IJEEP

INTERNATIONAL JOURNAL OF ENERGY ECONOMICS AND POLICY

EJ EconJournals

ISSN: 2146-4553

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2017, 7(4), 291-301.

EJ EconJournals

Cloud Based Solid Waste Transportation Optimisation for Energy Conversion

Palanichamy Naveen[1]*, Wong Kiing Ing[2], Michael Kobina Danquah[3], A. Abu-Siada[4], Amandeep S. Sidhu[5,6]

[1]Department of Electrical and Computer Engineering, Faculty of Engineering and Science, Curtin University, CDT 250, 98009 Miri, Sarawak, Malaysia, [2]Faculty of Engineering and Science, Curtin University, CDT 250, 98009 Miri, Sarawak, Malaysia, [3]Faculty of Engineering and Science, Curtin University, CDT 250, 98009 Miri, Sarawak, Malaysia, [4]Department of Electrical and Computing Engineering, Curtin University, Perth, Australia,[5]Curtin Sarawak Research Institute, Curtin University, CDT 250, 98009 Miri, Sarawak, Malaysia, [6]Faculty of Health Sciences, Curtin University, Perth, Australia. *Email: navp80@gmail.com

ABSTRACT

Effective and efficient management of solid waste is an incessantly growing and the obdurate problem of global and regional levels particularly for local authorities in urban centers. Several processes such as monitoring, collection, transporting, processing, recycling, and disposal are involved that requires immediate attention owing to economic and environmental concerns. Expressly the gathering and moving of solid waste to the energy production/recycling/ending destination has been prioritized higher because of its significant share of the total waste management budget. All these processes involve the mammoth amount of data and their manipulation for real-time use. Hence, this paper proposes a cloud based algorithm to optimize the transportation cost of solid waste from transfer stations to the final dumping stations subject to transfer vehicle constraints. The solid waste transportation dispatching is a direct analytical approach that provides three options: (i) Economic dispatch option provides a minimum operating cost of solid waste transfer and its corresponding emission; (ii) emission dispatch option provides a minimum vehicle emission for the same quantity of the solid waste transferred and its corresponding operating cost of transfer and finally (iii) an environmentally friendly economic transfer of solid waste. The efficacy of the algorithm has been shown with an enduring solid waste management system in the Indian context.

Keywords: Cloud, Economic and Environmental Concerns, Solid Waste Transportation
JEL Classifications: B41, C61, C88, R41

1. INTRODUCTION

Solid waste produced by inhabited, manufacturing, business, and commercial accomplishments is inextricably concomitant to population growth, public habits, urbanization, economic development, and local climate, etc. At present, the total amount of worldwide annual solid waste generated (from municipal, industrial and hazardous sources) is beyond 4 billion tons. The municipal solid waste (MSW) share of this is 1.6-2.0 billion tons, and owing to industrialization, increase in population and gross national income growth, noteworthy increases in these quantities are anticipated in developing countries (Hoornweg and Bhada-Tata, 2012; Nnaemeka and Kyung-Jin, 2015; Thomas, 2016). While, considering the MSW management, nearly 70% of the waste generated is disposed of in landfills (commonly in uncontrolled open dump sites), 11% is treated in waste-to-energy facilities, and the remaining is recycled including composting. It is appraised that over half of the worldwide populace does not have access to the rudimentary waste handling and controlling services like regular waste gathering and controlled disposal. The problem is predicted to become shoddier in urban areas owing to the rapid urbanization that might take place in the next 15-20 years (Chalmin and Gaillochet, 2006; Prasad et al., 2009).

The quantity of waste and waste composition have been increased in recent years due to the tremendous rise in global population, rapid industrialization, and sub-urbanization. The effect on waste production in developing countries is much pronounced, and it is expected to exceed a kilogram a day (UNEP, 2005; Wadim et al., 2013; World Bank, 2012). By 2050, in industrialized nations, around 85% of residents in urban areas share a notable amount of waste generation whereas, in developing nations, around 65% of residents contribute more than a kilogram a day (Palanichamy et al., 2015; UNPD, 2012). Due to the increase in urban residents, the density of urban population has increased resulting in life discomfort, the availability of land and land-use have become a bottleneck for their economic growth, and garbage collection and disposal have become a daily challenge for them. Apart from the huge amount of waste generation, the composition of the generated waste has been considerably changed from the past. The electronic wastes, medical wastes, and perilous wastes, etc. are a few examples of the waste generated in recent days (Ebenezer et al., 2013; Narayana, 2008; UNEP, 2000). Because of the rise in waste generation, and the harmful waste compositions, the existing waste handling schemes have become inadequate, and inefficient. As one of the waste management tasks, this paper presents a cloud based transportation optimization strategy for solid waste transfer from transfer stations to the final disposing point subject to economic and environmental constraints.

2. MSW TRANSPORTATION

The major expense on the waste handling schemes is the collection of MSW from the inhabitants' premises and moving them to the processing unit or to the disposal point. It can represent between 40% and 70% of the waste management system cost (Hoornweg and Bhada-Tata, 2012; World Bank, 2012; UNITAR, 2012; UN-HABITAT, 2010). The general concerns in solid waste collection and transport are:

- Derisory cooperation from public with the collection schedules and systems,
- Usage of incongruous kind and dimension of gathering trucks,
- Adopting irrational paths for waste gathering purpose,
- Impracticable crew size and shift duration,
- Derisory up keeping of vehicles, and poor vehicle body conditions,
- Long transportation times to final destinations,
- Spill-over of waste on the transferring routes, and
- Punitive driving conditions.

It is judicious to cogitate that even minor enhancements in this area can result in substantial financial savings. Moreover, these transportation procedures conjecture the existence of significantly higher fuel consumption and pollutant emissions since the activities involved are performed by heavy-duty road vehicles. Thus, noteworthy benefits can be resulting from the optimization of transportation of solid wastes.

2.1. Transportation Cost Optimization

The transportation cost is characterized as fixed cost and variable cost. Geographical conditions, nature of infrastructure, managerial margins, and energy usage, etc. (UN-HABITAT, 2010; Zdena et al., 2013; Mousa et al., 2013; Burhamtoro et al., 2013; Hummels, 2007) govern the magnitude of the transportation cost. The major component of the variable cost of the solid waste transportation is the cost of fuel consumed. The fuel consumption depends on the transportation vehicle routing which aims at optimizing the travel duration and travel distance (Hummels, 2007; Jie and Yanfeng et al., 2012; Murat et al., 2014; Komilis, 2008; Laporte, 2000; Kuo and Wang, 2011; Apaydin and Gonullu, 2008). Currently, environmental concern has higher priority and the emission from the vehicles need to be minimized by appropriate fuel consumption.

