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Exploring CO_2 Sources and Sinks Nexus through Integrated Approach: Insight from Pakistan

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ABSTRACT. Land cover changes are used to indicate various anthropogenic activities that lead to greenhouse gas GHG emissions (mainly carbon dioxide, CO_2). GHG mitigation policies are in place in mega cities of developing countries, such as the city of Faisalabad in Pakistan. The relationship between CO_2 sources and sinks, however, is still largely unknown. In the present study, we estimate sectoral CO_2 sources using actual data from the city's energy consumption as one of the critical parameters an anthropogenic activity, while sinks are extracted from land cover/land use change analysis of quad-temporal satellite images for the time period of 1975 to 2011. The integration of multiple tools/models makes this study unique for its kind. The results illustrate that the city area expanded by six times from 1975 to 2011 while CO_2 sources increased eight-fold, and are expected to rise further if not addressed in timely fashion. CO_2 sinks are being exhausted heavily in a large numbers. In particular, sparse and dense vegetation has shown a significant change over a mere decade. The forecast results, estimated by econometric model, likewise show an increasing trend in the future. It is also found that use of multiple tools and techniques deliver better results in carbon mitigation tracer research. This study could help in developing climate mitigation policies at a local level that will ultimately help in reshaping national policies.

Keywords: CO_2 emission, source-sink relationship, integrated tools, remote sensing, Faisalabad

1. Introduction

A simple and easy way to mitigate carbon emissions is to augment carbon sequestration and carbon storage. This could be possible through a multi-plantation structure in developping vicinities, especially in cities and urban areas. In the Millennium Development Goals (MDGs), focus is placed on the increment of forest areas especially in developing and least-developing countries, but reality is actually the reverse. Recently, the provincial government of Pakistan has allocated barren forestland to unemployed agriculture graduates for agricultural purposes. However, they portray no interest and action towards developing those forest areas, but rather reducing the forestlands. Under the MDGs, Pakistan agreed to increase its forest cover from 4% to 7% by 2015. But the situation is worsening by the day, and the forest cover has not even increased by even one percent to date, with only four years until the deadline (SDPI, 2010).

On the contrary, Pakistan has an agro-based economy in which the agricultural sector constitutes 21% of the nation's gross domestic product (GDP) and employs 45% of the labor force (Economic Survey, 2010). For the last two decades, policymakers have promoted Pakistan's industrial economy, triggering the demand for energy to increase substantially in the cities. Pakistan's total energy supply mix primarily consists of fossil fuels, which constitute approximately 60% of the energy supply. A reasonable share of biomass energy (i.e., wood fuel, agricultural waste and animal waste, which is also called animal dung) is present in Pakistan's energy supply as well (Asif, 2009). From 2007 ~ 2008, total comercial energy consumption was 74.4 million tonnes of oil equivalent (MTOE), and the per capita primary energy consumption was 0.49 tonnes of oil equivalent (TOE). Oil and gas were the chief ingredients of the energy supply mix, as they contributed to 38.3 and 43.8%, respectively, (Ali and Nitivattananon, 2012). Additionally, coal, hydroelectricity, and nuclear electricity constituted 5.4, 11.3, and 0.9%, respectively, (Muneer and Asif, 2007).

All information stated in the above paragraph is solely available at the country level, in this case, Pakistan, and not at local/city levels. There are no concrete GHG databases from which to assess conditions of densely populated urban areas carrying sources and sinks (vegetation) of CO_2. Particularly, empirical and/or absolute data on energy use and GHG emissions are absent in the cities of Pakistan. To cope with future challenges posed by climate change we must investigate em-

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pirical realities, strengths, weaknesses, and appropriate measures of climate change mitigation efforts so that policy-makers can suggest methods for mega cities and highly urbanized areas.

Another issue, in general, common in carbon emission related studies is that sinks are ignored when energy use and CO_2 emissions are taken into account (Avishek, et al., 2012; Awiti, 2012). A most important part of the carbon cycle, sinks must be considered; sources and sinks must be studied on a consistent scale to balance the analysis. Our study also intends to fill this gap in the research and link energy use, CO_2 sources, and sinks in one chain, analyzing them on a consistent scale. In order to study all these indicators at one time under one scenario, multiple tools and models are needed; without the integration of many tools and models it is not reasonable to analyze sources and sinks as one tool/model is simply insufficient. Historical trends and future predictions are also included in order to explain the long-term relationship of these indicators. Hence, all these issues and gaps are covered in this study for the very first time.

Climate change mitigation has been deliberated all over the world but with limited insights from developing and least-developing countries like Pakistan. There are rare studies, however, that analyzed such long-term historical and forecast data of CO_2 sources and sinks using multiple techniques. A few studies (Bryan et al. 2010; Birant, 2011) have considered carbon sequestration, energy use, and mitigation options in the different regions of the world but did not include the CO_2 sinks factor. Likewise, in developing countries, (Avignon et al. 2010; Cohen, 2012; Dendler, et al., 2012) various studies have been conducted that relate to energy use and carbon emission inventories, policy implications and GHG emission reduction, and different models/tools to fulfill their aims and/or objecttives, but with no discussion on CO_2 sinks. In Pakistan, there are even fewer similar studies available and most of them are focused on a national level and a sole sector or issue rather than on a city-level and/or multiple sectors. None, however, have considered the CO_2 sources-sinks relationship on a city level.

Thus, keeping in mind the gaps in research and policy, this paper presents a preliminary study of energy use and CO_2 sources inventory as well as the relationship of CO_2 sinks to the sources by explaining the historical trends, current situations, and forecast changes. This leads to the need for integration of different models, so-called integrated approaches (such as economic, environmental and remote sensing), because one tool is not sufficient to estimate all factors. Therefore, this paper accomplishes two objectives. First, we compile baseline information on the energy used and CO_2 emissions of five major sectors, including their historical, current, and forecastted trends of sources. Second, we study the CO_2 sources and sinks nexus in the city and determine whether more sources have risen than sinks.

The study is organized into the following sections: Section 2 comprises data collection and handling; Section 3 includes methodology; Section 4 discusses results and discussions; while Section 5 contains the conclusion drawn from the study.

