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Socio-Economic Analysis of Household Energy Security: Evidence from 3D Energy Losses Surface Maps (ELSMs) of a Town Using Conjuncture of Factors Matrix, Digital and Mathematical Analysis

EJAZ GUL and IMRAN SHARIF CHAUDHRY

Pakistan is facing perpetual and worsening energy crisis. For vision 2025, the most important litmus test is to overcome energy crisis and ensure energy security by imaginative and innovative energy alternatives. In the same context, scientists, experts and researchers have been focusing on renewables and non-renewable energy generation alternatives, but have largely ignored the flip side. The extravagant use of energy, unlawful connections and losses in distribution system are contributors to ongoing energy crisis. For energy security in a developing country like Pakistan, elimination of energy losses seems a viable option, alongside generation of energy. Therefore, there is a need to have socio-economic analysis of energy losses. In this paper, energy losses for electricity were estimated for Lali Bagh Town of Peshawar, Khyber Pakhtunkhwa Province using a versatile and innovative socio-economic framework. This framework was based on factors matrix comprising socio-economic, environmental and energy factors pertaining to households. Within the factors matrix approach, three methods were used for analysis of energy losses; the statistical analysis to obtain trend and ratings of electricity losses, digital analysis of the data by computer assisted qualitative data analysis software (CAQDAS) to get the digitally iterated and attenuated models along with representative equations and mathematical analysis of equations by Newton-Leibniz integration process to obtain numerical value of the ratings. Based on the results obtained, three dimensional energy losses surface maps (ELSMs) were prepared for Lali Bagh Town of Peshawar, Khyber Pakhtunkhwa Province. At the end, policy recommendations have been given in the context of vision 2025. Paper is a unique combination of theoretical, mathematical and digital cum spatial economics.

JEL Classification: O22, Q21, Q31, Q41.
Keywords: Socio-economic, Analysis, Energy, Security, Electricity, Losses, Factors, Matrix, Digital, Maps.

1. INTRODUCTION

There are two rationales for the current energy crisis in Pakistan; firstly, we don't have energy due to lack of efforts to produce energy albeit we are blessed with almost all renewable and non-renewable energy sources, secondly, we have huge energy losses owing to profligate and wasteful use, unlawful connections by consumers and faults in

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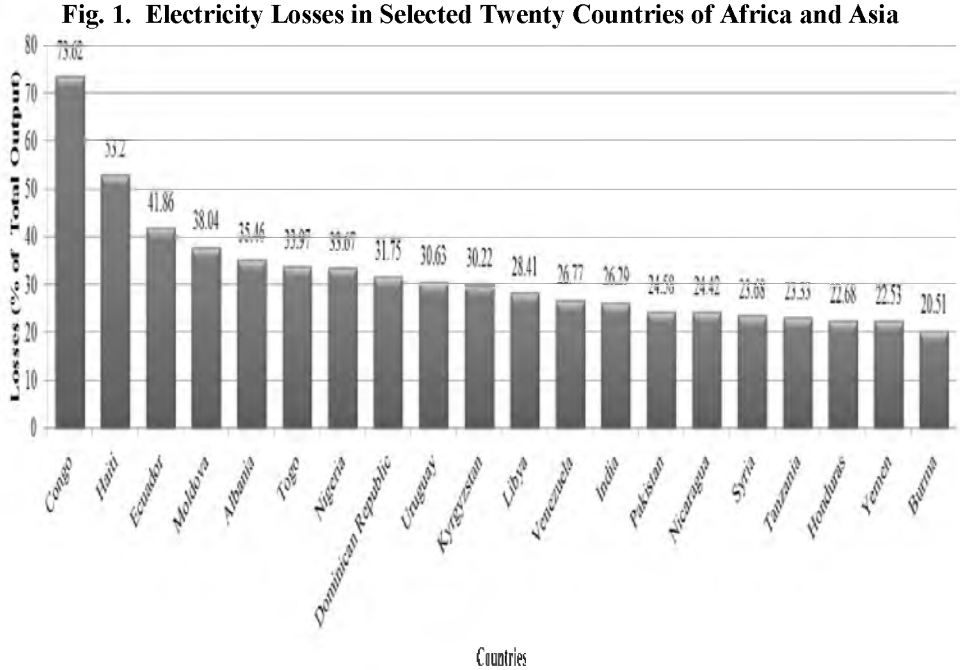
transmission and distribution system. These losses aggravate the crisis further. Recently it has been established that losses and leakages in the transmission and distribution lines coupled with illegal connections by consumers are both energy and economic burdens. This paper is about socio-economic analysis of losses of electricity in a small town Lali Bagh located in the center of Peshawar city, the capital of Khyber Pakhtunkhwa Province of Pakistan. From the estimated energy losses of Lali Bagh town, the magnitude and severity of crisis can be understood at the national level. The use of factors matrix for analysis of energy losses and the innovation of 3D ELSMs maps have proved to be useful as these tools can be used by energy planners for formulation and implementation of energy policy.

2. LITERATURE SURVEY

According to Auffhammer electricity is a secondary source of energy and is generated from the primary renewable and non-renewable sources like hydro, solar, wind, biomass, geothermal, gas, oil, coal and nuclear [Auffhammer (2008)]. Alam has indicated that developing countries have twofold dilemmas in the context of electricity. On the one hand, supply of electricity is reducing due to lack of comprehensive energy generation efforts, while on the other, demand is escalating owing to increasing population and industries [Alam (2004)]. Moreover Katiyar has investigated that countries around the globe are suffering from electricity losses due to faults in transmission and distribution system, unlawful connections by consumers and over consumption which further intensifies the ongoing crisis [Katiyar (2005)]. Countries in Africa and Asia have losses in excess of 20 percent of the total electricity output as shown in Figure 1.

Fig. 1. Electricity Losses in Selected Twenty Countries of Africa and Asia

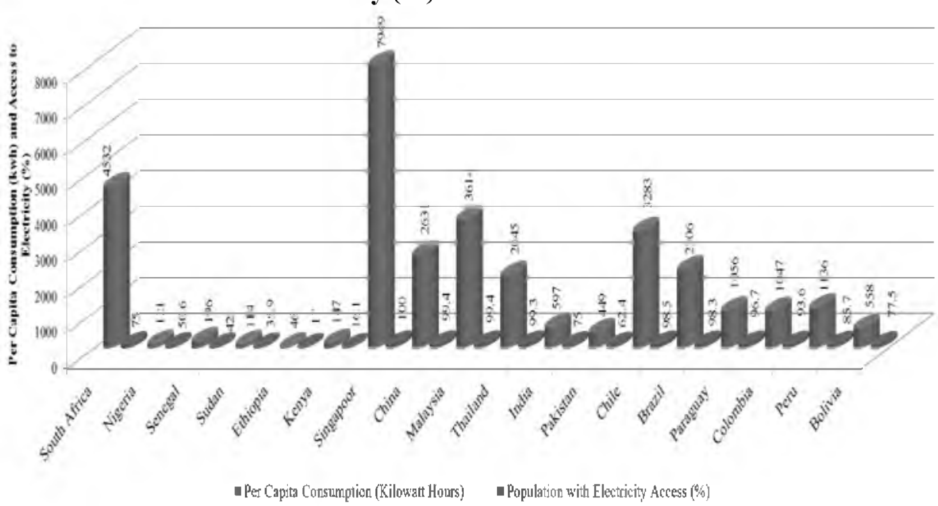


Source: http://www.nationmaster.com/country-info/stats/Energy/Electric-power).

The selected twenty countries in Figure 1 are those topping the list of electricity losses at the global level. These countries have losses more than 20 percent of the total electricity output. India and Pakistan are included in the list with losses 26.29 percent and 24.58 percent respectively. These losses have grave socio-economic implications. For instance, in Pakistan only 75.42 percent of the total electricity output is reaching the end users and electricity losses are not billed causing huge economic forfeiture to national exchequer [Pakistan (2014)]. According to Jamil an estimated Rupees (Rs) 50 billion are being lost per year due to electricity losses in Pakistan [Jamil (2013)].