The fuel consumption by the transportation vehicles is affected by many factors such as:

- Vehicle type
- Vehicle size
- Aging of the vehicle
- Vehicle speed and travel time
- Type of fuel used
- Quantity of waste
- Waste transfer distance
- Travel route and road condition
- Road traffic and number of stops and starts
- Driving skill
- Proper garage for vehicles to protect vehicles from wear and tear, and
- Preventive maintenance schedule of the vehicles.

All the measures discussed, if properly accounted, would result in the economic operating cost of the solid waste transportation system with environmental concern.

3. CLOUD'S SIGNIFICANCE IN OPTIMIZATION

3.1. Cloud Computing Model

Cloud computing or simply "the cloud" is the advanced IT based delivery model of computing resources on demand. The cloud services are such that the customers (end users) pay for the services provided by the cloud providers without any infrastructural investments by the end users (Adel, 2014). Figure 1 shows the basic structure of the cloud model, wherein the end users and cloud providers are interconnected through the internet.

3.2. Cloud Application Services

The cloud service has commonly three models such as Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS) users (Adel, 2014; Amjad et al., 2016) as in Figure 2. Depending upon the requisite, the end user can go for any of the three models.

IaaS is the basic layer in cloud computing model providing the infrastructures such as virtual machines and additional assets alike load balancers, IP addresses, and virtual local area networks, etc. Amazon Web Services, Microsoft Azure, and Google Compute Engine are some common examples of IaaS.

PaaS as a service model offers computing platforms that classically contains operating systems, programming language execution environment, database, and web server. It is the second layer on top of IaaS. Windows Azure, Google App Engine, and Apache Stratos are some common examples of PaaS.

Figure 1: Cloud model

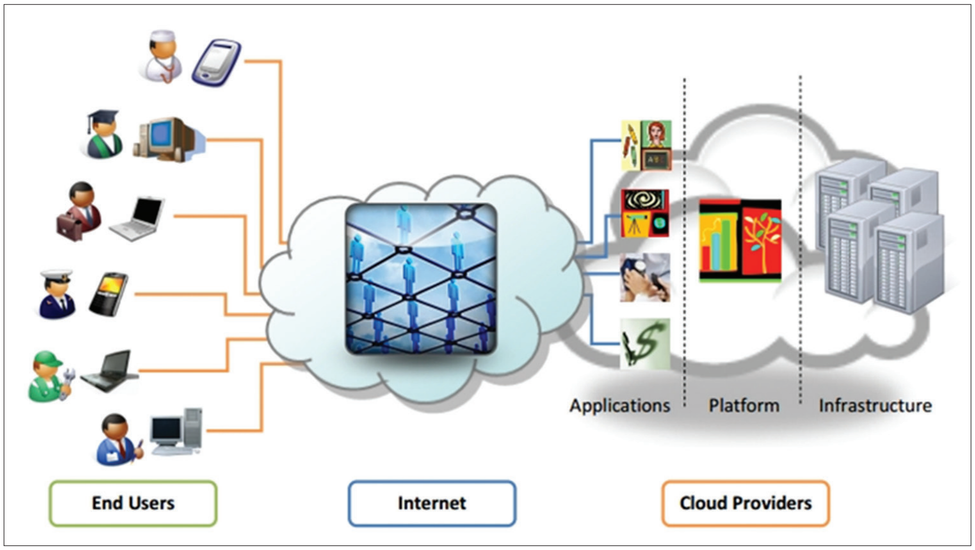
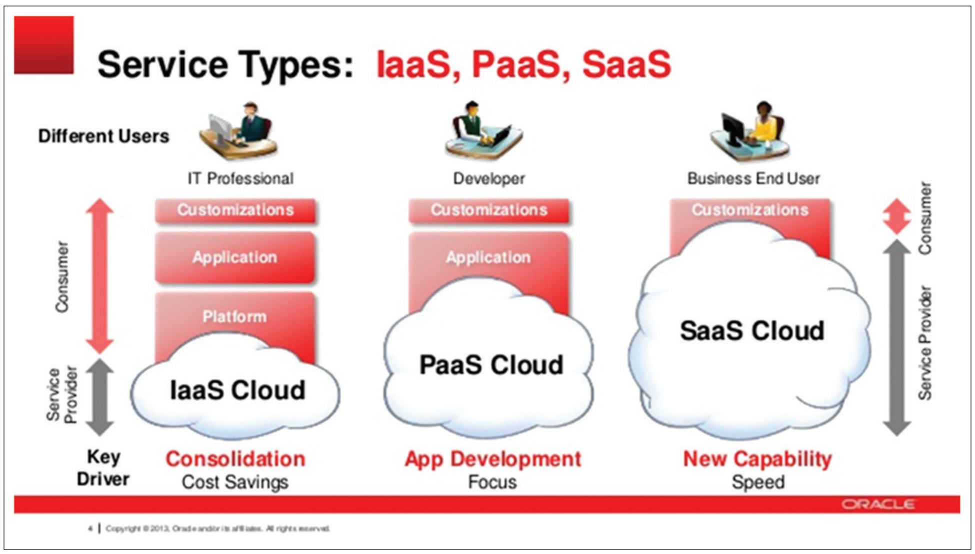


Figure 2: Service types



SaaS provides access to application services installed at a server. No botheration for the end user about the installation, maintenance or coding of that software since it is taken care of by the cloud provider. The end user has to pay for the usage only. Microsoft office 365, Google Apps, and Gmail are some common examples of SaaS.

3.3. Cloud's Suitability

Increased waste generation affects the solid waste management systems in a nous that the MSW generated has to be handled in an environmentally and economically supportable way. In conventional methodologies, trucks normally follow static routes which are usually planned without taking into account real-time data of the particular containers, but only using general considerations and historical data. As intelligent solid waste management is the need of the day, it is composed of different kinds of technologies and several tools and services based on them. It offers several possibilities for optimizing the process of collection and transportation and make up a robust solution which is able to use all the data reported in real-time.

The intelligent management involves a huge amount of data such as the quantity of waste generated in different localities, the waste collection mechanism, the quantity and quality of transportation systems, the dumping site conditions, the recovery/treatment and the disposal, etc. It also involves the various stakeholders like the city/district administration, weather stations, pollution control boards, citizens, traffic police, waste trucks owning companies, waste truck drivers, managers of dumps and recycling factories, etc. So as to manage the huge amount of data and a large number of stakeholders on a real-time basis, an intelligent system such as a cloud is more appropriate. Though there are three models of cloud services, the SaaS model is preferred due to its access flexibility, simplicity, and cost-effectiveness.