2. Data Collection and Handling

2.1. Area of Study

Faisalabad was selected as the area of study. Formerly known as Lyallpur, Faisalabad is the third largest city in Pakistan. Faisalabad is an industrial city that is also known as the "Manchester of Pakistan". A 106-year-old city, it is situated approximately 225 miles south of the Pakistani capital, Islamabad. Current population is almost 3 million, whereas the population was 10,000 in 1905 and 1.9 million in 1998 (PDS, 2010). According to the Economic Survey of Pakistan in 2010, Faisalabad's GDP (PPP) was $14 billion in 2009 and is expected to grow to $37 billion in 2025, with a growth rate 5.7% higher than the growth rates of the two metropolitan cities in Pakistan (i.e., Karachi and Lahore). The major economic activities in the city are related to industry, especially textiles. From 2007 ~ 2008, the number of industrial units reported in Faisalabad was 1,830. According to the World Bank, (2010), Faisalabad is the second best place for conducting business activities in Pakistan, after its capital city, Islamabad.

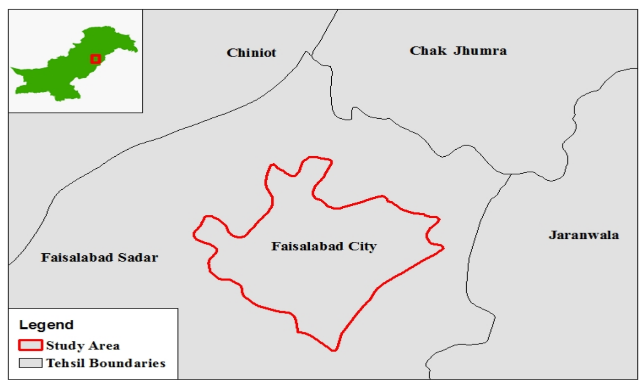

Figure 1. Map of Faisalabad City (Source: Faisalabad urban unit, 2010).

2.2. Data Collection

To estimate energy use and CO_2 emissions, five major sectors and four energy sources were chosen. The data collected from primary and secondary sources is comprised of 40 years' worth of energy consumption data (i.e., from 1971 to 2010) for five sectors: agricultural, commercial, industrial, residential, and transportation; and four energy sources: oil, gas, coal (direct sources), and electricity (indirect source). Likewise, secondary data collected include topographical maps, meteorological data, profile studies, Landsat satellite images, and land use distributions. We collected the primary data in response to the requirements of the remote sensing tool (which is used to estimate CO_2 sinks). A field survey technically called the 'ground truth' was used to confirm the locations of the different places in the study area. The following factors determined the sources of the satellite data: (1) the availability of a long-time series of images for the study area and (2) whether the area featured less than 20% cloud cover, which we witnessed in the months of September, October, November and December (i.e., the post-monsoon months). In accordance with these two criteria, we acquired four Landsat images of the Faisalabad region for the years 1975, 1980, 2000 and 2011. This would help in determining the CO_2 sinks through land use change analysis.

2.3. Data Sources

Energy usage data sources for the five sectors and four energy sources selected include the Ministry of Petroleum and Natural Resources of Pakistan, the Statistical Bureau of Pakistan, the Hydrocarbon Development Institute of Pakistan, city urban units, and Faisalabad Electric Supply Company. The Multi Spectral Scanner (MSS) sensor installed on Landsat 2 and Landsat 3 acquired the images from 2000 and 2011, while the Thematic Mapper (TM) senor of Landsat 5 acquired the satellite images from 1975 and 1980. No Landsat data fulfilling the requirements were available for the study period (1982 ~ 1998). Tables 1 ~ 3 present the details of the images and provide brief descriptions of the classes.

Table 1. Landsat Data Specifications

Date	Image Type	Path/Row	NSR
15/02/1975	Landsat 2 / MSS	161/038 (WRS-1)	79
03/06/1980	Landsat 3/ MSS	161/038 (WRS-1)	79
21/05/2000	Landsat 5 / TM	150/038 (WRS-2)	30
12/01/2011	Landsat 5 / TM	150/038 (WRS-2)	30

Note: NSR = Nominal Spatial Resolution.

Table 2. Classification of Land Use in Faisalabad

No.	Classes	Definitions
1	Trees/grasses	Trees and grasses within study area vicinity
2	Built-up areas	Area covered by concrete or asphalt which covered all built up areas and major roads with supporting infrastructures
3	Barren land	Area which includes the cultivated land without crops and barren rocks
4	Water	All areas of open water
5	Agriculture fields	Well bloomed agricultural crops
6	Sparse vegetation	Immature seasonal crops, may be mixed with sparse vegetation in fallow fields

3. Methodology

To achieve the objectives of this study, we adopted an integrated approach. The need to adopt this method was due to the different variables such as CO_2 emissions and sinks that cannot be estimated through a single method; in the meantime, the historical trends and forecasting long-term drifts and a single tool cannot identify relationships. That is why integration of different tools and models is necessary. Similarly, there is a need to explain the complete aspects of CO_2 sources and sinks nexus, for which background situation and future scenario is important to be discussed; for future scenario, autoregressive integrated moving average (ARIMA) model is utilized. There are other choices, but considering the limitations and assumptions of our analysis, the ARIMA model is best suitable for this study. Further, we assume that energy demand is equivalent to the city's energy consumption because a sectoral breakdown of energy in statistical data sources is not available for any city in Pakistan. We also assume that all of the energy is consumed within the city's boundaries. Of all of the GHGs, we selected only CO_2 to estimate the amount of greenhouse gases being emitted in the city.

