Holistic assessments of the linkage between well-being and energy use: studies on the Mexican case

Jordi Cravioto Caballero

Holistic assessments of the linkage between well-being and energy use: studies on the Mexican case

THESIS

Presented to the Department of Socio-Environmental Energy Science
of the Graduate School of Energy Science
Kyoto University
In Fulfillment of the
Requirements for the Degree of
Doctor of Philosophy in Energy Science

Jordi Cravioto Caballero, Master of Energy Science

September 2016

Table of Contents

Page

List of Figures

List of Tables

Table Page

Abstract

Throughout history, more effective harnessing of energy resources has significantly improved human conditions. Energy, now essential for virtually every activity, has been crucial to satisfy basic and complex human needs. Nevertheless, the current amount of energy consumption in the world is already posing serious threats to human life from numerous socio-environmental impacts associated to it.

Under this usual yet critical context, understanding the energy-well-being link is one, if not the most essential topic in the modern sustainability agenda. Low energy consumption with higher levels of well-being is the vision of a sustainable lifestyle, but steps towards such a vision are insufficient, mostly due to the poor understanding of the energy-well-being link and the difficulties associated to its study.

Although previous research related to the link can be tracked as early as the mid-19th century, in the literature is difficult to find explanations on how exactly energy use contributes to well-being levels. Novel methods considering numerous variables in the relationship, or novel concepts capable to bridge both ends closer are two aspects barely explored, but mostly needed to advance such understanding. The contribution of this thesis is inspired by this necessity, and therefore, it is aimed at analysing the connection between human well-being and energy use using two approaches. The first consists of a country-based holistic assessment of three aggregated comparative-performance-based indices. This approach in a macro perspective identifies key factors explaining higher well-being indices mixed with low energy use and environmental impact. The second, a more micro-scale analysis, is concerned with how both dimensions (well-being and energy use) get linked together through the concept of energy services at households. Both parts are elaborated focused on Mexico as a case study to more specifically contextualise findings.

The results in the first analysis point to the following conclusions: First, that more elements relate to higher well-being levels as seen through aggregated indices of alternative well-being measures compared to economic ones. Climate, region, religious group, language, age of population, affluence level, and work-life balance associated with higher

efficiency of aggregated indices of alternative measures of well-being (i.e. human development index and subjective well-being with total primary energy supply and carbon dioxide emissions from energy use). In contrast, only work-life balance and to a lesser extent geographic and demographic elements associated with higher production efficiency (i.e. GDP per capita aggregated with total primary energy supply and CO2 emissions from energy use).

Second, that for the case of Mexico to attain higher levels of such efficiencies, a refocus on an alternative development path divergent from the idea of increasing economic activity is needed. This path should consider the influence of cultural elements in more local contexts, given that there are considerable internal differences in terms of climate, geography and local customs reflecting values in Mexico. Technological improvements for more efficient use of energy should be promoted taking into account all these aspects. However, the most important of the analysed elements could be lifestyle. In particular, the amount of leisure time to improve work-life balance of the Mexican population. Associated with better efficiency levels holistically in all the aggregated measures, the hours devoted to leisure should be increased as well as the activities alternative to consumption for the population to engage with. This would also require the creation of the necessary infrastructure and incentives among agents involved in such a change.

On the other hand, energy and well-being analysed more locally through the concept of energy services at Mexican households concluded the following:

First, that the correlation between six energy services (communications, entertainment, food preservation, illumination, temperature regulation and transport) and (subjective) well-being levels ranged between 0.3 - 0.4, observing certain differences among the two income settings selected for the study.

Among these energy services, transport and temperature regulation were the most strongly correlated to increases in well-being levels (regardless of income level), followed by entertainment (being more important in the middle income setting), and lastly illumination, communications and food preservation.

Further results from principal component analysis in conjunction with these correlations suggested that improvements on energy services occur in blocks comprising relevant and rather irrelevant elements for well-being. Energy services, in general, seem to be linked more strongly at middle incomes compared to the lower ones.