4. PROPOSED TRANSPORTATION OPTIMIZATION STRATEGY

In electric power systems, generation scheduling is the common method of optimizing the generation cost of electricity to meet the power demand subject to equality and inequality constraints. For doing so, quadratic cost functions are used involving the power generation output as shown in equation (1).

$$F_T = \sum_{i=1}^{n}\left(a_i P_{Gi}^{\;2} + b_i P_{Gi} + c_i\right) \quad \$/h \qquad (1)$$

Where,
F_T: Total generation cost or fuel cost ($/h),
P_{Gi}: Power generation of plant i (MW),
a_i, b_i, c_i: Generation cost coefficients of plant i, and n: Number of generating plants.

In the solid waste transportation problem, the transportation vehicles use mostly fossil-fueled engines; hence the operating cost curves applicable to electric power systems are ideally suited for representing the operating cost of the transportation vehicles.

4.1. Objective Function

Principally, the cost of transportation has two components such as fixed costs (infrastructural) and variable costs (operational). This is otherwise known as the total operating cost which is the sum of the depreciation costs, interest rates, insurance costs, cost of fuel, cost of engine lubricants, tyre costs, maintenance costs, driver wages, overhead, etc. and each one is influenced by the speed of the vehicle and the load of the vehicle. This paper considers the solid waste dumped on the vehicle as the load and the optimization is preceded considering the load as the variable factor. Hence the objective function is written as:

$$TC_T = \sum_{i=1}^{n} TC_i = \sum_{i=1}^{n}\left(a_i W_{Di}^{\;2} + b_i W_{Di} + c_i\right) \quad \$ \qquad (2)$$

Where,
TC_T: Total operating cost ($),
TC_i: Operating cost of vehicle, i ($),
W_{Di}: Load of vehicle, i (Metric Ton),
a_i, b_i, c_i: Transportation cost coefficients of vehicle i, and n: Number of vehicles.

The essential operational constraints are the load balance constraint, where the total load at the transfer station must be equal to the load transferred to the dumping site plus the solid waste losses during transportation, and the vehicle loading capacity constraints, where individual vehicles must be operated within their specified loading capacity. Or in other words, the solid waste transportation is optimized subject to:

i. Load balance constraint (ignoring losses)

$$\sum_{i=1}^{n} W_{Di} = W_D \quad \text{Tons} \qquad (3)$$

Where, W_D: Total load at the transfer station (Tons), and

ii. Vehicle loading capacity constraints

The load on each vehicle, W_{Di} is constrained by its maximum limit, i.e.,

$$W_{Di} \le W_{Dimax} \qquad (4)$$

Where, $W_{Di\,max}$: The maximum loading capacity of vehicle i.

4.2. Optimum Load Sharing - Economic Dispatch

The incremental cost of dumped load at the transfer station is given by:

$$dTC_i/dW_{Di} = \lambda = 2a_i W_{Di} + b_i \quad \$/\text{Ton} \qquad (5)$$

or

$$W_{Di} = \lambda\,(1/2a_i) - (b_i/2a_i) \quad \text{Tons} \qquad (6)$$

From (6), the total load at the transfer station or total load dumped on all vehicles is obtained as:

$$\sum_{i=1}^{n} W_{Di} = W_D = 1\sum_{i=1}^{n}\left(1/2a_i\right) - \sum_{i=1}^{n}\left(b_i/2a_i\right) \qquad (7)$$

Let $k_1 = \sum_{i=1}^{n}\left(b_i/2a_i\right)$ and $k_2 = \sum_{i=1}^{n}\left(1/2a_i\right)$, then (7) becomes,

$$W_D = \lambda k_2 - k_1 \quad \text{Tons} \qquad (8)$$

or

$$\lambda = (W_D + k_1)/k_2 \quad \$/\text{Ton} \qquad (9)$$

Substituting the value of λ in (6) and rearranging gives the optimum load on the individual vehicles.

$$W_{Di} = (W_D + k_1 - b_i k_2)/2\,a_i k_2 \quad \text{Tons} \qquad (10)$$

The constants k_1 and k_2 are the functions of the operating cost coefficients. The equivalent operating cost equation of n-vehicles operating in parallel to meet the load, W_D can be obtained by substituting (10) in (1) and mathematical manipulations as in Palanichamy et al. (2014) result in a single equivalent operating cost function of all vehicles in terms of the operating cost coefficients, and the load as in (11).

$$TC_T = AW_D^{\;2} + BW_D + C \quad \$ \qquad (11)$$

Where, $A = \sum_{i=1}^{n} 1/4a_i k_2^2$; $B = \sum_{i=1}^{n} k_1/2a_i k_2^2$ and

$$C = \sum_{i=1}^{n}\left\{\left(1/4a_i\right)\left(k_1^2/k_2^2 - b_i^2\right) + c_i\right\}.$$

Equation (11) is the total operating cost of solid waste transportation without considering the losses while transporting.

4.3. Solid Waste Losses during Transportation

The entire quantity of waste dumped into a vehicle is not transferred to the dumping site in most of the cases. Some portion of the waste is lost during transportation that depends on the body built of the vehicle, the vehicle running condition, the road conditions, the climatic conditions, the driving skill of the driver, and covered or open transfer status, etc. Based on transmission loss evaluation of power systems, a way of representing transmission loss is suggested for estimating the solid waste losses during transportation is by means of transmission loss B-coefficients (Palanichamy and Sundar, 2008).

$$W_{TL} = \sum_{i=1}^{n}\sum_{j=1}^{n} W_{Di} B_{ig} W_{Dj} \quad \text{Tons} \tag{12}$$

Where,
W_{TL}: Solid waste losses during transportation (Tons),
B_{ij}: Transmission loss coefficients,
W_{Di}: Load of vehicle, i (Tons) and
W_{Dj}: Load of vehicle, j (Tons).

Since $W_{Di} = (W_D + k_1 - b_i k_2)/2a_i k_2$ by (10), then load of vehicle, j is $W_{Dj} = (W_D + k_1 - b_j k_2)/2a_j k_2$.