Table 3. Control Points and Pixels

Image date	No. of control points	RMSE (pixels)
15/02/1975	19	0.76
03/06/1980	19	0.69
21/05/2000	21	0.58
12/01/2011	22	0.51

Having said that, objectives are achieved step by step and we start from compiling baseline information on the city's sectoral energy use. Thus, we compile 40 years' worth of energy consumption data dating from 1971 to 2010. These data explain the past trends. Based on these historical data, we can forecast energy consumption in the city for the next 20 years. To perform the forecasts, we use the ARIMA model, the most popular econometric model for this purpose, and used in plenty of studies (Box and Jenkins, 1976; Brown et al., 1984; Kamal and Jafri, 1997; Zhang, 2001; Ediger et al., 2006; Zhou,et al., 2011). Worthy of note is that in using the ARIMA model, we must have either a stationary time series, or a time series that is stationary after one or more differencing operations. Thus, we used the OLS technique, unit root method, Dickey-Fuller (DF) method (all of which are based on econometric models/techniques) to make data stationary. The functionnal form of this model is as follows:

$$\begin{aligned} \Delta dY_t &= \delta + \phi_1 \Delta dY_t - 1 + \phi_2 \Delta dY_t - 2 + \ldots + \phi_p \Delta dY_t - p \\ &+ \varepsilon_t - \theta_1 \varepsilon_t - 1 - \theta_2 \varepsilon_t - 2 - \ldots \\ &- \theta_q \varepsilon_{t\text{-}q} OR (1 - \phi_1 B - \phi_2 B_2 - \ldots - \phi_p B_p)(1 - B)\mathrm{d}Y_t \\ &= \delta + (1 - \phi_1 B - \phi_2 B_2 - \ldots - \phi_p B_p)\varepsilon_t \end{aligned} \quad (1)$$

where Y_t is the observation at time t, Y_{t-p} is the observation at time t-p, δ is a constant term, ϕ_1, ϕ_p is the MA parameter, t is the white noise process or error at time t, ε_{t-q} is the white noise process or error at time t-q, Δd is the d^{th} order difference (i.e., the difference order d), and B is the backward shift operation (defined as $B_k X_t = X_{t-k}$). Furthermore, we use MS Excel, E-views 3.0, and Statgraphics plus software to simulate the model and generate our forecasting results.

Next step is to estimate the carbon sources generated by the selected sectors and sources. To achieve this goal, we use the same sectors, the same four energy sources and the same assumptions that we use to calculate energy consumption while applying equation 2 (adopted from IPCC 2006) to estimate the carbon dioxide generated by the direct energy sources, as shown by the following:

$$CO_{2\,direct\,energy} = \sum_i C_i \times I_i \qquad (2)$$

where $CO_{2\,direct\,energy}$ is the annual CO_2 emissions from the combustion of fuels for non-electricity energy, C_i is the annual consumption of fuel type i, and I_i is the CO_2 emitted by combusted fuel type i. The emission factors for each fuel type are derived from the default emission factors (tier 1) of the 2006 IPCC guidelines for National Greenhouse Gas Inventories and presented in Table 4.

Table 4. Emission Factors Used for the Estimation of CO_2 Sources

Energy source	Emission factors on net calorific basis	Source
Petrol	73,300 kg/(Tera Joule)	IPCC, 2006
Diesel	74,100 kg/(Tera Joule)	IPCC, 2006
Gas	56,100 kg/(Tera Joule)	IPCC, 2006
Coal	96,100 kg/(Tera Joule)	IPCC, 2006
Electricity	0.48 CO_2/Kilogram	FESCO
Liquefied petroleum gas	63,100 kg/(Tera Joule)	IPCC, 2006

Note: FESCO = Faisalabad Electric Supply Company.

We calculate the CO_2 emissions from the indirect energy source (i.e., electricity) by using the following formula:

$$CO_{2\,indirect\,energy} = C_{electricity} \times LF \times I_{electricity} \qquad (3)$$

where $CO_{2\,indirect\,energy}$ is the annual CO_2 emissions from electricity consumption, $C_{electricity}$ is annual amount of electricity consumption, LF is the line loss factor, and $I_{electricity}$ is the CO_2 emissions factor. Kennedy et al., (2010) proposed that GHG emissions from electricity consumption can be calculated by using equation 3. Thus, this equation is a valid method for calculating emissions from electricity consumption. It is assumed that all electricity generated is consumed within the city and source of power generation is from fossil fuels; thus generation is equal to consumption, transformation loses, and line loses all are sources of CO_2 emissions.

Our last goal is to detect CO_2 sources and sinks nexus in the city and determines whether more sources have risen than sinks. To detect changes in land use/land cover (LU/LC), we use post-classification comparison change detection, which is the most commonly used method to detect these changes. The procedure consists of the following steps: (1) pre-processing, (2) the formulation of classification schemes, (3) supervised image classification, and (4) change detection.

3.1. Pre-processing

The purpose of pre-processing is to perform a geometric synchronization of the satellite images, which is critical for producing spatially correct temporal maps that show LU/LC (Peng, et al., 2011). To overcome this problem, the quadtemporal satellite images were spatially co-registered using the AutoSync tool of ERDAS IMAGINE that uses an automatic edge to edge point matching algorithms, generating thousands of tie points. The RMSE was 0.52 pixels (Table 3).

3.2. Devising of the Classification Sketch

Table 2 shows the classification scheme developed in this study. Primary determination of the inputs of the classification was based on the researchers' prior knowledge of the study area.

3.3. Land Use/Land Cover Categorization

According to Singh, (1989) the most obvious method for detecting changes in land cover / land use is a comparative analysis of the spectral classification produced independently for times t_1 and t_2. It is noted that the accuracy of the change map will be a product of the accuracy for each individual classification. Accordingly, the study independently classifies the Landsat images for the four dates by implementing the supervised classification scheme with a maximum likelihood algorithm. Additional smoothing on the classified images is performed utilizing a 3 by 3 window of majority filter.

4. Results and Discussion

4.1. Energy Consumption of Faisalabad

Figure 2 illustrates the historical trends for coal consumption in Faisalabad from 1971 to 2010 for three sectors. Coal is used in three sectors in Faisalabad: the commercial, industrial and residential sectors. The results show that the industrial sector has dominated coal consumption and that has increased gradually since 1971 and is still increasing. Coal consumption in the commercial sector ended in 1989 and that was due to change in technology and machinery use. In contrast, the industrial sector consumption increased 2 ~ 3 times till 2010. Currently, the industrial, residential and commercial sectors consume 99, 1, and 0%, respectively, of the coal consumed in Faisalabad.