The issue of access to electricity has also been highlighted by many researchers. International Energy Agency (IEA) has clearly specified that access to 120 kilowatt hours (kWh) of electricity per capita per year for lighting is a basic need [IEA (2014)]. Kanagawa has explained that in developing countries substantial population still lives without access to electricity affecting their standard of life [Kanagawa (2005)]. According to IEA, in Pakistan 62.4 percent of the population has electricity access and the per capita electricity consumption by this 62.4 percent of population is only 449 kilowatt hours per year [IEA (2014)]. Statistics about electricity access and consumption for developing countries of Africa, Asia and Latin America are shown in Figure 2.

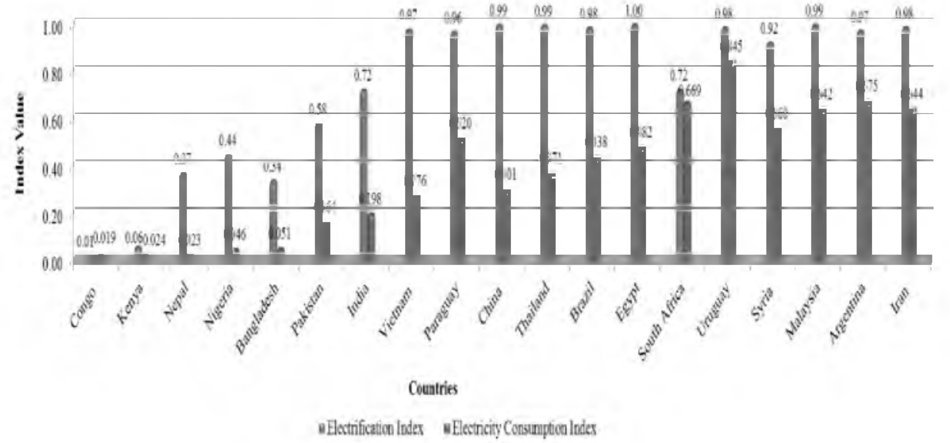
Fig. 2. Per Capita Consumption of Electricity (Kilowatt Hours) and Population with Access to Electricity (%)



Source: IEA (2014).

Figure 2 clearly indicates the shortfalls for Pakistan. According to Trujillo 37.6 percent of the population in Pakistan is still without electricity access and the per capita per year consumption is far below compared to developed countries [Trujillo (2006)]. As shown in Figure 3, World Energy Outlook (WEO) has indicated that Pakistan has electrification index of 0.58 and electricity consumption index of 0.164 which are low compared other developing and developed countries. For instance Richard has investigated that Vietnam has higher electrification and electricity consumption indexes than Pakistan [Richard (2013)].

Fig. 3. Electrification and Electricity Consumption Indexes of Selected Countries



Source: WEO (2014).

Similarly, according to Afia standard of living and human development index (HDI) has direct linkage with access to electricity. Therefore, the low access and low per capita per year consumption of electricity are contributing to the low HDI (0.57) of Pakistan [Afia (2007)]. As elucidated by Gul, there are many reasons for the ongoing energy crisis in Pakistan. Failure to select the best energy alternatives and lack of comprehensive planning for optimum utilisation of these alternatives for energy generation are the major reasons of energy crisis [Gul (2014)].

Joseph has indicated that increase in population, construction activities and industrialisation has further intensified the issue [Joseph (2010)]. Rossi has stressed that wasteful use, thefts and losses in distribution system have badly impacted the availability of electricity to all sectors of economy [Rossi (2007)]. Researchers have investigated the impact of illegal connections on the economy. Smith has elucidated that by having unlawful connections of electricity, we have become part of the problem instead of solution (Smith, 2004). Davoodi has clearly indicated that theft and unlawful use of electricity increases inequality and poverty [Davoodi (2002)]. McKechnie has investigated that poverty increases with electricity theft [McKechnie (2000)]. Joskow studied the economics of electricity networks and concluded that transmission and distribution losses cost heavily to the national exchequer [Joskow (2008)]. He also explained that such losses need to be eradicated by administrative and legal actions [Joskow (2013)]. Nagayama has investigated the impacts of power sector reforms on energy investments and transmission/ distribution losses and concluded that effective reforms can reduce transmission and distribution losses and boost the investments [Nagayama (2010)].

Sheikh in his work on energy has indicated that in Pakistan, the supply of electricity is approximately 14000 megawatts which is not matching with the demand of approximately over 20000 megawatts and gap between supply and demand is increasing with time [Sheikh (2010)]. Loughran has highlighted that frequent power shut down has been accepted as a viable strategy for demand management to cater for the widening gap [Loughran (2004)]. The average power shut down duration in Pakistan in the summer of

2014 was approximately 8 to 10 hours. Nakano has elaborately explained that power breakages have become the real economic challenge as these are causing social disruptions and hitting real GDP growth rate [Nakano (2008)].

Sheikh has also indicated that in the context of electricity generation in Pakistan, current energy mix is heavily reliant of non-renewables and is, therefore, highly uneconomical [Sheikh (2010)]. Asif in his work on energy has clearly elaborated that in Pakistan more than 40 percent of the electricity is generated from gas and more than 30 percent is generated by oil leaving only 30 percent to be generated by renewables like hydro, solar and wind [Asif (2009)]. Gas resources are depleting fast and electricity generation from oil is costly as oil is mostly imported causing huge dent on the economy. We need to think about the flipside of the situation. If the 25 percent losses are controlled, it may ease up situation to some extent and will also eliminate huge loss of Rs 50 billion per year to the national economy.

3. RESEARCH AREA

Peshawar is the capital city of Khyber Pakhtunkhwa located in the north west of Pakistan at a distance of 160 kilometers from capital city of Islamabad. Peshawar lies between 33° 44′ and 34° 15′ north latitude and 71° 22′ and 71° 42′ east longitude. Historically, Peshawar was the center of Gandhara civilisation. It's a city with rich traditions and social life. As per current demographic data, the population of Peshawar is approximately 3.6 million. Pakhtuns are the main inhabitants of Peshawar with Pashtu being the main language spoken in the city. Socio-economic indicators of Peshawar are shown in Table 1.

Table 1

Socio-economic Profile of Peshawar, Pakistan

Indicators	Calculation
Population	3.6 million approximately (2014)
Growth Rate	9.5%
Per Capita Income (Rupees per year)	125450 approximately (2014)
Literacy Rate	59%
Gender Ratio	Males are 15% more than females
Bed Patients Ratio	1040 patients per bed
Doctor Patients Ratio	3123 patients per doctor
Total Area	1257 square kilometers

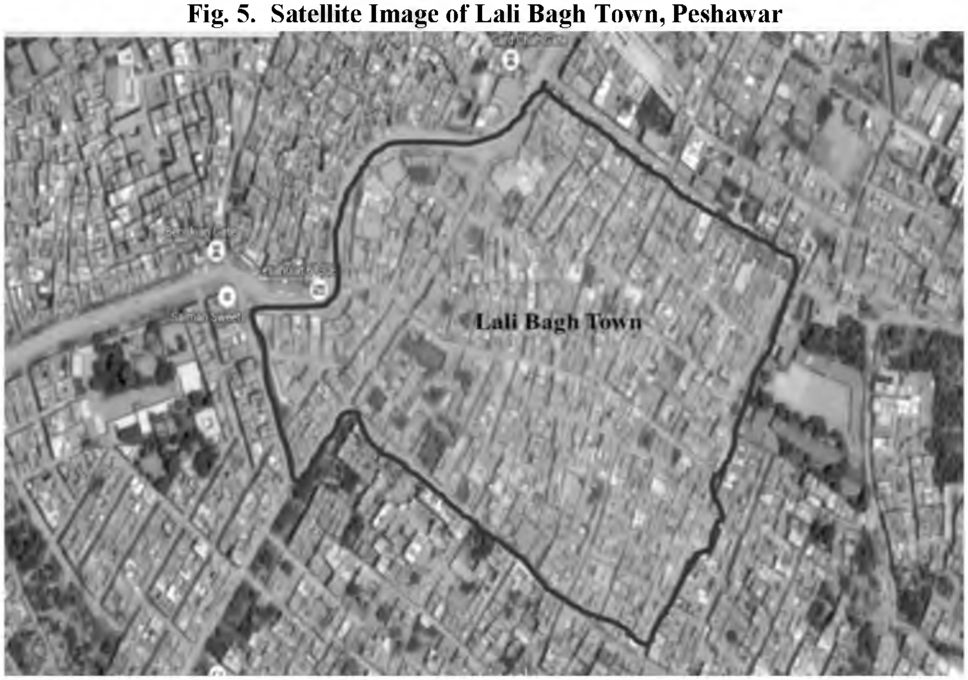
Source: Khyber Pakhtunkhwa, Bureau of Statistics available at kpbos.gov.pk/publications.php)

Presently an estimated quantity of approximately 550 megawatts of electricity is provided to the consumers of Peshawar on daily basis. The city suffers from frequent break downs of electricity in summers (May to August) each year.