Substituting W_{Di} and W_{Dj} in (12) and simplifying, the equation for solid waste losses during transportation, W_{TL} becomes,

$$W_{TL} = (\alpha W_D^2 + \beta W_D + \gamma) \quad \text{Tons} \tag{13}$$

Where,

$$\alpha = \left(1/4k_2^2\right)\{\sum_{i=1}^{n} B_{ii}/a_i^2 + 2\sum_{i\neq j}^{n} B_{ij}/a_i a_j\}$$

$$\beta = \left(1/4k_2^2\right) \{2\sum_{i=1}^{n}\left(k_1 - b_i k_2\right) B_{ii}/a_i^2 +$$

$$2\sum_{i\neq j}^{n}\left[2k_1 - k_2\left(b_i + b_j\right)\right] B_{ij}/a_i a_j\}\left(k_1 - b_i k_2\right)$$

$$B_{ii}/a_i^2 + \sum_{i\neq j}^{n} 2\left[2k_1 - k_2\left(b_i + b_j\right)\right] B_{ij}/a_i a_j\}$$

$$\gamma = \left(1/4k_2^2\right)\{\sum_{i=1}^{n}\left(k_1 - b_i k_2\right)^2 B_{ii}/a_i^2 +$$

$$2\sum_{i\neq j}^{n}\left(k_1 - b_i k_2\right)\left(k_1 - b_j k_2\right) B_{ij}/a_i a_j\}$$

In (13) the coefficients α, β and γ are functions of the constants k_1, k_2 and the transmission loss coefficients. Once the total load at the transfer station is known, transmission loss can be readily calculated by (13) and the quantity of waste possible to be delivered at the dumping site becomes a known factor.

4.4. Load Received at the Dumping Site

The total load received at the dumping site, W_R must be equal to total load dumped into the vehicles at the transfer station minus the solid waste losses during transportation.

$$\text{i.e., } W_R = \sum_{i=1}^{n} W_{Di} = W_D - W_{TL} \quad \text{Tons} \tag{14}$$

Substituting (13) in (14) and simplifying,

$$W_R = -aW_D^2 + W_D(1-b) - \gamma \quad \text{Tons} \tag{15}$$

Hence (15) expresses the total load received at the dumping site, W_R in terms of total load dumped into the vehicles at the transfer station, W_D and the solid waste losses during transportation. The load received from an individual vehicle, W_{Ri} at the dumping site after the transportation losses is then given by,

$$W_{Ri} = (W_R + k_1 - b_i k_2)/2a_i k_2 \quad \text{Tons} \tag{16}$$

The total vehicle emissions shall be obtained following the subsequent equations from Section 5. Since the objective of this optimization is transporting operating cost minimization, the emission would be higher, in this case.

5. TRANSPORTATION WITH ENVIRONMENTAL CONCERN

The majority of the solid waste transportation is of diesel-fueled vehicles which are prone for environmental pollutions. Moreover, they are 8-10 years old and they are less efficient. In actual fact, older vehicles, especially with low fuel efficiency pollute more than fairly new vehicles.

Moreover, day-night weather conditions play a significant role in local pollution concentration (Palanichamy and Natarajan, 2002). During the sunlight period, the hot air scatters the pollutants in a substantial amount of space at high altitude, which is harmless; and also diminishes the local absorption of the pollutants in the neighborhood of the polluting sources such as the MSW transportation vehicles, and nearby cities and towns. At night, thermal inversion happens when a layer of hot air settles over a layer of cooler air that lies near the earth. The warm air grasps down the cool air and averts the vehicle emissions from rising and scattering. If stagnated air circumstances happen during the night, the vehicle emissions concentration spreads an exceptionally dangerous level. So pollution control becomes inevitable; hence solid waste transportation needs to be scheduled in such a way that their exhaust emission is minimum.

5.1. Emission Dispatch

The objective of emission dispatch is to optimize the emissions of polluting sources such as power systems, industries, transports, etc. while operating [30]. Particularly, the emission dispatch problem for fossil-fuelled sources such as the heavy-duty vehicles is defined as to minimize,

$$E_T = \sum_{i=1}^{n} E_{Ti} = \sum_{i=1}^{n}\left(d_i W_{Di}^2 + e_i W_{Di} + f_i\right) \quad \text{kg} \tag{17}$$

Where,
E_T: Total emission (kg),
E_{Ti}: Emission of vehicle, i (kg),
W_{Di}: Load of vehicle, i (Metric Ton),
d_i, e_i, f_i: Emission coefficients of vehicle i, and n: Number of vehicles.

The emission dispatching is performed like economic dispatch algorithm as discussed in Section 4 with the emission coefficients in the place of operating cost coefficients. Once the specific loads of the transportation vehicles are known, the entire operating cost, TC_T and the corresponding emission, E_T is determined. The dispatch outcome results in minimum emission at higher operating cost.

5.2. Environmental Friendly Economic Dispatch

MSW transportation subject to minimum operating cost and minimum emission has two different objectives; hence, two dispatches are needed. It is preferable to go for a compromised dispatch of achieving a moderate operation cost with an acceptable level of emissions. Such an algorithm is named as environmentally friendly economic transfer algorithm wherein the emission costs are integrated with the normal operating costs with the use of a price penalty factor (Palanichamy and Srikrishna, 1986).

The environmental friendly economic dispatching problem can be modeled as,

$$\Phi = \sum_{i=1}^{n}\left(a_i W_{Di}^2 + b_i W_{Di} + c_i\right) + h\sum_{i=1}^{n}\left(d_i W_{Di}^2 + e_i W_{Di} + f_i\right) \ \$ \quad (18)$$

Where,
Φ: Total cost ($),
W_{Di}: Load of vehicle, i (Metric Ton),
a_i, b_i, c_i: Transportation cost coefficients of vehicle i,
d_i, e_i, f_i: Emission coefficients of vehicle i,
h: Price penalty factor, $/kg, and
n: Number of vehicles.

Equation (18) can be rewritten concisely as:

$$\Phi = \sum_{i=1}^{n}\left(a_i + h\, d_i\right) W_{Di}^2 + \left(b_i + h\, e_i\right) W_{Di} + \left(c_i + h\, f_i\right) \quad (19)$$

Where, $(a_i + h\, d_i)$, $(b_i + h\, e_i)$ and $(c_i + h\, f_i)$ are the integrated cost coefficients. The price penalty factor for a given load, W_D shall be determined as,

- Step 1: Compute the value of $AW_D^2 + BWD + C$ ($) given by (11) with the transportation cost coefficients of vehicles, a_i, b_i, and c_i
- Step 2: Compute the value of $AW_D^2 + BW_D + C$ (kg) given by (11) with the emission coefficients of vehicles, d_i, e_i, and f_i
- Step 3: Obtain the ratio of the value of Step 1 and Step 2 to get the value of the price penalty factor, h ($/kg).

The environmental friendly economic dispatch algorithm is alike to the economic dispatch as discussed in Section 4 with the replacement of the operating cost coefficients by the integrated cost coefficients. When the specific loads of the vehicles are known, the total operating cost, TC_T and the corresponding emission, E_T can be found. It can be noticed that the total emission will be in less the emission of economic dispatch and the corresponding operating cost will be less than the operating cost of emission dispatch. The corresponding cloud based dispatching algorithm is presented in Figure 3.