Four sectors are responsible for the city's total gas consumption. It is worth noting that the transportation sector started consuming gas in 1991 (Figure 3). The commercial, industrial, residential, and transportation sectors comprised 1, 97, 2, and 0%, respectively, of the total gas consumption in 1971. The industrial sector has always dominated the city's gas consumption. Although this sector's share has decreased to 57%, due to usage of gas in the rest of the sectors as well, it still consumes more gas than any of the other sectors. Since 1971, the industrial sector's gas consumption has increased by 6 times, whereas the residential sector's gas consumption has increased by 13 times. The transportation sector is an emerging consumer of gas in Faisalabad because prior to 1991 gas was not used in the vehicles of city.

Petroleum products are the only energy source that is currently being used by all of the sectors. Figure 4 shows that the transportation sector has always been the primary consumer of petroleum and is followed by the commercial and industrial sectors. In 2010, the total share of agriculture, commercial, industrial, residential, and transportation sectors was 0, 26, 23, 1, and 50%, respectively. Therefore, the consumption of petroleum products is increasing rapidly in the transportation and commercial sectors but is increasing at a slower pace in the industrial sector. This is due to an increasing number of private cars and motor bikes and the superlative popularity of petroleum as an energy source in the city.

Four sectors consume electricity. Among the studied sectors, only the transportation sector does not consume electricity because of lack of technology. Among them, the industrial and residential sectors are the dominant consumers (Figure 5). Similarly, the agricultural and commercial sectors also consume a considerable amount of electricity. These two sectors are responsible for 7 and 11%, respectively, of the city's total electricity consumption. From 1995 to 1999, electricity consumption declined in the industrial sector and increased in the residential sector. The electricity consumption of both sectors has continued to increase since this time period. A comparative observation shows that the residential sector's share of electricity consumption increased from 10% in 1971 to 40% in 2010, whereas the industrial sector's share decreased from 67% in 1971 to 42% in 2010. Reduction in industrial sector consumption is due to urbanization, with people relocating from rural to urban areas to improve their quality of living, seek jobs, and study. Nonetheless, all four sectors have increased their total electricity consumption.

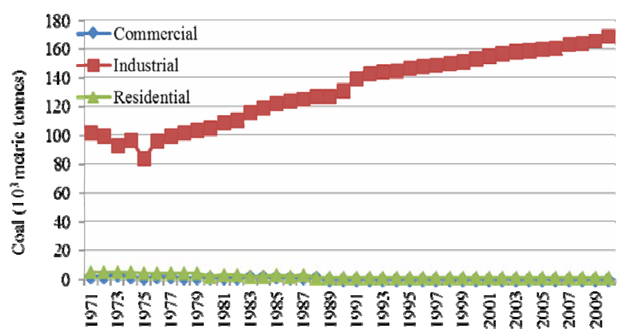

Figure 2. Coal consumption. Note: Energy use data of Faisalabad city is collected from HDIP, 2010.

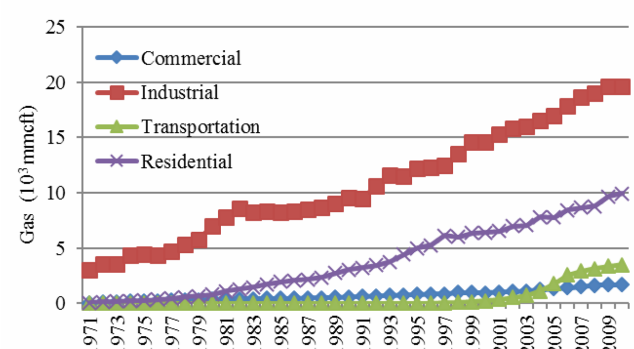

Figure 3. Gas consumption.

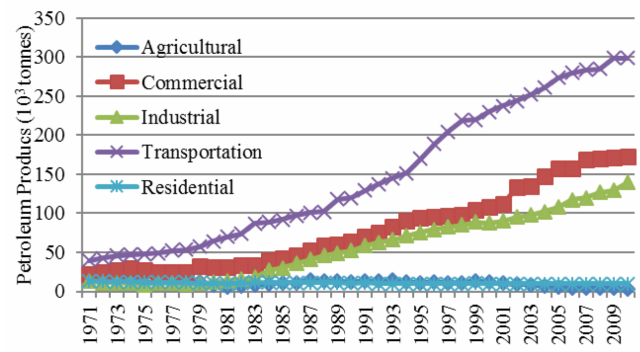

Figure 4. Consumption of petroleum products.

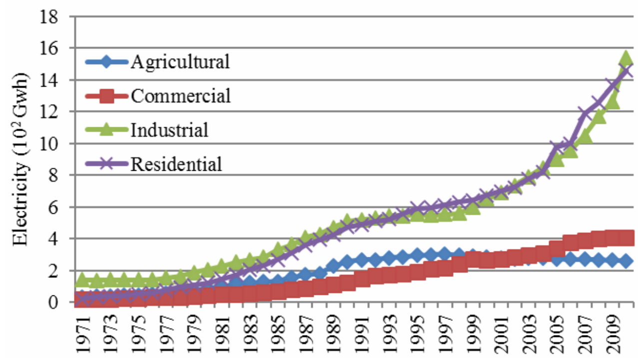

Figure 5. Electricity consumption.

4.2. CO_2 Sources Estimation

Keeping in view the energy use demands from the previous section, CO_2 emissions would be of a similar pattern, more or less. Thus, one can deduce that the shares of CO_2 emissions from coal consumption are also near zero and/or 1% for the commercial and residential sectors. The CO_2 emissions from coal in the industrial sector increased at a rate such that the emissions doubled from 1971 to 2010 (Figure 6). In contrast, the emissions generated from using coal in the other sectors are negligible. Thus, the industrial sector is the sole emitter of CO_2 generated from the use of coal energy.

As gas is an abundant energy source primarily utilized in the industrial sector from 1971 to 2010, CO_2 has increased almost 7-fold (Figure 7) since 1971 and is expected to increase at the same rate in the future as well. The rest of the sectors emit far less CO_2 from consuming gas than the industrial sector and it shows that the industrial sector relies highly on gas in the city than on other sources. The residential, commercial, and transportation sectors emit the second, third and fourth most CO_2, respectively. All of these sectors have grown in size and emit more GHGs from consuming gas than they did in the past. The residential sector is a frontrunner in gas consumption and with increments in population, this will follow suit.