Lali Bagh is a central town of Peshawar. Total area of Lali Bagh town is 10 square kilometers. A google map showing location of Lali Bagh town in Peshawar is given as Figure 4. It has total population of approximately 30 thousands. There are three health centres in the town with a 10-20 beds capacity. Inhabitants of the town are living in about 1000 concrete houses of varying sizes and overall outlook of the town is congested as reflected by satellite image shown in Figure 5.

Fig. 4. Location of Lali Bagh Town in Peshawar

Fig. 5. Satellite Image of Lali Bagh Town, Peshawar



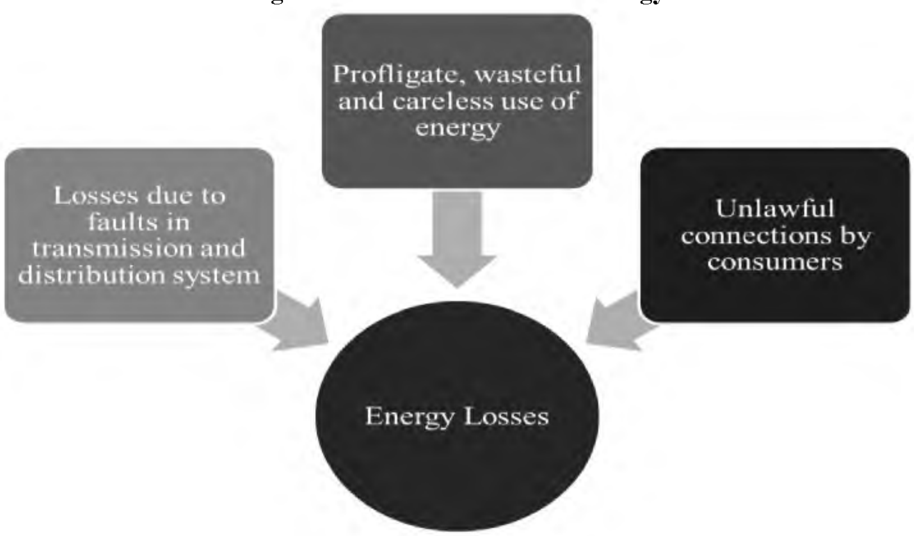
Large numbers of the houses are double storey occupying vertical space. There are two parks and playing grounds in town. There are seven high schools, ten middle schools and 20 primary schools in the town. Sanitation and waste disposal is mostly done on self-help basis. Central clean water facility from a community filtration plant is not available and inhabitants have installed kitchen filters for clean water availability. People mostly speak Pashto language with a small proportion of Hindko speaking community. Literacy rate is estimated as 55 percent.

Electricity is available in the town. Every house has electricity connection with unit counting device called meters. Electricity is provided through 11 kilovolt (1440 kilowatt hours) aerial distribution lines. Users are provided with single phase and three phase supply depending on the size of the house and number of occupants.

4. BENCH MARK CASE FOR SOCIO-ECONOMIC ANALYSIS

Our energy behaviour resulting into wastage of energy, mistaken norms to allow for unlawful electricity connections and lack of maintenance of electricity distribution system are all contributors to energy losses. We normally speak of non-availability of energy but we use energy as if we have it in excess. There are three folds losses of energy in Pakistan as shown in Figure 6. Overall electricity losses in Pakistan are in excess of 25 percent of the total electricity output. Taking 14000 megawatts as the output, the losses come to 3500 megawatts which is a huge amount of electricity. It means that the net total output is 10500 megawatts which can fulfil 50 percent of the increasing electricity demand which is currently more than 20000 megawatts. In terms of cost, it comes to over Rs 50 billion. As per National Electric and Power Regulatory Authority (NEPRA), losses up to 13 percent of the total output (1820 megawatts) are acceptable in the current vintage electricity distribution system. The remaining about 12 percent (1680 megawatts) out of estimated 25 percent are attributed to over consumption and theft. These losses cannot be justified by any standard.

Fig. 6. Three Folds Losses of Energy



To estimate electricity losses in Lali Bagh town, the electricity load of a hypothetical house, with all possible electric gadgets and appliances, was calculated for a month in summer as per Equation (1).

$$\text{Monthly units (kilowatt hours)} = \frac{\text{Quanity of electric gadget} \times \text{Power in watts} \times \text{Daily use in hours} \times 30}{1000} \quad \ldots \quad (1)$$

This was taken as the bench mark case for estimation of the losses in Lali Bagh Town. Calculation of electricity load of bench mark case is shown in Table 2.

Table 2

Electricity Load of a Hypothetical House Taken as Bench Mark Case

Electricity Items	Quantity	Power (Watts)	Total Power (Watts)	Daily Use (Hours)	Energy Consumption (Watt Hours)	Energy Consumption per Day (Kilowatt Hours)	Units Consumed per Month (Kilowatt Hours)
Tube lights	8	50	400	8	3200	3.2	96
Bulbs	8	100	800	8	6400	6.4	192
Energy Savers	8	20	160	8	1280	1.28	38.4
Colour Televisions	2	150	300	6	1800	1.8	54
Light Emitting Diode (LED)/ Liquid Crystal Display (LCD) Televisions	2	220	440	8	3520	3.52	105.6
Split Air Conditioner	2	1000	2000	8	16000	16	480
Window Air Conditioner	1	2000	2000	6	12000	12	360
Pressing iron	2	300	600	4	2400	2.4	72
Fans	10	50	500	16	8000	8	240
Electric Cooking Range	1	200	200	3	600	0.6	18
Microwave	1	150	150	2	300	0.3	9
Vacuum Cleaner	1	500	500	2	1000	1	30
Toaster	1	50	50	0.25	12.5	0.0125	0.375
Water Dispenser	1	50	50	12	600	0.6	18
Juicer	2	50	100	0.25	25	0.025	0.75
Blender	2	50	100	1	100	0.1	3
Washing Machine	1	400	400	3	1200	1.2	36
Desktop Computers	1	100	100	6	600	0.6	18
Laptops	2	50	100	6	600	0.6	18
Well Pump	1	500	500	0.5	250	0.25	7.5
Mobile Phones Rechargers	6	2	12	6	72	0.072	2.16
Refrigerator	1	500	500	8	4000	4	120
Freezer	1	500	500	8	4000	4	120
Electric Shavers	3	15	45	0.25	11.25	0.01125	0.3375
Total	-	-	10507	-	67970.75	67.97	2039.12

Table 2 clearly indicates that with all possible electric gadgets and appliances, a house can consume 2039.12 units (kilowatt hours) per month. Effect of load shedding was taken into consideration in the daily use of electric appliances while calculating electricity load for the bench mark case.

For calculation of losses due to unlawful connections by consumers, visual observations during field visits, registered reports with local police station and office of Peshawar Electricity Supply Company (PESCO) were considered. For calculation of losses due to faults in distribution system, faulty transformers, loose connections, hanging/sagging wires, low quality of connectors and fallen poles and pylons were focused.

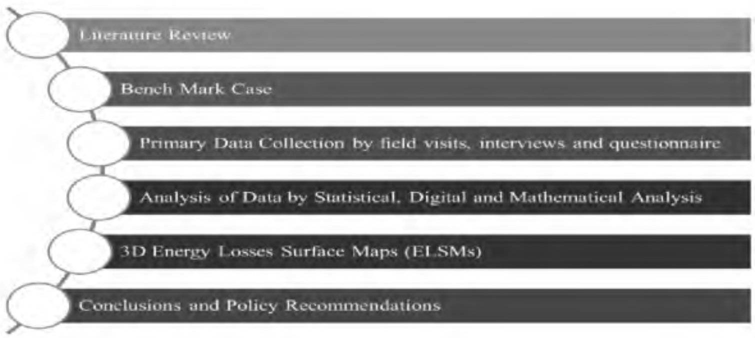
5. RESEARCH METHODS

Comprehensive research methodology was used for analysis of electricity losses. Primary data of socio-economic conditions and electricity losses was gathered by three methods; collection of observations during field visits, interview of experts and community leaders, and collection of households' opinion by questionnaire. Research design is shown in Figure 7.