By including predictors related to material improvements in the relationship, it was found that in the low-income location, basic infrastructure improvements in the house such as simple but effective reconditioning of wall and floor materials are the most effective aspects to enhance energy services (and ultimately well-being). Promoting access to "modern" energy would come in second place, and better appliance technology, despite the large environmental benefits, would come third, as it relates less on energy services. Additionally, public transport services would also be essential for households in this location.

In contrast, at households in the middle-income region indoor activities progressively relate to well-being levels, and thus, commodities and better technology become more relevant aspects. Their linkage to material gains, however, is weaker and it diminishes more as income further increase. This issue is crucial because promoting "sustainable" consumption might easily result into trifling gains. Thus, alternative strategies to simply acquiring more efficient commodities are essential, supporting the need for better lifestyles reported in the first part described above.

This dissertation has found that the connection between human well-being and energy use is determined by a set of geographic, demographic, material and lifestyle considerations that should be considered in future strategies to enhance well-being levels in Mexico, and has described in more detailed how exactly does energy and associated material predictors can contribute to enhance well-being levels in the light of Mexico as a case study.

Acknowledgements

Con esta tesis doctoral culmina finalmente una etapa de aprendizaje e inolvidables experiencias en la Universidad de Kioto. A través de esta breve mención quisiera expresar mi más sincero y profundo agradecimiento a todos aquellos que apoyaron este trabajo. En principio, a los profesores Keiichi Ishihara, Hideyuki Okumura y Eiji Yamasue, mis mentores japoneses, que generosa y pacientemente han dedicado todo su esfuerzo en formarme en el mundo de la investigación. Al Ministerio de Educación de Japón y a la Escuela de Posgrado en Energía, agradezco su noble apoyo económico para este estudio. Al personal administrativo de la escuela de posgrado y de la Unidad del Centro Global de Excelencia, gracias por su atenta ayuda siempre. A los profesores Hironobu Unesaki y Benjamin McLellan, gracias por estimular la mejora del contenido final de la tesis y aceptar formar parte de mi comité de revisión. Al Sr. Shoji Fujimoto, técnico de nuestro grupo, gracias por su cortesía, buen humor y eterna disposición. A mis compañeros y amigos del laboratorio, quedaré siempre agradecido por sus reflexiones y su continuo aliento. A mis amigos Randy Muth, Guillermo López, Rigoberto García, Jorge Gómez, Ndumiso Dlamini, mi hermana Michelle, así como al Dr. Kyle Knight, mil gracias por leer y comentar mis escritos, su opinión ha tenido un valor inestimable. A mis amigos Emilio Marrufo, Ana Luisa Garza, Luis Manrique, Xochitl Gálvez y Nizván Nava, gracias por su bondadosa ayuda para recopilar datos y hacer entrevistas en México. A tres de mis mentores en el Tecnológico de Monterrey: los profesores Eugenio Aguilar, Enrique Muñoz y Humberto Rodarte, gracias por su impulso, consejos y sobre todo inspiración para emprender este camino. A Ndumiso, Jorge, Rigo, Memo, Randy y tantos amigos que quizá hoy estoy omitiendo, mil gracias por hacerme pasar estos años en Japón muy feliz con su amistad. A mis queridos amigos Hugo Herrmann, Memo, Rodrigo Torres, Monica Martinez, Luis Salas, Miguel Verde, Orlando Jaramillo, Kyoko Takahashi entre muchos más, mil gracias por estar ahí en todo momento. Y finalmente, el mayor agradecimiento para mis dos dolidas familias que tantas veces he dejado de lado por concluir este sueño. Mamá, Papá, Aníbal, Mochi, Jing, Emiliano: les dedico con amor esta tesis.

Jordi Cravioto Caballero

Holistic assessments of the linkage between well-being and energy use: studies on the Mexican case

I. Introduction

1.1 Energy use, human well-being and sustainability

Energy is one of the most essential elements for human life. It is crucial to satisfy basic human needs, such as shelter, cooking or heating, and for more complex ones. Any human activity requires energy inputs, and the natural aim of these activities is to improve the living conditions of individuals. Improving living conditions translate into increases on human well-being, thus well-being can be regarded as the ultimate element in the overall chain of energy consumption (Jonsson et al., 2011; Haas et al., 2008; Norgard, 2000; Kahane, 1991).