All five sectors not only abundantly use petroleum energy, but also emit considerable amounts of CO_2. From 1971 to 1985, the transportation and commercial sectors dominated emissions of CO_2 from petroleum-based products (Figure 8). Since that time period, the industrial sector has also become a vibrant emitter of GHG produced by petroleum consumption. In the city, these three sectors are the largest emitters of CO_2 generated by the use of petroleum products. For an industrialized city, this trend of energy consumption is normal. Urbanization triggered a labor demand in the industry with increased production that led to higher emissions and use of energy. Connecting this logic, inter-commuting of people caused the transportation sector to be the largest CO_2 emitter. There is less use of public transport, with an increased number of motorbikes in the city. From 1971 to 2010, the transportation sector increased its CO_2 emissions 8-fold. Interestingly, Figure 8 shows that the agricultural and residential sectors have reduced their emissions from petroleum products. Both sectors have reduced their CO_2 emissions by 6 and 2 times, respecttively, from 1971 to 2010. Currently, the agricultural and residential sectors' shares of CO_2 emissions from consuming petroleum products are almost negligible (i.e., near 1% of the total share).

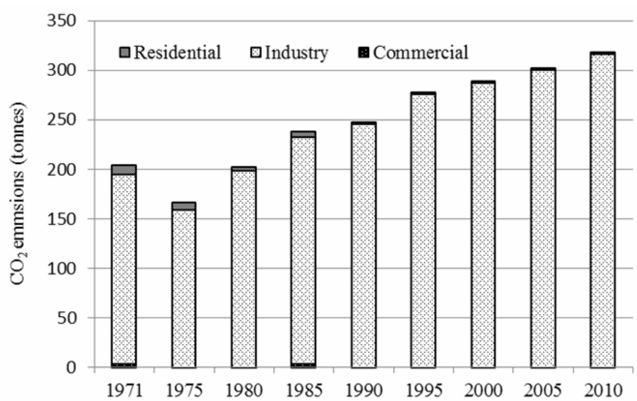

Figure 6. CO_2 emissions from coal.

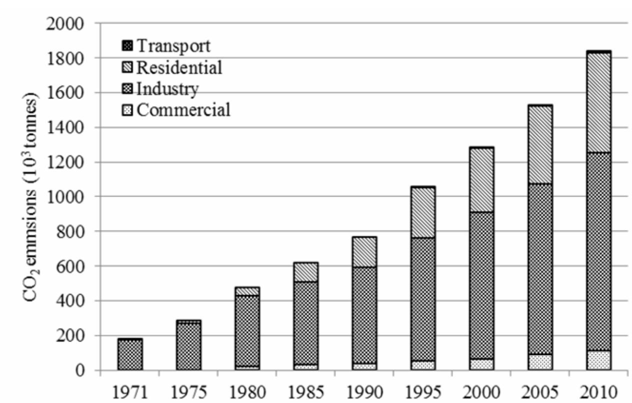

Figure 7. CO_2 emissions from gas.

Figure 9 shows the CO_2 emissions from electricity consumption for four sectors in Faisalabad from 1971 to 2010. The analysis shows that the CO_2 emissions are increasing. Amazingly, the residential sector's CO_2 emissions from electricity consumption have increased 70-fold since1971. From 1971 to 1990, the industrial sector led this category. Then the residential sector led from 1990 to 2007, and now in 2010, the industrial sector once again appeared to be the largest emitter of CO_2 generated by electricity consumption in the city. Fluctuation in the emissions rate is due to high electricity cost in the late 90s and the shutdown of few industrial plants from 1998 to 2006. All of the sectors are emitting CO_2 generated by electricity at continuously increasing rates. Conclusively, we can say that CO_2 emissions from coal and petroleum products are the smallest and largest, respectively.

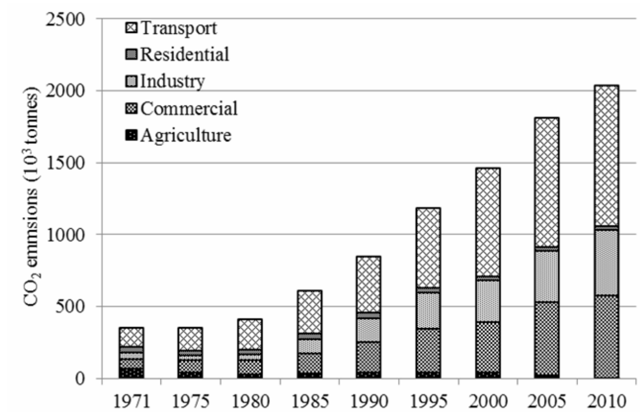

Figure 8. CO_2 emissions from petroleum products.

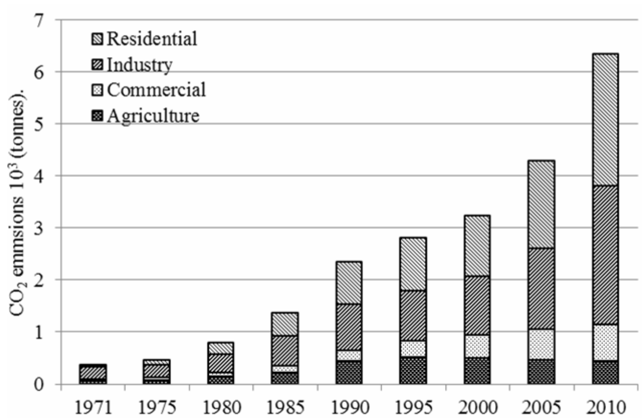

Figure 9. CO_2 emissions from electricity.

4.3. Forecasts of Energy Consumption

This section explains the results of our forecasts for the next 20 years. The forecasts were performed using the ARIMA model presented in Table 5. The same pattern is followed for the forecast of all energy sources and sectors as in previous sections. According to the forecast analysis, the residential sector will stop consuming coal in 2030. The industrial sector will continue to consume coal energy until 2030, and its consumption will increase by almost 1.5 times from 2010 to 2030. This increase is quite high for such a small energy source.