During the field visits observations were noted about distribution system of electricity to households. Loose connections, quality of connectors, transformers, pylons and distribution cables were critically observed. Unlawful connections were also noted. 20 technical experts and 10 community leaders were interviewed. Data regarding socio-economic conditions and electric load was collected from 500 houses out of total 1000 houses using survey method.

Collected data was analysed by three methods; statistical analysis to determine ratings of and central tendencies of electricity losses, digital analysis using computer assisted qualitative data analysis software (CAQDAS) to get digitally iterated and attenuated models for the losses and mathematical analysis using Newton-Leibniz integration process to get numeral value of losses ratings.

Fig. 7. Research Design for Calculation of Energy Losses of Lali Bagh Town



Then, the results obtained from the three analyses were shifted to latest mapping software SURFER and three dimensional energy losses surface maps (ELSMs) were created.

6. DATA COLLECTION

For estimation of electricity losses in Lali Bagh town was divided into five zones; north, east, south, central and west as shown in Figure 8. The panoramic view of each zone is shown in Figure 9. North zone has commercial markets and residential accommodation. Schools, hospitals and community marriage and meetings halls are located in this zone. East and central zones are purely residential with congested houses of varying dimensions. South and west zones are comparatively open with modern houses.

Fig. 8. Five Zones of Lali Bagh Town

Fig. 9. Panoramic View of the Five Zones of Lali Bagh Town

Using a factors matrix, first the data was collected from 500 houses (100 houses each zone) to assess the socio-economic and environmental conditions which included detail about size of house, number of rooms, number of occupants, per capita income, lights hours, dark hours, load shedding, maximum temperature. Based on the collected data, average values were calculated for each zone as shown in Table 3.

Table 3

Socio-economic and Environmental Conditions of Lali Bagh Town

Socio-economic and Environmental Factors	North Zone	East Zone	South Zone	Central Zone	West Zone
Average size of House (square foot)	1560	1520	1526	1380	1878
Average number of rooms (all inclusive)	10	8	8	8	12
Average number of occupants per house	9	10	12	10	8
Average per capita income (Rupees per year)	123020	110900	100943	163178	153220
Average light hours (most of the lights are on)	6	5	4	6	8
Average dark hours (most of the lights are off)	6	7	8	6	4
Average duration of electricity load shedding per day	8	8	8	8	8
Average maximum temperature in summers	45	45	45	45	45

The average numbers of electric gadgets were determined for each zone after survey of 100 houses per zone. The purpose of this survey was to calculate the average electricity load for each zone. Data obtained is shown in Table 4.

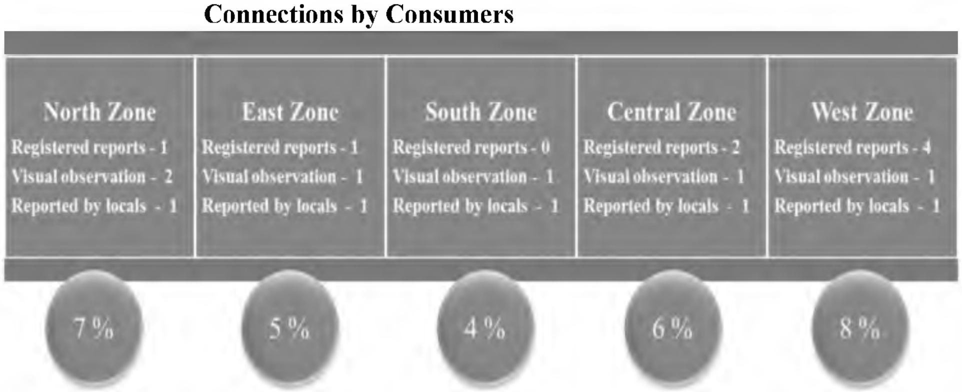
Table 4

Average Number of Electric Gadgets Per Zone

Electricity Items	North Zone	East Zone	South Zone	Central Zone	West Zone
Tube lights	4	4	3	4	5
Bulbs	3	3	4	4	5
Energy Savers	2	2	3	3	6
Colour Televisions	1	1	1	1	1
Light Emitting Diode (LED)/ Liquid Crystal Display (LCD) Televisions	1	1	1	1	1
Split Air Conditioner	0	0	1	1	2
Window Air Conditioner	1	1	0	0	0
Pressing iron	1	1	1	1	2
Fans	4	5	5	6	8
Electric Cooking Range	0	0	0	0	1
Microwave	1	1	1	1	1
Vacuum Cleaner	0	0	0	0	1
Toaster	0	0	1	0	1
Water Dispenser	0	0	0	1	1
Juicer	1	0	1	1	2
Blender	0	0	0	1	1
Washing Machine	1	1	1	1	1
Desktop Computers	1	0	1	0	1
Laptops	1	1	2	1	2
Well Pump	1	0	1	1	1
Mobile Phones Rechargers	3	3	4	4	3
Refrigerator	1	1	1	1	1
Freezer	1	1	0	0	1
Electric Shavers	0	0	0	0	2

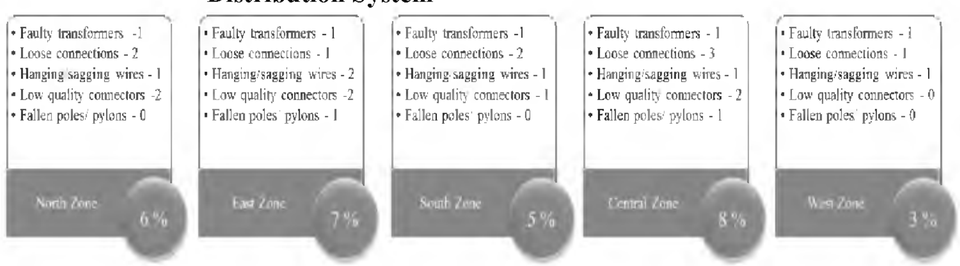
After this survey, data about theft and unlawful connections was collected by three methods; visual observation, number of registered reports with Peshawar Electric Supply Company and local police station and those reported by locals during field visits and survey of the zones. While calculating average electricity loss per zone due to unlawful connections by consumers, visual observation and unlawful connections reported by locals were taken as 2 percent loss of electricity while unlawful connections registered with Peshawar Electric Supply Company and local police station were taken as 1 percent loss. Average percentage of losses per zone is shown in Figure 10.

Fig. 10. Percentage Electricity Losses Per Zone Due to Unlawful Connections by Consumers



At the end, average electricity losses due to faults in distribution system were calculated for each zone. Each fault was taken as 1 percent loss to electricity as shown in Figure 11.

Fig. 11. Percentage Electricity Losses Per Zone Due to Faults in Distribution System



7. ELECTRICITY LOSSES ESTIMATION

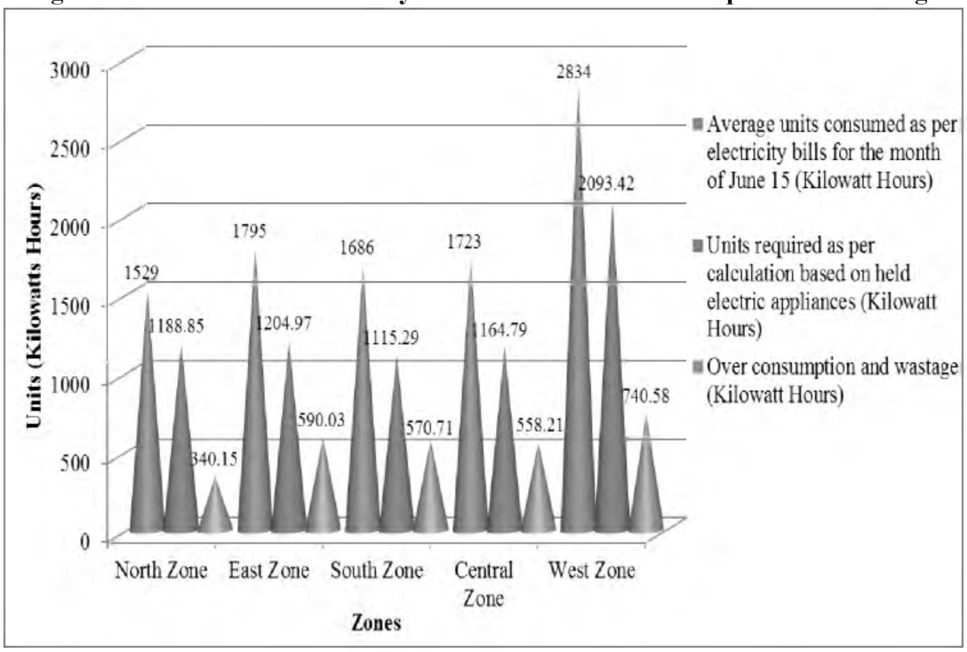
• ***Losses due to Over Consumption and Wastage***. After collection of data, electricity losses were estimated. First losses due to wastage and over consumption were ascertained. For this purpose, using Equation (1) average household electricity load in each zone was calculated based on the average holding of electric gadgets in the zones. The picture of calculation is shown in Appendix 1. This was followed by survey of electricity bills of the same 100 houses in each zone to know about the electricity units (kilowatt hours) for which those houses were billed. By this way the average units billed per zone were determined. This was compared with the actual average load per zone vide Appendix 1 and the difference was determined to ascertain the wastage and over consumption. Calculation is shown in table 5 while the graphical representation is shown in Figure 12.