Nevertheless, well-being equated solely with consumption as suggested by the neoclassical economic thought (Mol and Spaargaren, 2000; Vincent and Panayotou, 1997), contrasts with alternative views on well-being. Some groups define well-being in terms of objective indicators of quality of life (Veenhoven, 2005; 1996; 1995) and others in more subjective ones (see Diener et al., 2009 for a review). Both are less directly related to material use.

In sustainability science, well-being through the "alternative" measures have received more attention, because it allows to envision higher levels without the need of large amounts of consumption (Knight and Rosa, 2011; Dietz et al., 2009; Seyfang, 2009; Jackson, 2005; Prescott and Allen, 2001; Dietz et al., 2001). In addition, a significant body of research has demonstrated that consumption is a major cause of global environmental degradation, actually having negative effects on well-being levels (Redclift, 2013; York et al. 2003; Rothman, 1998).

Under such a context, energy is a major if not the most important element. Besides being directly used for human needs, energy is involved in all the stages of goods production.

Yet, at its current scale it is increasingly imposing serious threats to future human life from the scarcity of fuels (Smil, 2005) and from side effects associated. Social aspects concerning the production and supply is a major concern (Cravioto et al., 2011b; Higashikura et al., 2012). Air pollution from burning fossil fuels is another, causing innumerable deaths and related diseases (Cravioto et al., 2013; Mage et al., 1996; Pope et al., 1995), while fuel extraction affects ecosystems and local habitats (Tester et al., 2005). On a global scale, greenhouse gases, which originate in as much as 80 percent from energy use, are already well confirmed as one, if not the most, pressing issue for future life (Meinshausen et al., 2009). Needless to say, high concentrations of these gases give rise to climate change, disrupting cycles of ecosystems, food production and a large number of associated social impacts (Rosenzweig and Parry, 1994). Even the damage suffered from the loss of ecosystems or the psychological grief from the destruction of natural aesthetics can be associated with the excessive use of energy (Brady, 2006).

Given all this, a clear understanding of how exactly energy use contributes to higher levels of human well-being measured through "alternative" measures is crucial, but research on such direction has received little attention (Steinberger, 2016; Rosa et al., 1988; Rosa and Machlis, 1983). Investigation on the energy-well-being is increasingly needed because of many compelling reasons. For starters, higher levels of well-being with low environmental damage and energy consumption should be aimed as the future vision of a sustainable human life. This perspective has its roots on the influential Brundtland Report of 1987 that considered sustainability the goal of "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, p. 8). More recently, human sustainability resembles an efficient relationship of high quality of life with low pressure on nature (Chambers et al., 2014). The Sustainable Development Goals embrace such a view, as they propose to have clean and affordable energy (7th target) capable to enhance well-being levels (3rd target), eradicate poverty and improve health and education (UN, 2015). Academic research also supports this vision, arguing for the need to approach develop measurements of energy and well-being rather neglected in the past literature (Diekmann et al., 2010; Graedel and van der Voet, 2010; Smil, 2005).

Crucial aspects that current research should begin exploring are numerous. For example, the relationship between energy and well-being at multiple levels, contexts, and through more tractable notions. In addition, a particularly local focus is needed given the complexity of the scale and the multiple contexts where such link takes place. The next section will introduce a brief historical summary of multidisciplinary and transdisciplinary works related to this topic of research, highlighting their main contributions and shortcomings.

1.2 Academic research on the energy-well-being link

Although the first research on the connections between human aspects and energy use dates to the middle of the 19th century, the energy-well-being link itself has received rather little attention in the literature (Knight and Rosa, 2011; Rosa et al., 1988, Rosa and Machlis, 1983). Social scientists and natural scientists have focused on how energy penetrates other broad human concepts, gradually shifting to more specific notions and multidisciplinary research.