The forecast analysis (Table 5) shows that the industrial, residential, and transportation sectors are large consumers of gas in the city and that they will increase their gas consumption almost 1.5-, 2-, and 3-fold, respectively, in 2030. Conse-

Table 5. Forecasts of Energy Consumption in the City

Energy source	Energy use sector	2010	2011	2015	2020	2025	2030
Coal (10^3 metric tonnes)	Commercial	0	0	0	0	0	0
	Industrial	169	170.794	178.454	188.61	198.631	208.333
	Residential	1	0.94715	0.80913	0.53581	0.17673	0
Electricity (Gwh)	Agricultural	260.45	257.703	241.227	215.275	182.703	143.582
	Commercial	408.63	419.976	459.575	509.561	559.566	609.571
	Industrial	1543.68	1770.36	3904.74	12020.6	39479.4	132592
	Residential	1459.39	1557.1	2014.35	2795.55	3882.62	5391.79
Gas (mm cft)	Commercial	1695.45	1750.58	1906.56	2116.7	2331.01	2543.96
	Industrial	19667.6	20168.7	21880.1	23960.3	26106.6	28256.9
	Residential	9942.3	10451.8	12271.2	14782.6	17529.8	20512.1
	Transportation	3496	3634.3	4466.1	5801.61	7342.79	9072.55
Petroleum Product (tonne)	Agricultural	3107.75	2979.84	1578.24	0	0	0
	Commercial	172267	171002	182950	199671	217374	235339
	Industrial	139223	139977	164059	200807	239785	279623
	Residential	299079	9395.21	8866.01	8413.68	8001.41	7593.99
	Transportation	9539.3	304639	327657	357448	387750	418267

Table 6. Forecasts of CO_2 Sources in Tonnes of CO_2 eq.

Energy source	Energy user sector	2010	2011	2015	2020	2025	2030
Coal	Commercial	0	0	0	0	0	0
	Industrial	316.55052	319.337	331.932	347.636	363.214	378.777
	Residential	1.87308	1.77408	1.51557	1.00362	0.331025	0
Electricity	Agricultural	450.0576	445.311	416.841	371.996	315.711	248.11
	Commercial	706.11264	723.033	790.452	875.697	961.224	1046.69
	Industrial	2667.47904	3082.28	5837.94	10646.1	16293.4	22575.9
	Residential	2521.82592	2690.93	3536.19	5012.71	7107.96	10081.2
Gas	Commercial	112537.502	116197	126550	140499	154724	168859
	Industrial	1140755.71	1170000	1260000	1390000	1510000	1640000
	Residential	576670.907	606224	711753	857419	1016760	1189740
	Transportation	10544.5653	10348.9	11232.2	13373.3	14775	17206.3
Petroleum product	Agricultural	10165.3259	9746.94	5162.36	0	0	0
	Commercial	563478.139	570232	609094	670170	731494	792821
	Industrial	455392.046	457859	536629	656831	784328	914634
	Residential	31202.6687	30768	29032.2	27505.1	26115.4	24761.7
	Transportation	978276.1	1010000	1110000	1240000	1380000	1540000

Table 7. Land Cover/Use Change of the City from 1975-2011 (Unit: hectare)

Land cover/use class	Area in 1975	Area in 1980	Change in area (1975-1980)	Area in 2000	Change in area (1980-2000)	Area in 2011	Change in area (2000-2011)
Trees/grasses	1194.48	1097.37	-97.11	523.98	-573.39	202.77	-321.21
Built-up areas	2262.78	4896.00	2633.22	9547.83	4651.83	13771.08	4223.25
Agriculture fields	4097.43	3199.95	-897.48	2222.91	-977.04	2151.18	-71.73
Sparse Vegetation	5678.64	4778.28	-900.36	2760.57	-2017.71	2284.74	-475.83
Barren land	6256.98	5495.76	-761.22	4360.95	-1134.81	1006.47	-3354.48
Water	8.01	31.32	23.31	83.61	52.29	83.61	0

quently, the industrial sector will lead the other sectors in gas consumption, with the residential and transportation sectors constituting the next greatest consumers of gas by 2030.

According to the analysis, all sectors of the economy will consume petroleum products until 2030, with the exclusion of the agricultural and residential sectors. Consumption of petroleum products will increase by 43 times in the transportation sector and by 2 times in the industrial sector. Thus, the transportation and industrial sectors' shares of petroleum consumption will be higher than those of the commercial and residential sectors until 2030.

In the electricity consumption category, the forecast analysis shows that energy consumption will decrease almost 2-fold in the agricultural sector by 2030, whereas energy use will increase almost 2-fold in the commercial sector. Likewise, energy consumption in the industrial and residential sectors will rise by almost 2 and 4 times, respectively, from 2010 to 2030. Our forecasts show that the industrial sector will remain the leading consumer of electricity in the city and that its consumption rate will increase throughout this period.

As a result, the industrial sector will continuously increase its consumption of coal, gas, and electricity in the future. This indicates that the industrial sector will expand in size and demand for more energy, labor and resources will increase. Likewise, the transportation sector may increase its consumption of petroleum products, whereas the agricultural sector may decrease its consumption for the same reasons discussed in section 3.1. Thus, the overall trend serves as cautionary advice for policymakers and city planners to foresee alternative energy sources to meet possibly higher consumption levels.

4.4. Forecasts of CO2 Sources

The industrial sector will increase CO_2 emissions from coal consumption in 2030 by almost 2-fold. Table 6 indicates that the residential sector will stop emitting coal-based CO_2 in 2027, and that both this sector and the commercial sector will become zero-emissions sectors by the year 2030. This phenomenal change in the residential sector may be caused by usage preferences; coal consumption is not a preferred energy source in households. This might be replaced with other forms of energy in future.

Out of the four sectors that consume gas, the industrial sector will remain the leader until 2030, with a two-fold increase in emissions caused by gas consumption. The second highest emitter will be the residential sector, which will double its emissions from 2010 ~ 2030. The commercial and transportation sectors will increase their emissions by almost 1.5 times over the next two decades. Thus, all of the sectors are emitting CO_2 at an increasing rate, though the rate of increase may differ among the sectors.