6. APPLICATION TO A METROPOLITAN AREA

Chennai is a Metropolitan coastal city, the capital of the Tamil Nadu state. The Chennai Metropolitan Area (CMA) (CMDA, 2015) encompasses the Metro city (426 km^2 area and 6.5 million populations), 16 municipalities, 20 town panchayats and 214 village panchayats in 10 panchayat unions. The extent of CMA is 1189 km^2. Chennai urban area had a population of about 8.8 million in 2011 (Ministry of Urban Development, 2013). Chennai Corporation area is alienated into several zones and each zone is further sub-divided into about 15 divisions. The Corporation of Chennai is gathering around 5200 Tons/day (per capita generation is 700 g/day) of MSW. There are 11 solid waste transfer stations and two open landfill sites viz. Kodungaiyur and Perungudi. Solid wastes collected daily are transferred to the transfer stations and it is ensured that they are transported to the dumping sites thereafter within 24 h (CMDA, 2015; Corporation of Chennai, 2013). Both sites are in operation for >25 years and reaching their designed lifetime; seriously loaded and become harmful to nearby inhabitants.

The optimization strategy has been applied to the solid waste transfer from a city business center transfer station to the Perungudi dumping site. The daily average amount of waste received at the transfer station is 54 Tons and the distance between the transfer station and the dumping site is 19 km (to and fro). The duration to deliver the waste from the transfer station is approximately 30 min during the traffic peak hours 7.30-11.30 am and 4.30-9.30 pm.

For solid waste transportation from, transfer stations to dumping sites, lorries or dippers of capacities 6-12 tons are generally preferred in Chennai. Following the prevailing practice, three open lorries of each 6 tons' capacity with the aging of 6-9 years are chosen. Figure 4 shows the pictorial representation of the model vehicles, a transfer station and the dumping site of Chennai. Table 1 portrays the transportation cost or the operating cost coefficients (the cost of fuel, lubricants, maintenance, driver salary, depreciation, insurance, interest, and overheads, etc.), and the CO_2 emission coefficients of the vehicles identified. The other emissions are not considered for simplicity and clarity since their dispatching consideration is similar to the CO_2 emission.

The transportation cost equations of the vehicles are:

- Lorry 1: $TC_1 = 0.2012\ W_{D1}^2 + 2.0095\ W_{D1} + 38.3595$ $
- Lorry 2: $TC_2 = 0.2555\ W_{D2}^2 + 2.4339\ W_{D2} + 35.3260$ $
- Lorry 3: $TC_3 = 0.2479\ W_{D3}^2 + 2.3127\ W_{D3} + 39.0617$ $

And the corresponding CO_2 emission equations are:

- Lorry 1: $E_{T1} = 0.0650\ W_{D1}^2 + 0.8163\ W_{D1} + 49.24$ kg
- Lorry 2: $E_{T2} = 0.0520\ W_{D2}^2 + 0.9818\ W_{D2} + 53.53$kg
- Lorry 3: $E_{T3} = 0.0470\ W_{D3}^2 + 0.8468\ W_{D3} + 51.49$kg

The route for the waste transportation is fixed and the same vehicles need to operate repeatedly until the entire waste from the transfer station is transported to the dumping site at a fixed speed of 20 km/h. During transportation, depending on the body built of the vehicle, the vehicle running condition, the road conditions, the climatic conditions, the driving skill of the driver, and covered or open transfer status, etc., some portion of the waste is lost. Hence the quantity of waste received at the dumping site is usually