According to Rosa et al. (1983) the first record of academic interest on the effects of energy use on human well-being dates back to the beginnings of the field of sociology:

> "Hebert Spencer and Max Weber believed the process of societal advance and the differences in the advancement could be accounted by the ability to harness more and more energy for production" (Spencer, 1880 in Rosa et al., 1988).

As such, energy use was considered the foundation for a broad, though ambiguous, idea of human progress (Cottrell, 1955; White, 1959, 1949; Mumford, 1967, 1934; Carver, 1924). More modern approaches on specific indicators, such as economic development, human development and well-being were pioneered by this research.

Groups of natural scientists also contributed to the development of early theory, venturing on the first transdisciplinary approaches. Wilhelm Oswald, the 1909 Nobel prize in chemistry, suggested that the base of all social change was determined by the amount of "crude energy" transformed into "useful energy" (Ostwald, 1909), stating that "the greater this relation, the higher the social progress attained". Physician Sergei Podolinsky and later Frederick Soddy, another Nobel laureate, contributed further with a notion typical in natural science phenomena: the existence of limits to usable energy (Martinez-Alier and Naredo, 1982; Soddy, 1912). These works could be considered the foundations in the development of multidisciplinary approaches, greatly influencing subsequent economic theory (Daly, 1991; Lovins, 1977; Georgescu Roegen, 1976, 1971) and concerns on the material and environmental limits (Dietz et al., 2009; Rees, 1992).

The broad idea of human progress gradually transformed into more operational concepts often turning to economic growth for a concrete measure. These assumed that utility or consumption were good measures (Schurr and Netscheret, 1960), and such perspective continues even in more recent studies assuming them in close connection to human well-being (Naseri, 2000).

In contrast, another group has examined the relationship between energy and well-being indicators more directly. Among these, Mazur and Rosa (1974) were probably the first to describe that there is a threshold of energy consumption, above which gains on real well-being decrease in scale. This perspective undermined many of the mainstream economic rationale that equated well-being with economic growth, and along with growing concerns on environmental damage (Daly, 1991) and disruptions on energy supply (Boulding, 1974), it influenced more recent multidisciplinary research clearly alluding to the importance to assess how higher well-being with low energy and environmental damage might be attained (Steinberger et al., 2016; Lamb et al., 2014; Steinberger et al., 2012; Mazur, 2011; Knight and Rosa, 2011; Steinberger and Roberts, 2010; Dietz et al., 2009; Martinez and Ebenhack, 2008; Pasternak, 2000).

1.2.1 Transdisciplinary approaches from engineering. Engineers as part of natural scientists, although usually less interested with realms beyond the technical, have also been concerned with how the use of energy relates to well-being levels.

Engineers have typically targeted efficiency and technology in the energy provision system, and thus have been traditionally less concerned with human-related domains (Smil, 2005, 1994; Tester et al., 2005). Some research, however, has ventured in studying social implications of efficient energy use. Environmental, economic, political, regulatory or social implications of efficient energy use are analysed by Industrial Ecology through approaches focused on material and energy flows (Lifset and Graedel, 2002; Erkman, 1997; Jelinski et al., 1992). These constitute most of the relevant literature describing such implications.

Others refer more directly to the energy-well-being link (Jonsson et al., 2011; Haas et al., 2008; Norgard, 2000), despite their scope do not cover explanations how energy use contributes to well-being levels. Yet, some recent approaches have applied methods used in operations research, which seem to be a fertile ground for integrating multiple dimensions into aggregated performance indices. Cravioto et al. (2011a) and Ramanathan (2002) constructed two multidimensional indices of energy, environmental stress and well-being using economic and alternative well-being indices. Further work is needed, however, in terms of discussing such approaches with more up-to-date theory.

1.3 Novelty of this thesis

The previous review has shown that research has focused little on the links between energy use and well-being. Clear understanding of how exactly energy use contributes to higher levels of human well-being is crucial, but research on such direction has received little attention. The novelty of this thesis lies in the development of three novel assessments to understand how energy use contributes to well-being levels at different scales of analysis.

