Energy Policy 86 (2015) 233–238

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

LMDI decomposition approach: A guide for implementation

B.W. Ang

Department of Industrial and Systems Engineering, National University of Singapore, Singapore

HIGHLIGHTS

- Guidelines for implementing LMDI decomposition approach are provided.
- Eight LMDI decomposition models are summarized and compared.
- The development of the LMDI decomposition approach is presented.
- The latest developments of index decomposition analysis are briefly reviewed.

ARTICLE INFO

Article history:
Received 20 March 2015
Received in revised form
4 July 2015
Accepted 7 July 2015

Keywords:
Index decomposition analysis
LMDI
Energy indicators

ABSTRACT

Since it was first used by researchers to analyze industrial electricity consumption in the early 1980s, index decomposition analysis (IDA) has been widely adopted in energy and emission studies. Lately its use as the analytical component of accounting frameworks for tracking economy-wide energy efficiency trends has attracted considerable attention and interest among policy makers. The last comprehensive literature review of IDA was reported in 2000 which is some years back. After giving an update and presenting the key trends in the last 15 years, this study focuses on the implementation issues of the logarithmic mean Divisia index (LMDI) decomposition methods in view of their dominance in IDA in recent years. Eight LMDI models are presented and their origin, decomposition formulae, and strengths and weaknesses are summarized. Guidelines on the choice among these models are provided to assist users in implementation.

1. Index decomposition analysis

Index decomposition analysis (IDA) was first used by researchers to study electricity consumption trends in industry in the early 1980s. The objective was to disentangle the impact on electricity consumption of changes in industrial output structure from that in industrial sector energy intensities. Since then there has been tremendous growth in the number of publications in this research area. Several literature reviews have been reported. Ang and Zhang (2000) provide a comprehensive review which covers both the methodological and application fronts. Other and more recent reviews focus on specific sub-areas. For instance, Liu and Ang (2007) deal with industrial energy analysis, while Xu and Ang (2013) concentrate on energy-related CO_2 emissions.

The literature review by Ang and Zhang (2000) lists 87 journal articles up to 1999 that can be appropriately classified under IDA. It is still the most comprehensive review of IDA to date. Our latest count shows that the number has increased to 559 through 2014.[1] The breakdown by time period is as follows: 55 prior to 1995, 125 from 1995 to 2004, and 379 from 2005 to 2014 (all years inclusive). The growth has been exponential, especially in the last ten years. In addition, there have been many reports with a strong policy focus released by research institutes, national agencies, and international organizations. The evidence that IDA is a useful tool in energy analysis and decision making, some 30 years after it was introduced, is strong and growing.

With the increasing maturity of the IDA methodology and changes in the global energy scene, several developments in IDA application can be observed over time. Prior to 1990, the main focus of researchers was on studying the relative impacts of changes in the aggregate level of a group of industrial activities, activity structure of the group, and activity energy intensities on energy consumption. Studies on other energy consuming sectors, namely transportation, residential, and service, started to emerge after the early 1990s. At the same time, after 1990, rising concerns about global warming have led to increased use of IDA in energy-related CO_2 emission studies. The growth in CO_2 emission studies has been very strong. Indeed since 2000 there have been more IDA journal articles dealing with emissions than energy. In the past ten years, application of IDA has also gone beyond the traditional areas of energy and emissions. New areas

E-mail address: iseangbw@nus.edu.sg

[1] In this study, journal articles cover only those written in English and appear in archival peer-reviewed academic journals. The IDA publication statistics given in various places of this paper have been generated based on the 559 titles that have been collected by the author.

http://dx.doi.org/10.1016/j.enpol.2015.07.007
0301-4215/

reported include water use, material and non-energy resource requirements, food production, pollutant emissions, and toxic chemical management. See, for example, Fujii and Managi (2013), Kastnera et al. (2012), Oladosu et al. (2011), Pothen and Schymura (2015), and Zhao and Chen (2014). Traditionally IDA has been used to analyze past developments, i.e. retrospective analysis of changes of an aggregate. Lately there have been a growing number of studies that deal with "prospective analysis". The three main applications are as follows. The first is making future forecasts on the basis of the decomposed effects obtained in retrospective analysis (Lescaroux, 2013; O'Mahony et al., 2013). The second is unraveling projected energy savings or reduced emissions for a future year by effect through decomposing the differences between the projected energy consumption or emission levels for the year for two different scenarios, where one of the scenarios is often the business-as-usual case (Gambhir et al., in press; Kesicki, 2013; Smit et al., 2014). The third is harmonizing and comparing projection results across different models and scenarios through quantifying the underlying drivers or effects which provide a common basis for comparisons (Föster et al., 2013; Hasanbeigi et al., 2014; Park et al., 2013).