Figure 3: Cloud based dispatching algorithm

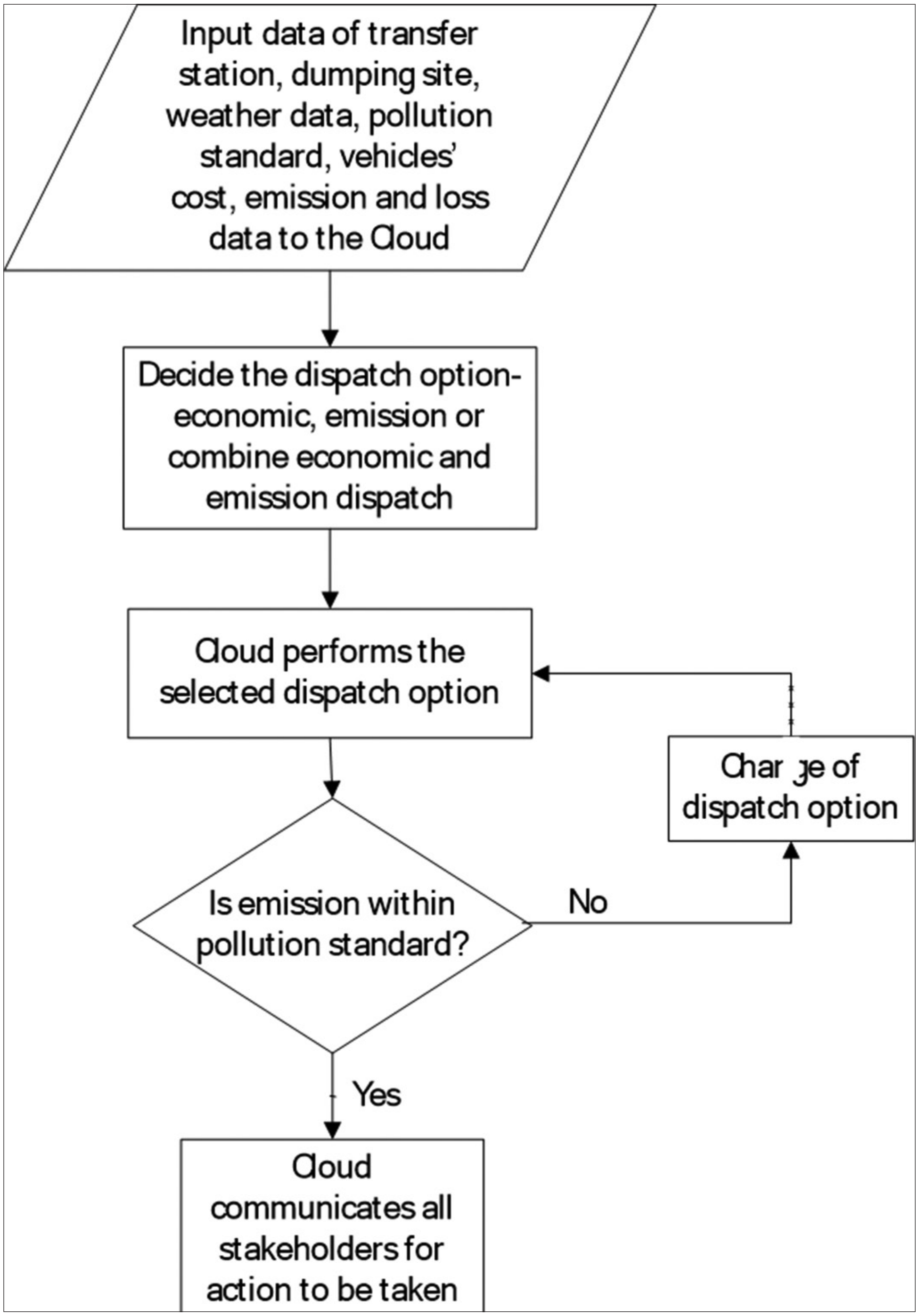


Table 1: Transportation vehicle parameters

Transport	Transportation cost coefficients			CO_2 emission coefficient		
	a_i ($/Ton²)	b_i ($/Ton)	c_i ($)	d_i (kg/Ton²)	e_i (kg/Ton)	f_i (kg)
Lorry 1 6 years old, 6T capacity	0.2012	2.0095	38.3595	0.0650	0.8163	49.24
Lorry 2 9 years old, 6T capacity	0.2555	2.4339	35.3260	0.0520	0.9818	53.53
Lorry 3 8 years old, 6T capacity	0.2479	2.3127	39.0617	0.0470	0.8468	51.49

less than the waste loaded on the vehicles at the transfer station. Considering all the above factors, the transportation (transmission) loss coefficients of the three lorries are found to be as shown in Table 2.

Figure 4: Transportation

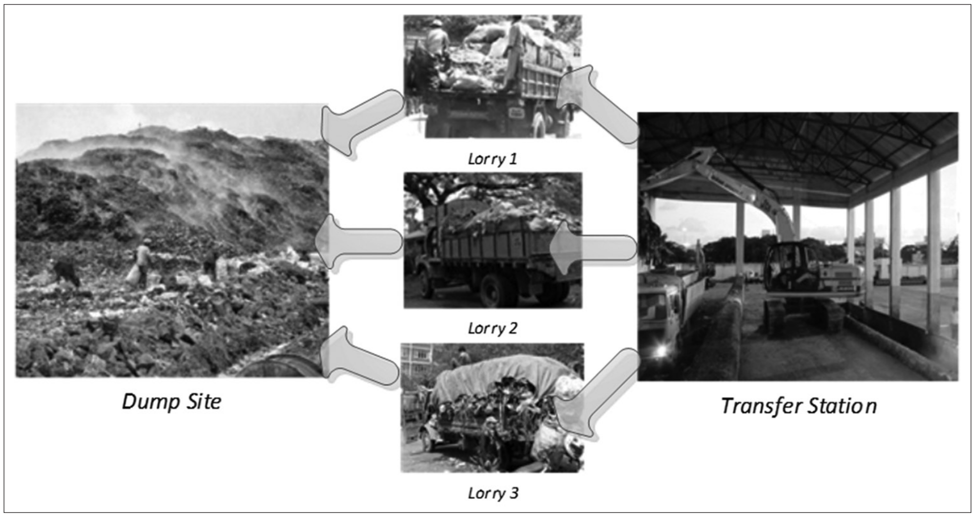


Table 2: Transmission loss coefficients

	1	2	3
1	0.0065		
2		0.0082	
3			0.0073

6.1. Economic Dispatch Outcome

Since solid waste management is budget constrained, economic dispatching has been performed and the dispatch outcome is presented in Table 3. Though all the vehicles are of the same capacity, the optimal loading of the vehicles is different variations from 15.97 Tons to 21.33 Tons. Particularly Lorry 1 shares the maximum load since its operating cost is the lowest compared to the other two vehicles. Lorry 2 shares the minimum load as its operating cost is the highest among all. The transportation loss of the solid waste incurred also varies from 2.15 Tons to 2.72 Tons and the total loss of waste is found to be 7.08 Tons (13.11% of the total load). As far as CO_2 emission owing to the waste transfer is concerned, Lorry 3 emits less and Lorry 1 emits the highest. Though the optimal loading of Lorry 3 is higher than Lorry 2, its corresponding CO_2 emission is lesser than that of Lorry 2 since its emission characteristic is lesser than that of Lorry 2. Lorry 1 emits the highest owing to its higher load share compared to the rest. Lorry 1 has to perform 4 to and fro replete trips of solid waste; Lorries 2 and 3 ought to accomplish individually 3 to and fro awash trips since their maximum loading capacity is 6 Tons only. The total operating cost of 54 Tons of solid waste transfer is found to be \$ 458.94 and the corresponding total CO_2 emission is 257.43 kg. Another way of the performance evaluation is based on the operating cost of the vehicles in terms of cost of transporting 1 Ton of solid waste to a distance of 1 km (\$/Ton/km) and the CO_2 emission while transporting 1 Ton of solid waste to a distance of 1 km (kg/Ton/km). For Lorries 1, 2, and 3, these values are found to be 0.1066 \$/Ton/km, 0.1531 \$/Ton/km, and 0.1542 \$/Ton/km (operating cost) and 59.36 g/Ton/km, 90.59 g/Ton/km, and 82.72 g/Ton/km (CO_2 emission) respectively. From the economic dispatch outcome, it is palpable that the optimum loading capacities, the operating cost, and the emissions are dissimilar for the different vehicles, though they have the same maximum loading capacity.

6.2. Emission Dispatch Outcome

The emission dispatch is performed to minimize the pollutants from the Lorries intended for transferring the solid waste from the transfer station to the dumping site. Since fossil-fuelled Lorries emit a righteous amount of CO_2, the local pollution concentration level gets altered and it might violate the stipulated limit set by the state pollution control board. A contemporary analysis of Chennai's air quality (Papia, 2013), done by Centre for Science and Environment, indicates that though Chennai experiences deceivingly moderate pollution echelons owing to its location nigh the sea, local impacts and revelation are high and the pollution levels are accruing steadily, consequently increasing public health menaces. Besides, day-night weather conditions of Chennai play a momentous role in local pollution concentration. So pollution control becomes preordained; hence solid waste transportation needs to be scheduled in such a way that their exhaust emission is minimal.