1.3.1 A holistic perspective. One assessment is inspired in the need for holistic approaches to analyse the numerous effect of energy use on human well-being. As described previously, energy use relate to economic activities and ultimately well-being levels through multiple paths. Nevertheless, it is clear that high economic development, environmental performance and human well-being (health, education or subjective well-being) are the goals of humanity. Achieving these goals in the most efficient way from a resource and environmental perspective are the goals of a sustainable lifestyle. Given this, a holistic assessment is proposed to evaluate performance considering all those multiple dimensions. An engineering methodology known as Data Envelopment Analysis is utilised for such purpose, and theory is brought into the analysis to find explanations regarding as what factors relate to energy use mixed with low environmental impact and higher well-being levels. Using a particular case study (Mexico) further discussion is elaborated regarding sustainable development paths.

1.3.2 Energy services: a better linking concept. In addition to a more holistic approach, research on energy and human well-being needs innovative concepts capable of better linking both ends. In the aforementioned literature, two barely explored concepts have such potential: end-uses of energy and energy services.

End-uses of energy, on one hand, refer to "the content of primary energy supplied to the consumer at the point of end-use" (Sovacool, 2011). They are physical quantities (of gas, wood, gasoline, electricity, etc.) measured in units of heat or work. As such, they are considered disaggregated measures of energy use. Energy services (ES) are matrices of end-uses mixed with other elements, which result in specific benefits for human satisfaction or well-being (Sovacool, 2011; Modi et al., 2006). Provided with an adequate measurement, energy services can act as well-being surrogates from direct (end-uses) or indirect (goods used for the service) energy consumption.

Such an approach measuring ES as surrogates of well-being had never been done before and is here presented. Through such, the effects of energy use on well-being are better understood locally, and using the same case study (Mexico) a discussion of locally-based sustainable development paths is elaborated.

1.4 Purpose

The present thesis is aimed at exploring the connection between human well-being and energy use in two scales of analysis. The first consists of a country-level analysis of efficiency indices of production, development and well-being in relation to energy use and environmental impact. The second, a household-level analysis concerned on how exactly energy use contributes to higher levels of human well-being through energy services at households. Both assessment are focused on Mexico to understand the findings in a more concrete context.

1.5 Layout

The subsequent chapter (II) presents the data and methods used in this dissertation. Chapter III presents the country-based holistic assessment (based on the work by Cravioto et al., 2011a). Chapters IV and V presents the local analysis through the concept of energy services (based on Cravioto et al., 2014). And lastly, chapters VI and VII summarise the conclusions and the key areas for further research.

1.6 References

Boulding, K.E. (1974). Social system and the energy crisis. Boulder, CO: University of Colorado.

Brady, E. (2006). Aesthetics in practice: Valuing the natural world. Environmental Values, 15(3), 277-291.

Carver, T.N. (1924). The economy of human energy. New York: Macmillan.

Chambers, N., Simmons, C. and Wackernagel, M. (2014) Sharing nature's interest: ecological footprints as an indicator of sustainability. Routledge.

Cottrell, F. (1955). Energy and society. New York: McGraw-Hill.

Cravioto, J., Yamasue, E., Okumura, H. and Ishihara, K.N. (2011a). Performance analysis between well-being, energy and environmental indicators using data envelopment analysis. In Zero-Carbon Energy Kyoto 2010 (pp. 49-55). Springer Japan.

Cravioto, J., Bakr, M., Aoyagi, S., Park, S. and Utama, N.A. (2011b). Community acceptance of nuclear power generation in Japan and relevant influencing factors. In Clean Energy and Technology (CET), 2011 IEEE First Conference on (pp. 248-252). IEEE.

Cravioto, J., Yamasue, E., Okumura, H. and Ishihara, K.N. (2013). Road transport externalities in Mexico: Estimates and international comparisons. Transport Policy, 30, 63-76.

Cravioto, J., Yamasue, E., Okumura, H. and Ishihara, K.N. (2014). Energy service satisfaction in two Mexican communities: A study on demographic, household, equipment and energy related predictors. Energy Policy, 73, 110-126.

