists of 443,500 man-hours of labor, 838,000 liters of diesel fuel and $2,485,000 in administrative, maintenance and accumulated vehicle depreciation costs.

In 2030, the respective figures are

- transportation 4,454,000 km
- man-hours 833,600 h
- diesel fuel 1,335,000 l
- total cost $19,740,000





In the decentralized solution (left hand picture), the transportation routes are visibly shorter. The total distance for the waste transportation to Dandora and the other five facilities is 1,348,000 km p.a., which translates to $4,550,000 in total costs per year. This consists of 338,200 man-hours of labor, 404,000 liters of diesel fuel and $1,840,000 in combined administrative, maintenance and accumulated vehicle depreciation costs.

In 2030, the respective figures are

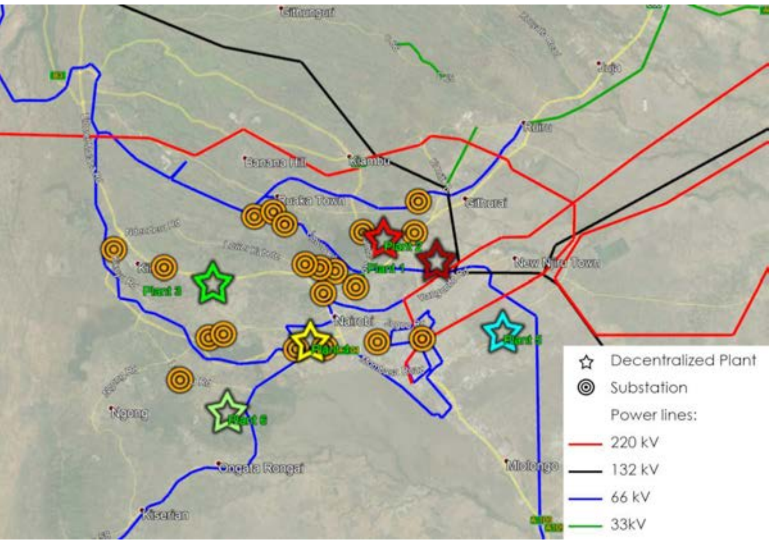
- transportation 2,186,000 km
- man-hours 614,700 h
- diesel fuel 656,000 l
- total cost $13,800,000

The above results are based on the assumptions in the right-hand table. Every effort has been made to depict the solid waste collection and transportation process and associated costs as realistically, if not conservatively, as possible.

Costs or savings related to using smaller local roads, transporting fuel to the vehicle depots, waste collection within the sub-counties or personnel commuting are not considered here. Neither is traffic congestion due to waste trucks running back and forth on the main roads.

Cost Item (in 2018)	Cost
Waste truck price	$90,000 /vehicle
Waste truck's economic life cycle	15 years
Waste truck capacity	8,000 kg/vehicle
Waste loading rate	3,865 kg/h
Waste unloading time (centralized)	45 min
Waste unloading time (decentralized)	15 min
Waste truck fuel consumption	30 l/100km
Diesel fuel price	$1.06 /liter
Waste truck maintenance cost	$10.24 /d /vehicle
Waste truck insurance cost	$1.024 /d /vehicle
Average transportation speed	28 km/h
Average transportation speed	15 km/h
Working hours per week	52 h
Waste transportation time per day	8 h
Driver's salary	$2.00 /h
Waste collection team's salary	$4.75 /h
Annual average cost increase	5 %
Admistration costs (of direct costs)	20 %

Results - Power Transmission



The Kenyan power transmission network around Nairobi is currently operating at its full capacity. Any major power plant development project will need build its own transmission lines to connect to the country's power transmission network.

A centralized waste-to-energy power plant in Dandora capable of generating 60 MW of electricity would face severe space issues in where to locate the plant itself, its transformer field and how to route the transmission lines through the heavily populated surroundings. The decentralized WtE plants could connect directly to the local substations with no additional costs to the City and simultaneously improve the power availability in the sub-counties.