When transportation budget is not an issue and environmental apprehension has the priority, emission dispatch befits crux to meet the threshold emission standard. For the same quantity of transferring 54 Tons of solid waste, emission dispatching has been performed and the results are depicted in Table 4. The total operating cost is found to be \$471.26 and the corresponding total CO_2 emission is 254.14 kg. With respect to economic dispatch, an increase in operating cost of \$ 12.32 and a reduction of 3.29 kg of CO_2 is noticed. Mainly Lorry 3 shares the maximum load since its emission characteristics are the lowest compared to the other two vehicles and Lorry 1 shares the minimum load as its emission characteristic is the highest among all. As far as the number of to and fro trips are concerned, Lorries 1 and 2 needed to perform individually three trips and Lorry 3 ought to accomplish 4 inundated trips since their maximum loading capacity is 6 Tons only. For Lorries 1, 2, and 3, the cost of transporting 1 Ton of solid waste to a distance of 1 km realized as 0.1333 \$/Ton/km, 0.1569 \$/Ton/km respectively, and 0.1233 \$/Ton/km (operating cost) and the corresponding CO_2 accounted to be 88.00 g/Ton/km, 86.53 g/Ton/km, and 56.43 g/Ton/km respectively. From the economic dispatch and emission dispatch outcomes, it is perceptible that the optimum loading capacities, the operating cost, and the emissions are disparate for the different vehicles, though they have the same maximum loading capacity.

6.3. Environmental Friendly Economic Dispatch Outcome

From the economic and emission dispatch outcomes, it is conspicuous that operation cost is lower and emission level is higher in the economic dispatch whereas it is vice versa in the emission dispatch. The environmental friendly economic dispatch algorithm is akin to the economic dispatch with the only difference that the operating cost coefficients are supplanted by the blended (integrated) cost coefficients. The blended cost coefficients are calculated as exemplified below:

- Step 1: The equation of $AW_D^2 + BWD + C$ (\$) given by (11) with the transportation cost coefficients of vehicles, a_i, b_i, and c_i is 0.0774 W_D^2 + 2.2328 WD + 112.6392 and its value is \$ 458.94.
- Step 2: The equation of $AW_D^2 + BW_D + C$ (kg) with the emission coefficients of vehicles, d_i, e_i, and f_i is 0.0179 W_D^2 + 0.8849 W_D + 154.1890 and its value is 254.14 kg
- Step 3: The ratio of the value from Step 1 and the value from Step 2 gives the value of the price penalty factor, h (\$/kg) as 1.78 \$/kg
- Step 4: The blended cost coefficients are calculated by using the expressions ($a_i + h\ d_i$), ($b_i + h\ e_i$) and ($c_i + h\ f_i$) from (19).

The environmental friendly economic dispatch has been performed in a similar manner as the economic dispatch with the blended cost coefficients and the dispatch outcome has been presented in Table 5.

The operating cost for transferring 54 Tons of MSW from the same transfer station to the same dumping site through the same route

Table 3: Economic dispatch outcomes

Item	Lorry 1	Lorry 2	Lorry 3	Total waste loaded at transfer station, (Tons)	Total waste received at dumping site (Tons)	Total transmission loss (Tons)	Total operating cost (\$)	Total CO_2 emission (kg)
Waste dumped, W_D (Tons)	21.33	15.97	16.70	54	46.92	7.08	458.94	257.43
Waste delivered, W_R (Tons)	18.61	13.82	14.49					
Transmission loss, W_{TL} (Tons)	2.72	2.15	2.21					
Transportation cost, (\$)	172.78	139.33	146.83					
CO_2 emission (kg)	96.23	82.46	78.74					
Number of trips	4	3	3					

Table 4: Emission dispatch outcomes

Item	Lorry 1	Lorry 2	Lorry 3	Total waste loaded at transfer station, (Tons)	Total waste received at dumping site (Tons)	Total transmission loss (Tons)	Total operating cost (\$)	Total CO_2 emission (kg)
Waste dumped, W_D (Tons)	15.39	17.65	20.96	54	46.70	7.30	471.26	254.14
Waste delivered, W_R (Tons)	13.38	15.14	18.18					
Transmission loss, W_{TL} (Tons)	2.01	2.41	2.78					
Transportation cost, (\$)	116.95	157.85	196.46					
CO_2 emission (kg)	77.20	87.05	89.89					
Number of trips	3	3	4					

Table 5: Environmental friendly economic dispatch outcomes

Item	Lorry 1	Lorry 2	Lorry 3	Total waste loaded at transfer station, (Tons)	Total waste received at dumping site (Tons)	Total trans-mission loss (Tons)	Total opera-ting cost (\$)	Total CO_2 emission (kg)
Waste dumped, W_D (Tons)	19.40	16.62	17.98	54	46.70	7.30	471.26	254.14
Waste delivered, W_R (Tons)	16.93	14.37	15.63					
Transmission loss, W_{TL} (Tons)	2.47	2.25	2.35					
Transportation cost, (\$)	153.10	146.30	160.81					
CO_2 emission (kg)	89.55	84.20	81.91					
Number of trips	4	3	3					

at the same time by the same vehicles is found to be $460.20 and the corresponding CO_2 emission from the vehicles is 255.66 kg. The operating cost is moderate between the cost of economic and emission dispatches and similarly the CO_2 emission. The transportation loss is less by 0.23 Tons with respect to the emission dispatch. As far as the vehicles to and fro trips are concerned, Lorry 1 has to perform 4 trips, and Lorries 2 and 3 ought to accomplish individually 3 trips. The cost of transporting 1 Ton of solid waste to a distance of 1 km by Lorries 1, 2 and 3 are found to be 0.1038 $/Ton/km, 0.1544 $/Ton/km, and 0.1569 $/Ton/km respectively and the corresponding CO_2 emission accounted to be 60.74 g/Ton/km, 88.88 g/Ton/km, and 79.92 g/Ton/km respectively.

7. CONCLUSIONS

Economically suitable and ecologically sustainable solid waste transportation is the need of the day for Indian cities irrespective of their sprouting status. As an illustration, the CMA has been considered for the solid waste transportation optimization study with cloud computing strategy. Three dispatching algorithms were proposed. Economic dispatching ensued in minimum transferring cost while emission dispatching resulted in minimum emission. The environmentally friendly economic dispatch offered a temperate cost and emission. The option of choosing the type of dispatch depends on factors such as the solid waste management budget, the local weather conditions, the pollution control board constraints, the time of travel, whether peak hours or lean hours, and the type and aging of the transferring vehicles used, etc. The magnitude of the environmental credit (if available) also plays a decisive role in choosing the dispatch option. For instance, in the emission dispatch, the emission is minimum compared to economic dispatch while the operating cost is higher. In that case, the net operating cost after the environmental credit benefit would be the deciding factor i.e., the dispatch outcome with minimum net operating cost would be preferred. Though only one specific route and one type of pollutant were considered, the dispatching logic remains the same irrespective of the route and vehicle emission characteristics. The proposed optimization algorithms are also suitable for optimizing the solid waste collection with varieties of fossil-fuelled vehicles.

