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# Extended exergy accounting for Karachi

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**Abstract**

Exergy is stepping stone for thermos-economic analyses of complex system. In this paper, we presented an exergy-based resources accounting framework for urban systems. The cumulated exergy consumption in transformations of various resources and energy are presented in details. A case study of Karachi in Pakistan was conducted, in which the main energy supplier is found to be natural gas, followed by coal, nuclear Power and petroleum. The fluxes of labor and capital were also quantified by the exergy metrics, showing that the labor force input to Karachi is twice as much as that of the economy in context of the whole societal system.

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*Keyword:* Extended exergy, urban metabolism, resources shortage, economic capital, labor force

**Nomenclature**

Abbreviation

EEA Extended Exergy Accounting

CEC Cumulative exergy consumption

ER Exergy remediation

EW Exergy of human labor

EC Exergy of equivalent

DO Labor output

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## 1. Introduction

Along with the rapid economic growth and urbanization, the city has been seriously affected by resource shortage and environmental pollution generated from the human production and consumptions of natural resources. Therefore it is necessary to seek for a powerful tool to identify the amount of resource shortfall and explore a more efficient utilization way with less environmental impacts in the urban areas.

Exergy is defined as the maximum work can be performed by a system until it reaches an equilibrium state, according to second law of thermodynamics, which is real scare resource consumed by the physical irreversible process [1, 2, 3]. It can be used as a unified metric for estimating the resource use efficiency and environmental impact [4]. So far, exergy analysis has been widely used in the fields of process optimizations and resource accounting, providing rational and rigorous founded thermodynamic quantification of the natural resource consumptions, environmental losses and degradation of ecosystems [5, 6].

There are some previous case studies conducted on the national scales based on extended exergy such as Norway [3], the US [7], China [6, 8, 9], UK [10], etc. Generally, the concerned system diagram embraces independent sectors like agricultural, residential, commercial, transportation and industrial sectors. In this paper, the exergy value is derived from energy generation of Pakistan in 2014 with modification in the context of Pakistan. The total amount of input exergy into and output exergy from different sectors of Karachi with respect to economic growth are calculated. The labor force within the city was also investigated to reveal the relationship between labor force and economic growth.

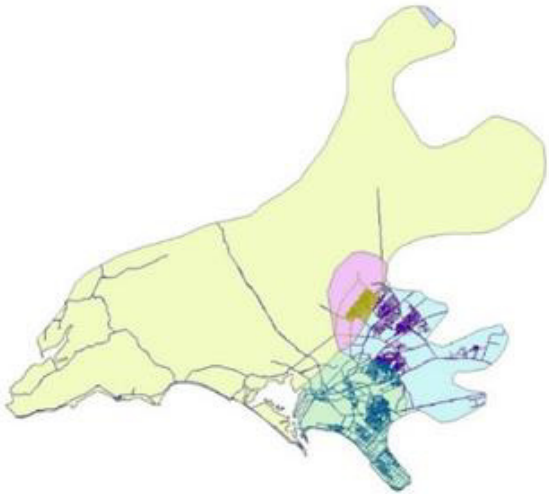

Fig 1 Study area of Karachi in Pakistan

## 2. Methodology

The cumulative exergy consumption (CEC) represents the total exergy inflows cumulated in the production formation including the “raw material” exergy. Parameters which are used in this paper are listed in Table 1 [8, 9]. $E_C$ is the exergy equivalent of monetary flows, $E_W$ is the exergy of human labor of

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