Daly, H. (1991). Steady-state economics: with new essays. Island Press.

Diekmann, A., Dietz, T. and Jaeger, C. (2010). Human footprints on the global environment: Threats to sustainability. Cambridge, MA: MIT Press.

Diener, E., Kahneman, D. and Helliwell, J. (2010) International differences in well-being. Oxford University Press.

Dietz, T., York, R. and Rosa, E.A. (2001) Ecological democracy and sustainable development. Open Meeting of the Human Dimensions of Global Environmental Change Research Community, Rio de Janeiro, Brazil. Vol. 8.

Dietz, T., Rosa, E.A. and York, R. (2009). Environmentally efficient well-being: Rethinking sustainability as the relationship between human well-being and environmental impacts. Human Ecology Review, 16(1), 114-123.

Erkman, S. (1997). Industrial ecology: An historical view. Journal of Cleaner Production, 5(1), 1-10.

Georgescu-Roegen, N. (1971). The entropy law and the economic process. Cambridge, MA: Harvard University Press.

Georgescu-Roegen, N. (1976). Energy and economic myths. New York: Pergamon.

Graedel, T.E. and van der Voet, E. (Eds.) (2010). Linkages of sustainability. Cambridge, MA: MIT Press.

Haas, R., Nakicenovic, N., Ajanovic, A., Faber, T., Kranzl, L., Müller, A. and Resch, G. (2008). Towards sustainability of energy systems: A primer on how to apply the concept of energy services to identify necessary trends and policies. Energy Policy, 36(11), 4012-4021.

Higashikura, S., Wijaya, M. E., Cravioto, J., Ibano, K., Tamunaidu, P., Kinjo, R. and Lim, J. Y. (2012). Measures for nuclear power substitution in the electricity supply to Kyoto City. In Zero-Carbon Energy Kyoto 2011 (pp. 85-91). Springer Japan.

Jackson, T. (2005) Live better by consuming less?: is there a “double dividend” in sustainable consumption? Journal of Industrial Ecology 9.1-2 (2005): 19-36.

Jelinski, L.W., Graedel, T.E., Laudise, R.A., McCall, D.W. and Patel, C.K. (1992). Industrial ecology: concepts and approaches. Proceedings of the National Academy of Sciences, 89(3), 793-797.

Jonsson, D.K., Gustafsson, S., Wangel, J., Höjer, M., Lundqvist, P. and Svane, Ö. (2011). Energy at your service: highlighting energy usage systems in the context of energy efficiency analysis. Energy Efficiency, 4(3), 355-369.

Kahane, A. (1991). New perspectives for energy efficiency and system optimization. Energy Policy, 19(3), 199-201.

Knight, K.W. and Rosa, E.A. (2011). The environmental efficiency of well-being: A cross-national analysis. Social Science Research, 40(3), 931-949.

Lamb, W.F., Seinberger, J.K., Bows-Larkin, A., Peters, G.P., Roberts, J.T. and Wood, F.R. (2014) Transitions in pathways of human development and carbon emissions. Environmental Research Letters 9.1: 014011.

Lifset, R. and Graedel, T.E. (2002). Industrial ecology: goals and definitions. A Handbook of Industrial Ecology, 3-15.

Lovins, A.B. (1977). Soft energy paths: Toward a durable peace. Cambridge, MA: Ballinger.

Mage, D., Ozolins, G., Peterson, P., Webster, A., Orthofer, R., Vandeweerd, V. and Gwynne, M. (1996). Urban air pollution in megacities of the world. Atmospheric Environment, 30(5), 681-686.

Martinez, D.M. and Ebenhack, B.W. (2008). Understanding the role of energy consumption in human development through the use of saturation phenomena. Energy Policy, 36(4), 1430-1435.

Martinez-Alier, J. and Naredo, J.M. (1982). A Marxist precursor of energy economics: Podolinsky. The Journal of Peasant Studies, 9(2), 207-224.

Mazur, A. (2011). Does increasing energy or electricity consumption improve quality of life in industrial nations? Energy Policy, 39(5), 2568-2572.