Table 6 shows that petroleum products can generate a reasonable amount of CO_2 emissions. The commercial, industrial, and transportation sectors are significant contributors in this regard, as they will emit 792,821, 914,634, and 1,540,000 tonnes of CO_2 eq., respectively, in 2030. Their emissions in 2010 are almost 2 times less than those forecasted in 2030. The transportation sector leads this category, with the industrial and commercial sectors constituting the next most prolific emitters of CO_2 generated by this source of energy. Only the agricultural sector, which will contribute the smallest amount of CO_2 caused by petroleum use, will decrease in its use of petroleum products. All of the other sectors will continue to emit CO_2 at an increasing rate until 2030, as shown by our analysis. Additionally, they may continue to do so in the following years as well.

All of the sectors, except for the agricultural sector, will emit CO_2 generated from electricity consumption at increasing rates. CO_2 emissions from consuming electricity will decrease two-fold in the agricultural sector, whereas CO_2 emissions from electricity consumption will increase by 2, 9 and 4 times for the commercial, industrial and residential sectors, respectively. The industrial sector will be the largest emitter of CO_2 generated by the consumption of electricity. Lower emissions from the agricultural sector may be due to land use change in the study area and probable advancement in machinery and technology though factual change that will be available according to analysis.

Conclusively, among all of the energy sources, gas and petroleum products are the major sources of GHG emissions. Although the rest of the sources also contribute to GHG emissions, their contributions are quite lower than the emissions of these two energy sources. Industries may consume more energy due to high dependency on these energy sources, the elastic supply of these sources and/or the industries' technological reservations. Therefore, different sectors will go through different phases, with an expected increase of CO_2 emissions. Thus, there is the need to consider mitigation options and use clean energy sources.

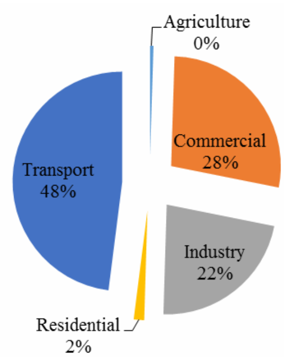

Figure 10. Total CO_2 emissions share of sectors in 2010.

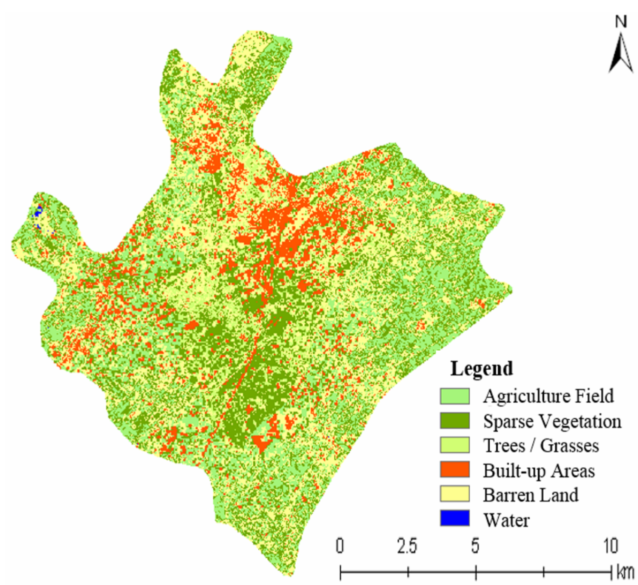

Figure 11. Land use/ cover basic map of Faisalabad City 1975.

4.5. Land Use/Land Cover (LU/LC) Change Analysis

Table 7 shows that the entire study area, which is 19.498 hectares (ha) in size, has LU/LC classes for 1975, 1980, 2000 and 2011. When analyzing the changes in land use from 1975 ~ 1980, urban sprawl increased by 2633 ha. This finding is complemented by the official census (http://www.mongabay.com/igapo/Pakistan.htm), which indicates that the population increased at a constant rate and that industrialization increased in the study area. When the changes from 1980 to 2000 are analyzed, it is found that urban sprawl increased by 4651.83 ha. This is again supported by the census data, which shows a sharp increase in population in the early 1980s. This population increase can be considered the main factor contributing to the growth in urban sprawl. The same trend is observed when the land use changes from 2000 to 2011 are analyzed. From 1975 to 2011, it is found that the size of the farmland, natural vegetation, barren land and water bodies gradually decreased.

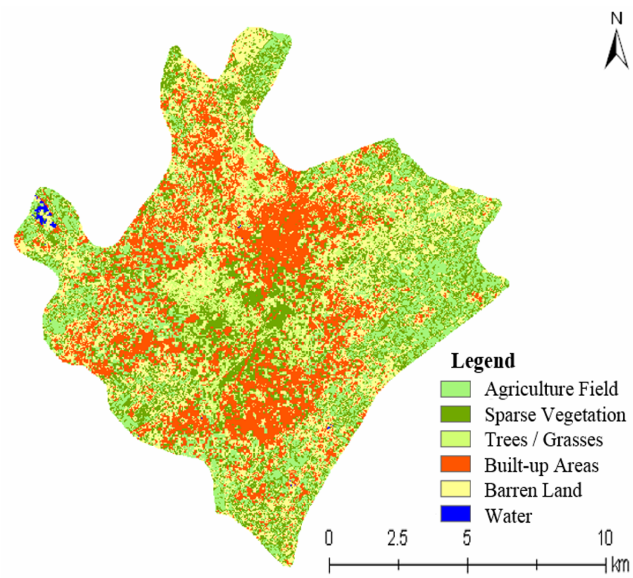

Figure 12. Land use/ cover change map of Faisalabad City 1980.