Table 5

Calculations of Electricity Losses Due to Overconsumption and Wastage

Electricity Items	North Zone	East Zone	South Zone	Central Zone	West Zone
Average units consumed as per electricity bills for the month of June 15 (Kilowatt Hours)	1529	1795	1686	1723	2834
Units required as per calculation based on held electric appliances (Kilowatt Hours)	1188.85	1204.97	1115.29	1164.79	2093.42
Over consumption and wastage (Kilowatt Hours)	340.15	590.03	570.71	558.21	740.58

Fig. 12. Calculations of Electricity Losses Due to Overconsumption and Wastage



• ***Losses due to Unlawful Connections by Consumers***. The electricity is provided to consumers through an 11 kilovolt line which has power of 1440 kilowatts. Average percentage losses for each zone were worked out as shown in Figure 8. Losses due to unlawful connections by consumers were calculated by Equation (2) and calculation is shown in Table 6.

$$\text{Losses per Month due to Unlawful Connections (kilowatt hours)} = \text{Power Line (kilowatts)} \times \text{Losses percentage} \times \text{Duration} \times 30 \quad \ldots \quad (2)$$

Table 6

Calculations of Electricity Losses Due to Unlawful Connections

Zones	Power Line (Kilovolts/ Kilowatts)	% Losses	Losses (Kilowatt Hours)	Duration (Hours)	Loss of Units (Kilowatt Hours)	Loss of Units per Month (Kilowatt Hours)
North	11/1440	6	86.4	12	1036.8	31104
East	11/1440	7	100.8	12	1209.6	36288
South	11/1440	5	72	12	864	25920
Central	11/1440	8	115.2	12	1382.4	41472
West	11/1440	3	43.2	12	518.4	15552

- ***Losses due to Faults in Distribution System***. Average percentage losses for each zone due to faults in distribution system were worked out as shown in figure 9. Electricity losses due to faults in distribution line of 11 kilovolts (1440 kilowatts) were calculated by Equation (3) and calculation is shown in Table 7.

$$\text{Losses per Month due to faults in Distribution System (kilowatt hours)} \\ = \text{Power Line (kilowatts)} \times \text{Losses percentage} \times \text{Duration} \times 30 \qquad (2)$$

Table 7

Calculations of Electricity Losses Due to Faults in Distribution System

Zones	Power Line (Kilovolts/ Kilowatts)	% Losses	Losses (Kilowatt Hours)	Duration (Hours)	Loss of Units (Kilowatt Hours)	Loss of Units per Month (Kilowatt Hours)
North	11/1440	7	100.8	12	1209.6	36288
East	11/1440	5	72	12	864	25920
South	11/1440	4	57.6	12	691.2	20736
Central	11/1440	6	86.4	12	1036.8	31104
West	11/1440	8	115.2	12	1382.4	41472

8. ANALYSIS OF ELECTRICITY LOSSES IN LALI BAGH TOWN

First of all statistical analysis of the data was carried out. Table 8 shows the statistical analysis of the data. Results indicated that total of 308655.68 kilowatt hours of electricity is lost per month in Lali Bagh town. Average 599.936 kilowatt hours per month per zone are wasted; 30067.62 kilowatt hours per month per zone are lost due to faults in distribution system while 31104 kilowatt hours per month per zone are lost due to unlawful connections by the consumers. Statistics are indicated in Table 8.

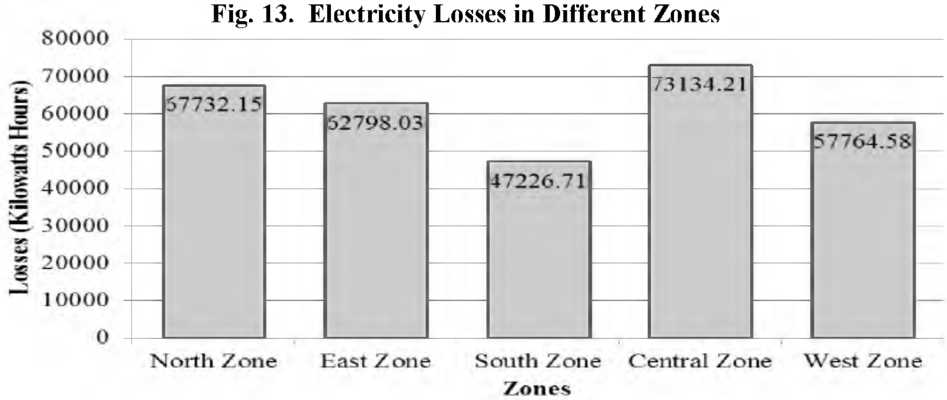
Table 8

Statistical Analysis of Electricity Losses

Reasons of Losses	North Zone	East Zone	South Zone	Central Zone	West Zone	Total	Average	Median	Standard Deviation	Variance	Skew-ness	Kur-tosis
Profligate, wasteful and careless use	340.15	590.03	570.71	558.21	740.58	2799.68	559.936	570.71	143.14	16392.57	-0.67	2.12
Line losses due to faults in distribution system	31104	36288	25920	41472	15552	150336	30067.2	31104	9971.62	79546614	-0.59	-0.021
Unlawful connections by consumers	36288	25920	20736	31104	41472	155520	31104	31104	8196.62	53747712	0	-1.2
Total	67732.15	62798.03	47226.71	73134.21	57764.58	308655.68	-	-	-	-	-	-

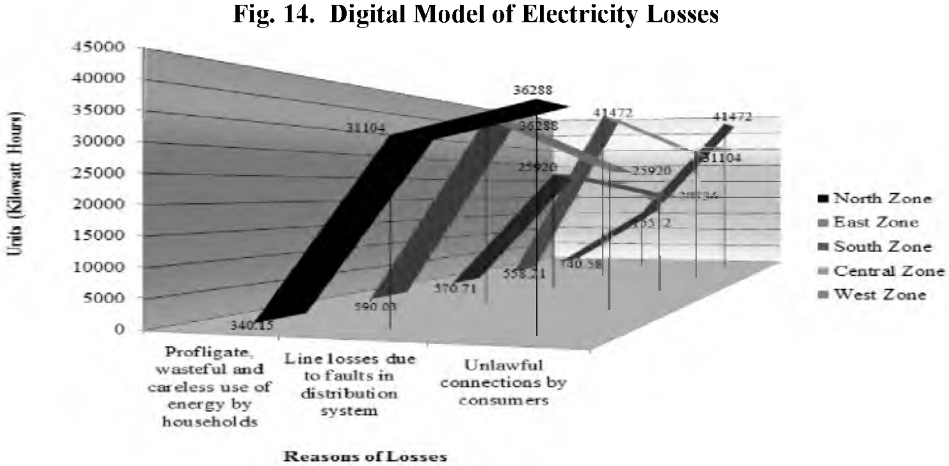
As per calculations, electricity losses are more in central zone, followed by north and east zones. Losses are comparatively less in south and west zones as shown in Figure 13.