The electricity transmission cost has three components; investments in the transmission lines and transformer equipment (CAPEX), their operating and maintenance (O&M) cost and the the transmission losses during the power plant operation. The cost of land, studies, permits and similar is not considered here.

The total cost is partly an estimation, since the study did not attempt to optimize connecting the centralized power plant to the grid. The CAPEX is ~6,500,000$, the O&M ~130,000$ p.a. and the annual transmission losses ~$2,600,000. Thus, the total cost in the power transmission is around $2,860,000 p.a. assuming a 50-year lifespan

Results - Carbon Emissions

The transportation sector generates the largest share of global greenhouse gas emissions; 28.5%. The CO_2 emissions resulting from the use of fossil fuels in the waste trucks in Nairobi add up to 2,220 tons in the centralized model and 1,052 tons in the decentralized model in 2018. In 2030, the annual figures are 3,475 and 1,705 tons, respectively.

Emissions are calculated as follows

$$TE = F * EF_f * D \quad \text{where}$$

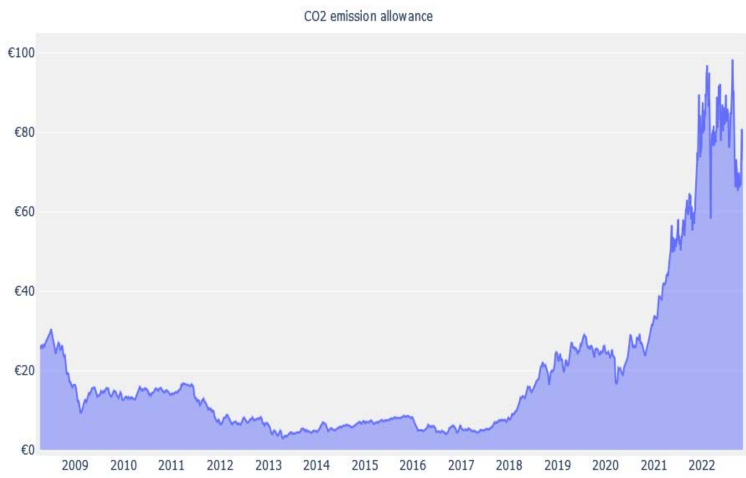
TE is the total emissions in kg of CO_2
F is the estimated fuel consumption (30 l/100km
EF_f is the fuel-specific emission factor (2.6008 kg/l)
D is the transportation distance in kilometers

The total project development and construction time for a large centralized waste-to-energy facility capable of handling 2,500 to 4,000 tons of waste per day is on average seven years, whereas smaller facilities take around two years to erect. Since the distributed facilities can be built simultaneously, they gain roughly five years of operational time.

Incinerating the organic waste matter prevents the anaerobic digestion process releasing methane, which is a greenhouse gas 25 times more potent than CO_2. Based on daily waste deposition of 2,500 tons, the GHG saving in $eqCO_2$ is over 4,000 tons, equaling 1,300,000 tons per annum. These savings are only valid for the five-year interval between the plant erection times.

The carbon emission trading is a market-based method of controlling pollution generation. It has been adopted by most developed countries and is gradually spreading across the globe. Although none of the emission trading systems currently include road transportation emissions, a theoretical value can be given to them as well.

The value of the emission allowances (one ton of $eqCO_2$) has experienced a sharp rise recently, up from a long-time average of $10.00 per allowance to current $72.00. Using this recent contract price yields values for transportation and methane emissions as $159,000 and $93,600,000 respectively.



The transportation savings between the centralized and decentralized waste-to-energy solutions are directly attributable to the shorter routes

- less fuel consumption
- less working hours
- less vehicles
- less maintenance

The annual savings amount to

- 2018; $1,800,000
- 2030; $5,940,000

In 2030, the decentralized model requires 81 less trucks and 440 less personnel than the centralized one. To put it another way, the 4,000 tons per day in 2030 can be collected with the same resources it takes to transport all the waste to Dandora in 2018.