The agricultural sector is the only sector that can potentially help reduce CO_2 emissions in the city. However, this CO_2 reduction occurs in the agricultural sector for two reasons: (1) the size of the agricultural area decreases as urbanization increases and urban sprawl grows, (2) and a shift in energy use technology occurs. In the past 20 ~ 30 years, farmers operated their machines by intensively using fuels such as diesel oil, petrol, and high speed diesel (HSD). Nowadays, farmers use electricity- and gas-based machinery, which rely less on petroleum products, although the same may not be true for the other mega cities in Pakistan. LU/LC also describes the changes in urban and vegetation areas, which have increased by 4223.25 ha and decreased by 796 ha, respecttively. These changes provide clear proof that carbon sequestration capacity has been reduced by almost 35 ~ 40% in the city while the built-up area increased abundantly within the last 40 years. Urbanization has increased in accordance with the reductions in the size of the agricultural and vegetation areas. In the LU/LC classification scheme, all of the classes have reduced the size of their areas, with the exclusion of the urban area. As shown in Figures 11 ~ 14, the urban area has increased by 60% from 1971 to 2011.

Consequently, a positive relationship exists among energy use, CO_2 sources, and sinks in Faisalabad. Sinks reduced with the passage of time. CO_2 sequestration capacity has been reduced effectively. These changes increased the demand for intensive energy use and, thus, caused CO_2 emissions to increase substantially in the city. It is expected that this trend will continue in the future if policymakers do not address this issue.

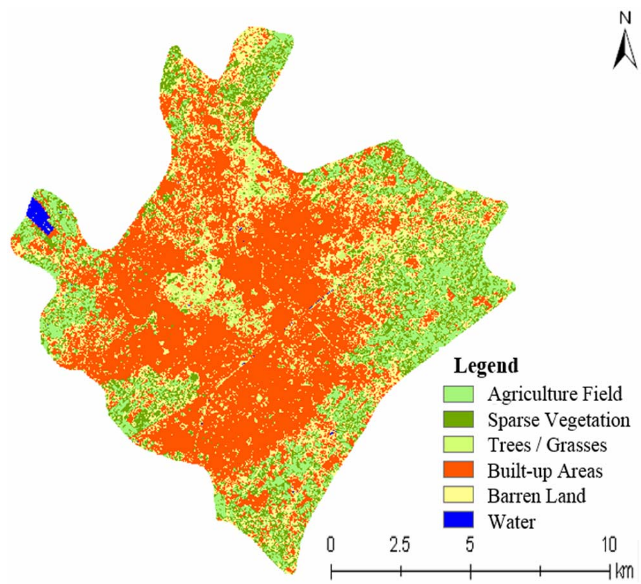

Figure 13. Land use/ cover change map of Faisalabad City 2000.

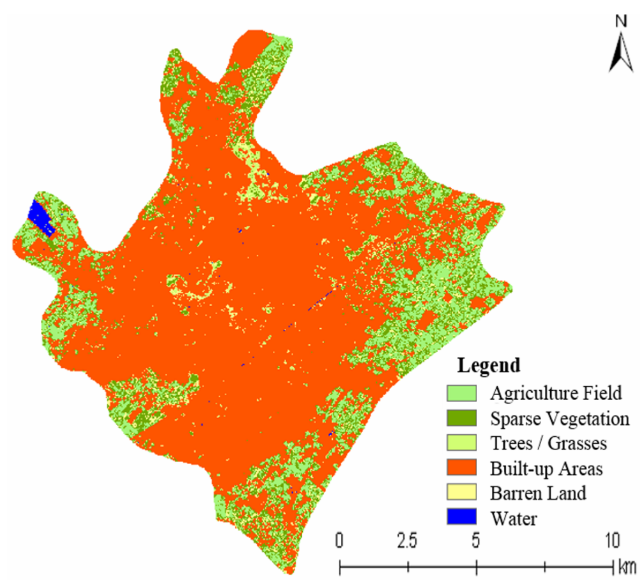

Figure 14. Land use/ cover change map of Faisalabad City 2011.

5. Conclusions

This study had two objectives which were accomplished through the analyses. An inventory of energy use and CO_2 emissions from 1971 to 2010 was able to be compiled. The analyses show that energy use has increased over the past several decades and that energy is expected to increase at relatively the same rate in the future as well. A radical shift in the commercial energy sources utilized by the industrial, residential, commercial, and transportation sectors of the city has occurred. Of these sectors, the industrial sector is the most vulnerable to changes in energy policies and requires immediate attention. Conversely, the agricultural sector has reduced its energy use since 1971. Currently, the commercial, industrial, residential and transportation sectors are responseble for 17, 41, 16, and 26% of CO_2 emissions, respectively, in 2010. It is expected that their shares should continue growing at the same growth rate. Likewise the CO_2 emissions shares of five sectors are shown in Figure 10. The industrial sector led in CO_2 emissions in almost all of the energy consumption sources. The same trend is expected to continue until 2030. From 1971 to 2010, the commercial and residential sectors increased their gas consumption by 59 and 163 times, respecttively.

The rate of CO_2 emissions from all of the sectors in the economy is increasing and should continue to increase until the date forecasted by the ARIMA model (i.e., 2030), except for the agricultural sector, which showed a decreasing emissions rate. This finding indicates that the agricultural sector is expected to show more changes in the future. Overall, the total CO_2 emissions from all of the energy sources and sectors increased almost 8-fold from 1975 to 2010. Therefore, this confirms that CO_2 sources have increased substantially from past to present and will continue to do so in the future as well.

Additionally, our analysis of land use/land cover changes demonstrates that the urban area has grown the most rapidly, with a total increase in size of 60% from 1975 to 2011. In contrast, the tree/grasses and vegetation areas shrank from 6 to 1%, and 29 to 11%, respectively. This finding supports the argument that CO_2 sources increased but that CO_2 sinks shrunk over the past several decades in the city. These changes may be the cause of the increase in CO_2 emissions and other related GHG emissions within Faisalabad city.

Furthermore, this study is a preliminary attempt to break down energy use and CO_2 emissions by sector and forecast future trends. This study may serve as a baseline study for future studies. There is an additional need to conduct studies that can include all of the energy sources, including the city's noncommercial energy sources, to determine all of the factors affecting CO_2 emissions and energy use in the city. These studies should employ different approaches. Determining how one can mitigate CO_2 emissions with the least-cost strategies can provide important policy implications for local policy-makers who wish to prevent increasing energy use and CO_2 emissions in the city. Finally, with such databases and baseline studies, policymakers can design a comprehensive climate action plan and help the state cope with future disasters. In doing so, they may help prepare against future threats from climate change.

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