Fig. 13. Electricity Losses in Different Zones



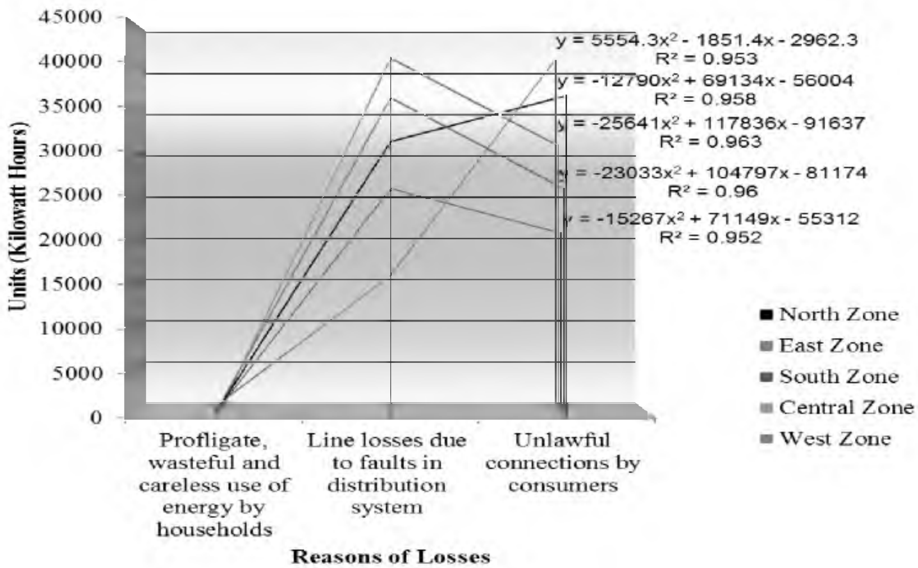
After statistical analysis, digital analysis was carried out to obtain the digitally iterated and attenuated model of electricity losses in Lali Bagh town. This was done by using computer assisted qualitative data analysis software (CAQDAS). The digital model obtained is shown in Figure 14.

Fig. 14. Digital Model of Electricity Losses



To get the exact ratings of electricity losses, digital model was converted into digitised mathematics mode (DMM) which gave the representative mathematical equations of aggregate electricity losses with R^2 values. Equations for all zones were quadratic in nature with R^2 values as 1. Digital model in the DMM is shown in Figure 15.

Fig. 15. Digital Model in DMM Showing Representative Equations of Electricity Losses



The representative equation of each zone obtained from digital analysis was solved using Newton-Leibniz integration process. For example the representative equation of north zone obtained from digital analysis is

$$\text{Electricity losses in north zone } = \int_{n=1}^{n=3} (\text{equation obtained from digital analysis})\, dx \qquad (4)$$

Where "*n*" is the category of losses under consideration which are 3 in this case (wastage, theft and faults in distribution system). Putting the representative equation in equation (4) we have

$$\text{Electricity losses in north zone } = \int_{n=1}^{n=3} (-12790x^2 + 69134x - 56004)dx$$

$$\text{Electricity losses in north zone } = \lim_{1\to 3}\left[-\frac{12790x^3}{3} + \frac{69134x^2}{2} - 56004x + C\right]$$

where "C" is a constant to account for errors in data and variables. By putting the limits in equation we obtained the quantified value of rating for the losses in north zone.

$$\text{Electrcity losses in north zone } = \left[-\frac{12790(3)^3}{3} + \frac{69134(3)^2}{2} - 56004(3) + C\right] - \left[-\frac{12790(1)^3}{3} + \frac{69134(1)^2}{2} - 56004(1) + C\right]$$

$$\text{Electricity losses in north zone} = [-115110 + 311103 - 168012 + C] - [-4263.33 + 34567 - 56004 + C]$$

$$\text{Electricity losses in north zone} = [27981 + C] — 25700.33 + C$$

$$\text{Electricity losses in north zone} = [27981 + C + 25700.33 - C]$$

$$\text{Electricity losses in north zone} = 53681.33$$

Similarly, equations were solved for remaining four zones and the values obtained are shown in Table 9. These values of aggregate electricity losses were almost in conformity with the values obtained from mathematical estimation and statistical analysis.

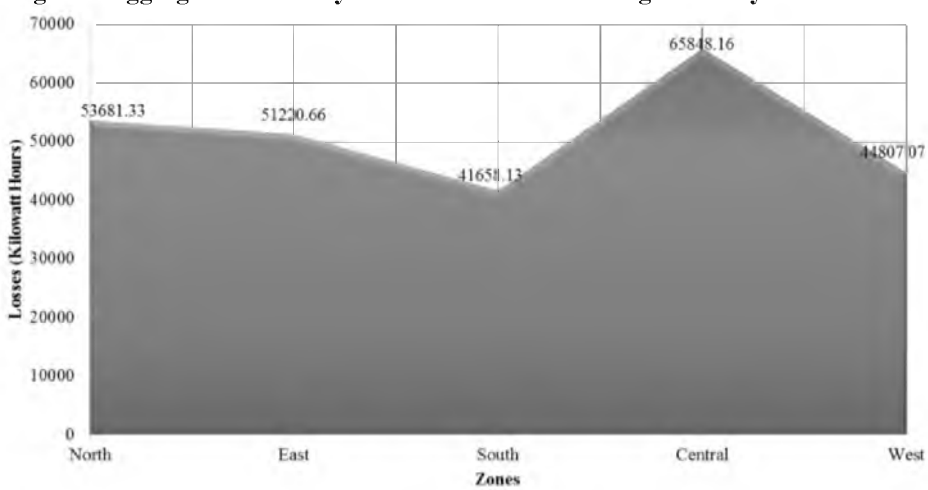
Table 9

Values of Aggregate Electricity Losses Obtained from Newton-Leibniz Process

Zones	Numerical Value of Digital Ratings of Losses (Kilowatt Hours)
North	53681.33
East	51220.66
South	41658.13
Central	65848.16
West	44807.07

The graphical representation of aggregate electricity losses is shown in figure 16. Figure clearly indicates that minimum losses were in south zone while maximum losses were in central zone.

Fig. 16. Aggregate Electricity Losses Obtained from Digital Analysis and DMM



9. THREE DIMENSIONAL ENERGY LOSS SURFACE MAPS (ELSMS)

After analysis of losses, data was shifted to latest mapping software SURFER to create 3D energy losses surface maps (ELSMs). For this purpose, three steps were followed. First, data grid was created in the grid module of software; second, grid map was created for electricity losses in each zone separately; third, grid map was converted into 3D energy losses surface maps showing electricity losses in each zone separately and also for the complete Lali Bagh town. Each map has longitude on x-axis and latitude on y-axis. Also each map has interactive key with it which shows values of losses as per the colour scheme. Elaboration of maps is as under:

- Figure 17 shows 3D energy losses surface map (ELSM) for electricity losses due to over consumption and wastage. Map indicates that electricity losses due to over consumption and wastage are more in the west and central zones.
- Figure 18 shows 3D energy losses surface map (ELSM) for electricity losses due to faults in distribution system. Map indicates that electricity losses due to faults in distribution system are more in the central and east zones.
- Figure 19 shows 3D energy losses surface map (ELSM) for electricity losses due to unlawful connections by consumers. Map indicates that electricity losses due to unlawful connections are more in the west and north zones.
- Figure 20 shows 3D energy losses surface map (ELSM) for aggregate electricity losses in Lali Bagh town. Map indicates that aggregate electricity losses are more in the central and north zones.

All the maps are interactive and shows clear picture of electricity losses. These can be used as useful tool for energy policy formulation and implementation.