The transmission savings are mainly attributable to the lack of transmission losses in the decentralized model. The rest are the depreciation and O&M of the centralized power plant transformer and transmission lines. The annual savings amount to

- 2018; $2,860,000
- 2030; $2,960,000

Savings

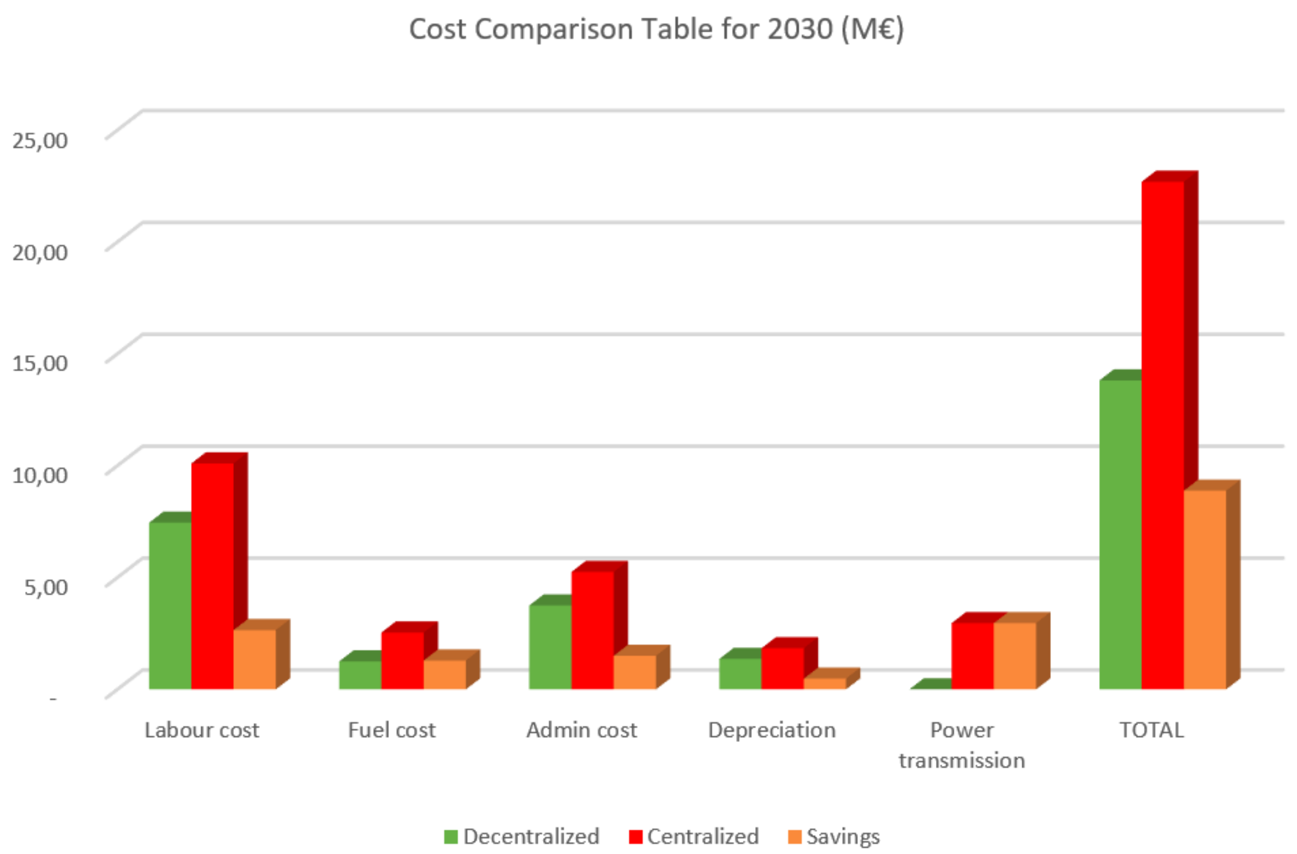
The total savings of the decentralized waste management and power generation model compared to the centralized one are a combination of transportation savings and power transmission savings. These approximately add up to

- 2018; $4,660,000
- 2030; $8,900,000

Over the time period of 12 years in the study, the accumulated savings amount to $83,550,000 or 39% of the total cost. The above values assume an annual inflationary increase of 5% on all the costs.