REFERENCES

Adel, N.T. (2014), On the Economics of Infrastructure as Service Cloud Providers: Pricing, Markets, and Profit Maximization. Ph.D. Thesis, Department of Computing and Information Systems, the University of Melbourne.

Amjad, K., Mohamed, M.S, Moncef, Z. (2016), Using GIS-Based Tools for the Optimization of Solid Waste Collection and Transport: Case Study of Sfax City. Tunisia: Hindawi Publishing Corporation Journal of Engineering. p7.

Apaydin, O., Gonullu, M.T. (2008), Emission control with route optimization in solid waste collection process: A case study. Saehan Academy Proceedings in Engineering Sciences, 33, 71-82.

Burhamtoro. M.S., Achmad, W., Bisri, M., Soemarno G. (2013), Model of municipal solid wastes transportation costs type dump truck (Case study at the Malang City, Indonesia). International Journal of Engineering and Technology, 13, 34-40.

Chalmin, P., Gaillochet, C. (2006), From waste to resource - An abstract of world waste survey. Cyclope. France: Veolia Environmental Services, Edition Economica.

CMDA. (2015), Chennai Metropolitan Development Authority - Solid Waste Management. Available from: http://www.cmdachennai.gov.in.

Corporation of Chennai. (2013), Available from: http://www.chennaicorporation.gov.in/.

Ebenezer, O.S., Emmanuel, H., Ebenezer, B. (2013), Forecasting and planning for solid waste generation in the Kumasi metropolitan area of Ghana: An ARIMA time series approach. International Journal of Sciences Research, 2, 69-83.

Hoornweg, D., Bhada-Tata, P. (2012), What a Waste: A Global Review of Solid Waste Management. Washington, DC.: World Bank.

Hummels, D. (2007), Transportation costs and international trade in the second Era of globalization. Journal of Economic Perspectives, 21, 131-154.

Jie, L., Yanfeng, H. (2012), Ant Colony Algorithm for Waste Collection Vehicle Arc Routing Problem with Turn Constraints. The 7th International Conference on Computational Intelligence and Security.

Komilis, D. (2008), Conceptual modeling to optimize the haul and transfer of municipal solid waste. Waste Management, 28, 2355-2365.

Kuo, Y., Wang, C.C. (2011), Optimizing the VRP by minimizing fuel consumption. Management of Environmental Quality: An International Journal, 22, 440-450.

Laporte, G., Gendreau, M., Potvin, J.Y., Semet, F. (2000), Classical and modern heuristics for the vehicle routing problem. International Transaction in Operational Research, 7, 285-300.

Ministry of Urban Development. (2013), Guidance Note Municipal Solid Waste Management on a Regional Basis. Government of India. Available from: http://www.urbanindia.nic.in.

Mousa, A.M., Debra, R.R., Fatina, T.G., Pamela, M.B. (2013), Emissions from US waste collection vehicles. Waste Management, 33, 1079-1089.

Murat, A.H., Christian, P., Andrea, C.S. (2014), Exact and heuristic algorithms for solving the generalized vehicle routing problem with flexible fleet size. International Transactions in Operations Research, 21, 153-175.

Narayana, T. (2008), Municipal solid waste management in India: From waste disposal to recovery of resources. Waste Management, 29, 1163-1166.

Nnaemeka, V.E., Kyung-Jin, B. (2015), Sustainable energy development in Nigeria: Overcoming energy poverty. International Journal of Energy Economics and Policy, 5(2), 580-597.

Palanichamy C, Naveen, P, Wong, K.I., Michael, K.D., Indumathi, J. (2015), Energy efficiency enhancement of fossil-fuelled power systems. International Journal of Energy Economics and Policy, 5(3), 765-771.

Palanichamy, C., Natarajan, S.B. (2002), Day-night weather-based economic power dispatch. IEEE Transactions on Power Systems, 17, 469-475.

Palanichamy, C., Naveen, P., Muthusundar, S.K. (2014), A sustainable renewable energy mix option for the secluded society. Journal of Renewable and Sustainable Energy, 6(3), 1-6.

Palanichamy, C., Srikrishna, K. (1986), Analytical approach for economic generation. Journal of the Institution of Engineers India, 67, 117-120.

Palanichamy, C., Sundar, B.N. (2008), Analytical solution for combined economic and emissions dispatch. Electric Power Systems Research, 78, 1129-1137.

Papia, S. (2013), Chennai Faces a Unique Pollution Challenge. New Delhi: Centre for Science and Environment.

Prasad, M., Yang, J., Yu, H., Choudhury, R.M. (2009), Shanghai Manual: A Guide for Sustainable Urban Development in the

21st Century - Municipal Solid Waste Management: Turning Waste into Resources.

Thomas, S. (2016), Energy imports, geo-economics, and regional coordination: The case of Germany and Poland in the Baltic energy system - Close neighbors, close(r) cooperation? International Journal of Energy Economics and Policy, 6(4), 789-800.

UNEP. (2000), Basel Convention on the Control of Trans-Boundary Movements of Hazardous Wastes and their Disposal - Series/SBC No. 99/009 (E) Geneva, 2000.

UNEP. (2005), United Nations Environment Programme International Source Book on Environmentally Sound Technologies (ESTs) for Municipal Solid Waste Management (MSWM). Available from: http://www.unep.or.jp/ietc/ESTdir/Pub/MSW/index.asp.

UN-HABITAT. (2010), Collection of Municipal Solid Waste in Developing Countries. United Nations Human Settlements Programme (UN-HABITAT). Nairobi: UN-HABITAT.

UNITAR. (2012), Global Partnership on Waste Management Biennium Conference Osaka, 5 and 6 Nov. Japan: UNITAR.

UNPD. (2012), World Urbanization Prospects, the 2011 Revision. Department of Economic and Social Affairs, Population Division, United Nations. New York: UNPD. Available from: http://www.esa.un.org/unup/pdf/WUP2011_Highlights.pdf.

Wadim, S., Štěpán, K., Evgeny, L. (2013), Energy economics and policy of renewable energy sources in the European Union. International Journal of Energy Economics and Policy, 3(4), 333-340.

World Bank. (2012), What a Waste: A Global Review of Solid Waste Management. Urban Development Series Knowledge. Washington, DC: World Bank.

Zdena, Z., Viriato, S., Filipa, B. (2013), Operation costs and pollutant emissions reduction by definition of new collection scheduling and optimization of MSW collection routes using GIS. The case study of Barreiro, Portugal. Waste Management, 33, 793-806.