Fig. 17. 3D Energy Losses Surface Map (ELSM) for Electricity Losses Due to Over Consumption and Wastage

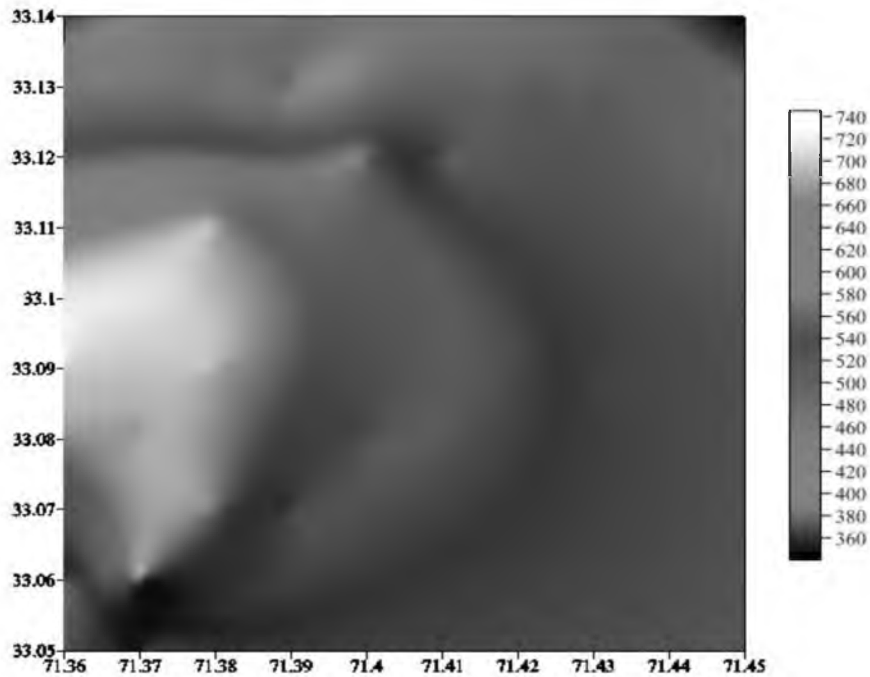


Fig. 18. 3D Energy Losses Surface Map (ELSM) for Electricity Losses Due to

Faults in Distribution System

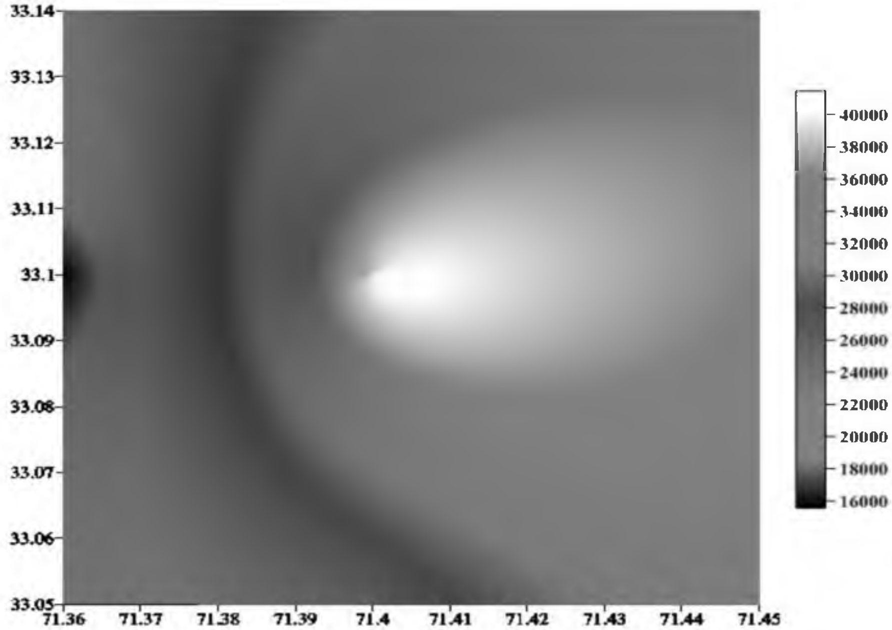


Fig. 19. 3D Energy Losses Surface Map (ELSM) for Electricity Losses Due to Unlawful Connections by Consumers

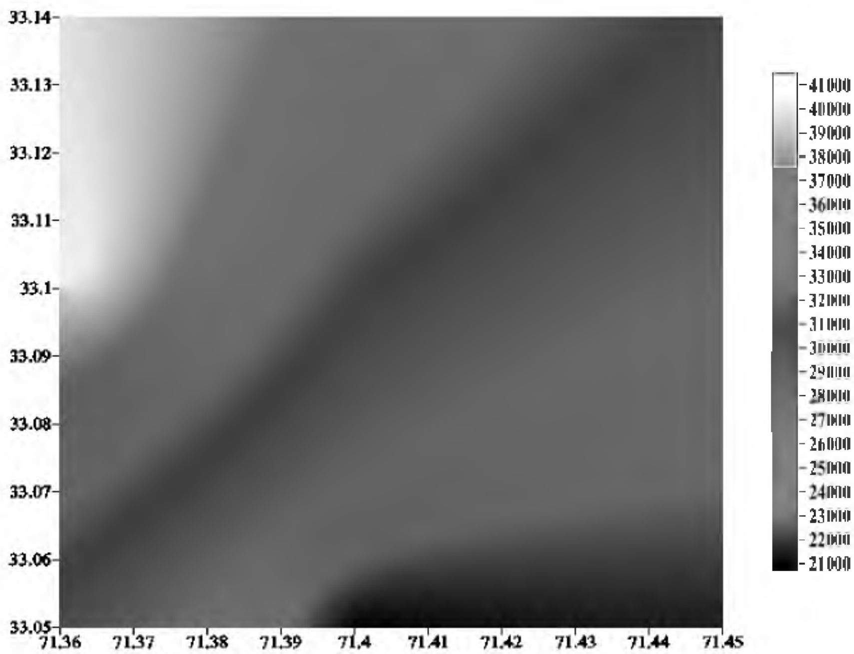
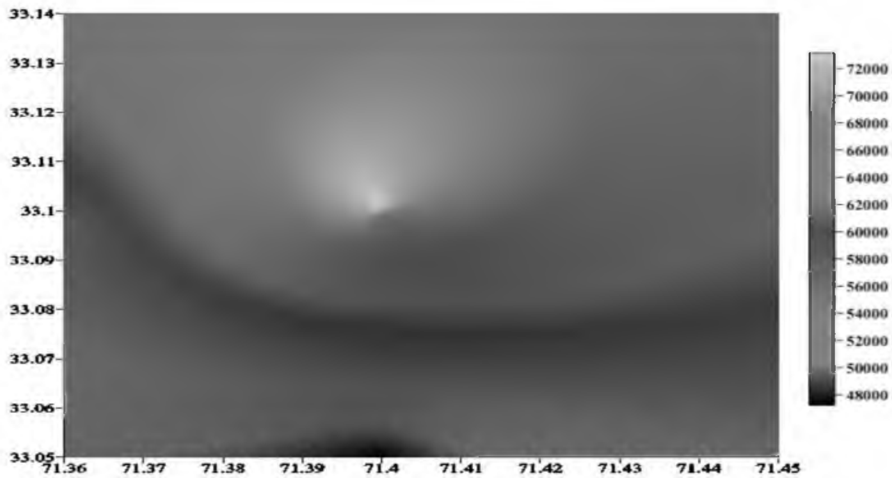


Fig. 20. 3D Energy Losses Surface Map (ELSM) for Aggregate Electricity

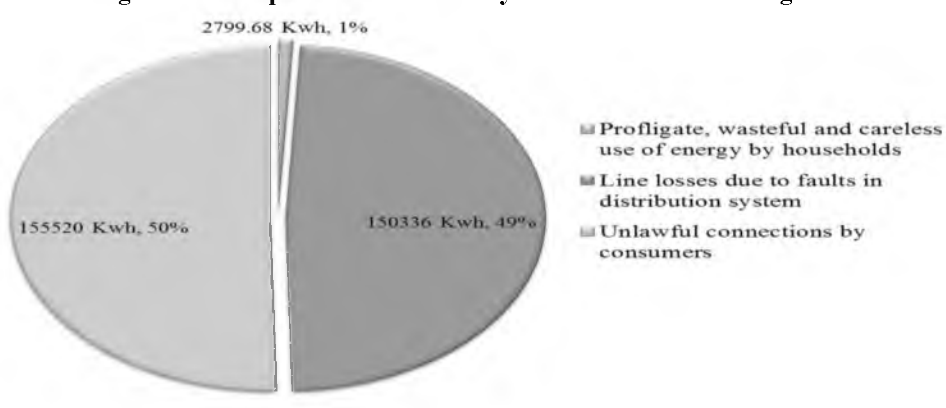
Losses in Lali Bagh town



10. RESULTS AND DISCUSSION

Results indicated that total of 308655.68 kilowatt hours of electricity is lost per month in Lali Bagh town. Figure 21 shows the overall share of three categories of losses. Losses due to over consumption and wastage are 2799.68 kilowatt hours which are just 1 percent of the total losses. The losses are less because households have the option of unlawful connections resulting into losses of 155520 kilowatt hours (50 percent of the total losses). Losses due to faults in distribution system were 150336 kilowatt hours (49 percent of the total losses). Combined together, consumers are responsible for 51 percent of losses (wastage and unlawful connections) and system is responsible for 49 percent of losses (faults in distribution lines). Therefore, we can not put complete responsibility of electricity losses on system. In fact we are more responsible for the losses than the system. If these losses are eliminated or atleast controlled, we shall have greater availability of electricity in our home.