Forecasting the value of future savings attributable to cost items that are unknown, mainly labor cost and oil price, is difficult with any accuracy. When looking at historical data, the oil price volatility alone in the past eight years has been 37%. This is where the Monte Carlo simulation will help in producing the most likely outcome of future events to help make better decision today.

Based on the simulation, the generated savings will be between $60,270,000 and $145,560,000 with 90% probability.



Other Benefits

The decentralized waste-to-energy model is not only a financially sound solution, but it also generates several other tangible and intangible benefits, such as

- increased recycling to save virgin raw materials
- higher waste collection rates at decreasing cost
- more flexibility in the waste collection and transportation
- significantly reduced water, land and air pollution attributable to waste
- positive health implications with less vermin and rodents
- visual benefits due to less waste deposits

The small-size WtE facilities offer a chance for cost-efficient experimentation on whether waste incineration can be the right solution for the area / country. Due to their small footprint, modular structure and high level of pre-fabrication, they require less design and engineering, have faster permitting processes and will be up and running much faster than traditional plants.

Since the power generation is distributed around the city closer to the end-users, the facilities can offer exactly the type of energy that the local community demand; electricity, steam or thermal energy as heating or cooling. Combining this with material recycling offers new SMEs a viable growth platform.

Many large cities, including Nairobi, are stuck with an old landfill located right in the middle of the city. They were originally established on the outskirts of the town, but rapid growth has left them locked within the city limits.

Existing landfills are equally as good a fuel source for the WtE facilities as newly generated waste. Landfilled waste is fed through the pre-sorting plant, where recyclables and inert materials are removed. The already composted soil is put aside for later landscaping purposes and the inorganic material incinerated for energy. The former landfill can be redeveloped for e.g. housing or recreational purposes.

Discussion

This study still leaves room for further waste-to-energy generation decentralization optimization. Some key elements could be

- *Number of WtE facilities.* Now the number was predefined as six locations each using ~400 tpd of waste and delivering $6MW_e$. The plants could be further distributed to 10 or even 15 locations.
- *WtE facility locations.* Only one round of optimization was done regarding the locations. Combining locations, number of plants and route selection would yield better results.
- *Use of transfer stations.* Pre-sorting the waste in localized transfer stations and only transporting the non-recyclable material could be studied.
- *Waste treatment solutions.* Only waste pre-sorting and incineration solutions were considered. E.g. biogasification and composting could also be studied as complementary solutions.
- *Generated energy commodities.* The study concentrated in electricity generation, although steam or thermal energy might have more demand from local industrial off-takers.
- *Land ownership and cost.* Land title and cost for the power plants and transmission lines could prove a major hurdle in the planning.
- *Truck size.* Only eight-ton-capacity trucks were considered in the study. The distributed model could even make due with one-ton trucks.
- *Route selection.* Only main roads were used in the route optimization. Adding lower category roads would likely generate additional savings.
- *Waste collection timing.* It was assumed that all waste was transported during the normal day shift. Especially the short-route localized collection and transportation could be done outside the rush hours.
- *Impact of congestion.* Both models used the same static truck speed values independent of the time of day. A dynamic VRSP would also consider the impact of rush hours.
- *Ability to relocate.* As the city evolves, the small WtE facilities could be relocated to support the urban planning scheme.
- *Financing costs during construction period.* Especially the centralized model suffers from financing costs during the 5-to-7-year construction period.

Each of the above factors support the decentralized model more than the centralized one, thus creating additional savings and benefits.

"In the next 12 years, the decentralized waste-to-energy solution would save the City of Nairobi in total over USD83.5 million"

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