Another important development is the use of IDA as the analytical component of the accounting framework to track economy-wide energy efficiency trends. This began in the 1990s following the initiatives undertaken by a number of national and international organizations, including the International Energy Agency (1997) and the Office of Energy Efficiency (2013) of Canada.[2] Since then, national-level studies have been undertaken in a number of other countries, including Australia, New Zealand and the United States (Ang et al., 2010). More recently, IDA was adopted by the International Energy Agency in a special focus on energy efficiency in the World Energy Outlook 2012 (International Energy Agency, 2012) and Energy Efficiency Market Report 2014 (International Energy Agency, 2014), as well as by the European Union in the Industrial Competitiveness Study 2012 (European Commission, 2012). IDA is presently being used by the World Bank and collaboration agencies as the tool for tracking progresses made in energy efficiency globally in the Global Tracking Framework of Sustainable Energy for All (SE4ALL, 2013).[3] The latest SE4ALL global tracking framework report can be found in International Energy Agency and the World Bank (2015).

The term "index decomposition analysis" was coined in Ang and Zhang (2000). It has since been widely accepted to represent what had formerly been known as "decomposition analysis" or "factorization analysis". The study points out that adding the word "index" before "decomposition analysis" is to differentiate this line of work from that of structural decomposition analysis (SDA) which is based on input–output analysis.[4] The basic principle of IDA has strong linkages with index number problems in statistics and economics. The underlying concept was largely formalized in the 1980s. Refinement and extensions to the technique have been regularly made by researchers. Examples are the search for methods that produce decomposition results without leaving a residual term, catering to cases where decomposition involves many factors or effects, spatial decomposition analysis, integrating physical and economic activity indicators in a decomposition exercise, ensuring consistency in sector aggregation when the data set has more than one level of sector aggregation, and attribution analysis of the estimated impacts by sub-sector or sub-category.

With such refinement and the need to cater to a wider range of application areas and problems, there has also been convergence with regard to IDA methods used by researchers. Prior to 1990, decomposition analysis was conducted largely based on the concept of the Laspeyres index. In the 1990s, a gradual shift towards the Divisia index was observed, or more specifically towards the method proposed by Boyd et al. (1988) which has later been referred to as the arithmetic mean Divisia index (AMDI) method. Since 2000, the most popular IDA approach has been the logarithmic mean Divisia index (LMDI) methods. The LMDI decomposition methods were adopted in two-thirds of the 254 IDA journal papers published over the five-year period from 2010 to 2014. On an annual basis, the share of papers using LMDI has been rising, from 50 percent in 2010 to 76 percent in 2014. The trend indicates that LMDI is likely to further increase its dominance over time.[5]

2. The LMDI decomposition approach

The LMDI decomposition approach comprises two different methods, LMDI-I and LMDI-II. The difference between them lies in the weights formulae used. In each case several decomposition models have been reported. The first model was proposed in 1997 and the term "LMDI" was introduced a year later in 1998. The two methods, LMDI-I and LMDI-II, were only formally introduced in 2001. The popularity of the LMDI approach stems from a number of desirable properties it possesses (Ang, 2004) which will be presented in later sections. A practical guide to LMDI-I is reported in Ang (2005). With LMDI now firmly established as the preferred approach in IDA, it is timely to conduct stocktaking by providing a precise and definitive documentation of the various LMDI models, including their origin, basic formulae, and key features. This will help potential users to make sensible choices and decisions when implementing it in their studies.

For both LMDI-I and LMDI-II, a decomposition analysis problem can be formulated either additively or multiplicatively. In additive decomposition analysis, the arithmetic (or difference) change of an aggregate indicator such as total energy consumption is decomposed. The aggregate change and decomposition results are given in a physical unit. In multiplicative decomposition analysis the ratio change of an aggregate indicator is decomposed. In this case, the aggregate change and decomposition results are expressed in indexes.

Furthermore, other than a quantity indicator such as energy consumption, the aggregate indicator whose change is to be decomposed can be an intensity indicator, such as energy use per value-added (for industry), per passenger-kilometer (for passenger transportation), or per unit floor space (for the residential sector).

[2] Office of Energy Efficiency (2013) is the 16th edition reporting on the national energy efficiency studies initiative undertaken by Canada that started in the 1990s.

[3] SE4ALL is a global initiative led by the Secretary-General of the United Nations to achieve universal energy access, improve energy efficiency, and increase the use of renewable energy.

[4] For a study on the similarities and differences between IDA and SDA, see Hoekstra and van den Bergh (2003).

[5] Slightly less than a third of the publications from 2010 to 2014 use a variety of other IDA methods. They include the AMDI, Laspeyres index, Fisher ideal index, Shapley/Sun, generalized Fisher index, and some other *ad hoc* methods. When decomposition analysis is for an aggregate energy intensity indicator and involves only two factors to give structure and intensity effects, greater variations in the choice of IDA methods among studies are observed. The decomposition problem is similar to separating national income and product accounts to prices and quantity effects where a large variety of index numbers can be applied. For studies that involve more than two factors, which are the norm in energy-related emission IDA studies, some of these indexes, such as the Fisher ideal index, cannot be easily applied as the formulae become fairly complex. In such cases, LMDI methods tend to dominate since their formulae take the same form irrespective of the number of factors and are therefore easy to implement (see Section 3.3).