Fig. 21. Decomposition of Electricity Losses into Three Categories



The calculated electricity load of a hypothetical house with all possible electric gadgets is 2039.12 kilowatts hours per month. This means that if we eliminate these losses, we shall be able to provide electricity to 151 more houses (308655.68/2039.12 = 151.36) or else we can provide 308 additional units to each house of Lali Bagh town (308655.68/1000 = 308.65 kilowatts hours) and free the households from the clutches of electricity load shedding. This will enhance energy security of the households at Lali Bagh town.

The economic impact of losses was also determined which indicated that substantial economic loss was incurring due to electricity losses. Calculations are as under:

- Total units provided to Lali Bagh Town = 1440×12×30 = 518400 kilowatt hours
- Units billed = 9567 kilowatt hours
- Public utilities (schools, hospital, street lights etc.) = 200177.32 kilowatt hours
- Units lost (wastage, thefts, faults in distribution) = 308655.68 kilowatt hours
- Cost of units lost (Rs 15 per unit) = 15 x 308655.6 = Rs 4629835.2 (Rs 4.63 million)

This calculation indicated severity of the issue. For a town of 1000 houses the economic loss was Rs 4.63 million. Moreover, there was a gap between the units provided and the units billed. Out of 318222.68 kilowatt hours provided to households only 9567 kilowatt hours (3 percent of the total units provided) are billed while remaining 308655.68 kilowatt hours (97 percent of the total units provided) are lost due to wastage, unlawful connections and faults in distribution system. Because of this gap complete system of electricity provision is running into loss.

11. CONCLUSIONS AND POLICY RECOMMENDATIONS

3D electricity losses surface maps indicated that losses were experienced in the five zones of Lali Bagh town in varying proportions. Following pertinent conclusions can be drawn from the study:

- Total electricity losses in Lali Bagh town of 1000 houses were 308655.68 kilowatts hours per month costing Rs 4.63 million per month.
- Roughly Rs 0.5 billion is lost annually due to electricity losses in Lali Bagh town.
- Consumers and electricity providers both are responsible for electricity losses almost in equal proportion.
- Losses due to profligate and wasteful use of electricity are just 1 percent of the total losses because consumers have covert option of getting electricity through unlawful connections which are not billed.
- 3D electricity losses surface maps indicate precisely the magnitude of losses in different geographical locations. Such maps are useful for eradication of electricity losses at the country level and thus ensure greater energy security to households.

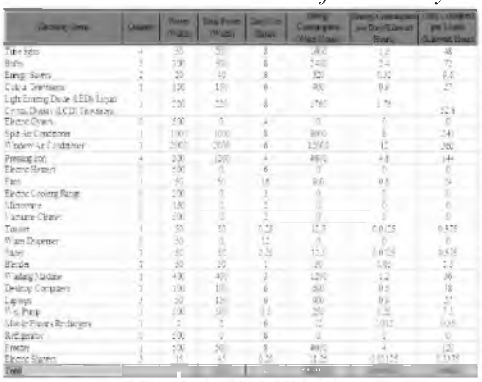
Following policy recommendations are proffered for energy security of the households in the context of vision 2025:

- Electricity losses are costing heavily to our country. While keeping focus on energy generation from different renewable and non-renewable energy alternatives, comprehensive campaign should be launched to eradicate electricity losses for greater energy security to households.
- Energy conservation drive could not be successful so far due to mind set of population and lack of administrative and legal back up. Following measures are required to be enforced with complete legal framework:
    - Use of energy friendly technologies like energy savers should be institutionalised. There should be complete ban on other sources of illuminations like bulbs and tube lights of more than 100 watts.
    - There should be scale of energy consumption (number of bulbs, fans, split coolers, iron etc.) as per number of inhabitants in a house/ dwellings, commercial plazas, offices and other infrastructure. Excessive illumination should be avoided. Violators should be strictly dealt with.
    - Optimum utilisation of daylight hours in the gatherings, offices, halls and other buildings by use of transparent roof tops. Maximum ceremonies should be planned in the day time. Dark light illumination should be minimised.
- At the country level 13 percent of the total production of electricity is lost due to faults in transmission and distribution system. These losses are costing Rs 50 billion per year. More than 60 percent of the transformers and aerial wires are outdated and needs replacement. Investment in this field will help reducing energy crisis and will ensure greater energy security of households.
- Unlawful connections by consumers account for more than 12 percent of electricity losses at the country level. These losses are related to consumers' behaviour and are against the social norms. Such losses not only put burden on the electricity consumption but also cost heavily in economic terms by increasing the quantity of unbilled units. These losses should be eradicated through strict legal and administrative actions.
- 3D energy losses surface maps are extremely useful for energy planning and implementation. These should be prepared at the country level and areas with high electricity losses should be immediately focused to rescue households from the paws of load shedding in peak summers.

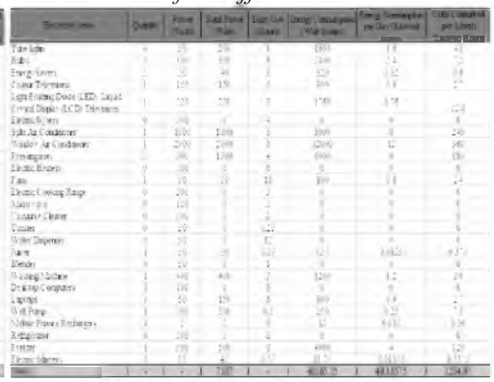
Although, energy generation efforts are required to reduce the gap between energy supply and demand, eradication of electricity losses will ease up the situation to some extent. Economic cost of Rs 50 billion per year due to electricity losses should be avoided to achieve two fold advantages of greater energy security of households, and benefit of saving Rs 50 billion per year. The eradication of electricity losses is the most effective energy alternative for Pakistan.

Appendix 1

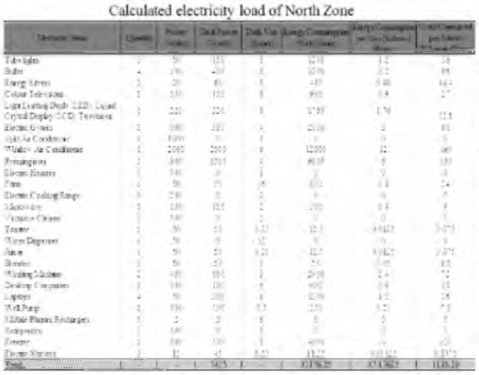
Collective Picture of Electricity Load Calculation for Different Zones



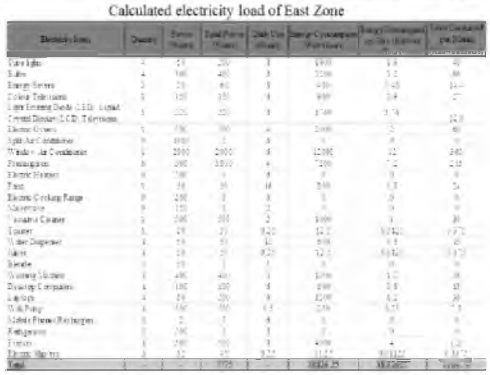
Calculated electricity load of North Zone



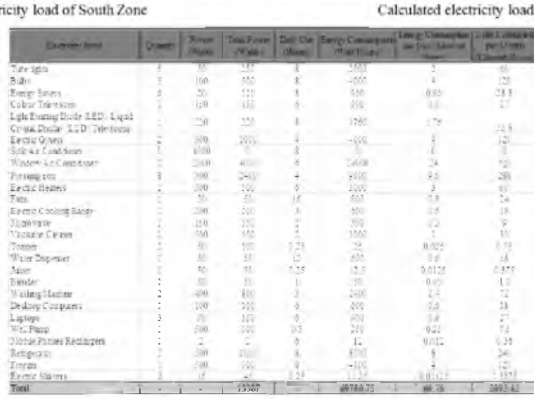
Calculated electricity load of East Zone



Calculated electricity load of South Zone



Calculated electricity load of Central Zone



Calculated electricity load of West Zone

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