Mazur, A. and Rosa, E.A. (1974). Energy and lifestyle: Cross-national comparison of energy consumption and quality of life indicators. Science, 1(86), 607-610.

Meinshausen, M., Meinshausen, N., Hare, W., Raper, S.C.B., Frieler, K., Knutti, R., Frame, D.J. and Allen, M.R. (2009). Greenhouse-gas emission targets for limiting global warming to 2°C. Nature, 458(7242), 1158-1162.

Modi, V., McDade, S., Lallement, D. and Saghir, J. (2006). Energy services for the millennium development goals. New York: Energy Sector Management Assistance Programme, United Nations Development Programme. UN Millennium Project and The World Bank.

Mol, A. and Spaargaren, G. Ecological modernisation theory in debate: a review. Environmental politics 9.1 (2000): 17-49.

Mumford, L. (1934). Technics and civilization. New York: Harcourt, Brace & World.

Mumford, L. (1967). Technics and human development. New York: Harcourt, Brace & World.

Naseri, H. (2000). The relationship between energy and human development. In IAOS Conference on Statistics, Development and Human Rights, Session C-Pa 6e, Montreux, CH.

Norgard, J.S. (2000). Models of energy saving systems: The battlefield of environmental planning. International Journal of Global Energy Issues, 13(1), 102-122.

Ostwald, W. (1909). Energetische grundlagen der kulturwissenschaft (Vol. 16). Klinkhardt.

Pasternak, A. (2000). Global energy futures and human development: A framework for analysis (rep. no. UCRL-ID-140773: 1–25). Lawrence Livermore National Laboratory, California (USA).

Pope, C.A., Thun, M.J., Namboodiri, M.M., Dockery, D.W., Evans, J.S., Speizer, F.E. and Heath Jr., C.W. (1995). Particulate air pollution as a predictor of mortality in a prospective study of US adults. American Journal of Respiratory and Critical Care Medicine, 151(3 pt 1), 669-674.

Prescott-Allen, Robert (2001) The wellbeing of nations: a country-by-country index of quality of life and the environment. Washington, DC: Island Press.

Ramanathan, R. (2002). Combining indicators of energy consumption and CO_2 emissions: a cross-country comparison. International Journal of Global Energy Issues, 17(3), 214-227.

Redclift, M. (2013) Wasted: counting the costs of global consumption. Vol. 12. Routledge.

Rees, W.E. (1992). Ecological footprints and appropriated carrying capacity: What urban economics leaves out. Environment and Urbanization, 4(2), 121-130.

Rosa, E.A. and Machlis, G.E. (1983). Energetic theories of society: An evaluative review. Sociological Inquiry, 53(2-3), 152-178.

Rosa, E.A., Machlis, G.E. and Keating, K.M. (1988). Energy and society. Annual Review of Sociology, 149-172.

Rosenzweig, C. and Parry, M.L. (1994). Potential impact of climate change on world food supply. Nature, 367(6459), 133-138.

Rothman, D.S. (1998) Environmental Kuznets curves—real progress or passing the buck?: A case for consumption-based approaches. Ecological economics 25.2: 177-194.

Schurr, S.H. and Netscheret, B.C. (1960). Energy in the American economy, 1850-1975. Baltimore: Johns Hopkins University Press.

Seyfang, G. (2009) The new economics of sustainable consumption. Minería transnacional, narrativas del desarrollo y resistencias sociales. Buenos Aires: Biblos (2009).

Smil, V. (1994). Energy in world history. Boulder, CO: Westview Press.

Smil, V. (2005). Energy at the crossroads: Global perspectives and uncertainties. Cambridge, MA: MIT Press.

Soddy, F. (1912). Matter and energy. London: Oxford University Press.

Sovacool, B.K. (2011). Conceptualizing urban household energy use: Climbing the "Energy Services Ladder". Energy Policy, 39(3), 1659-1668.

Spencer, H. (1880). First principles. New York: A.L. Burt.

Steinberger, J.K. and Roberts, J.T. (2010). From constraint to sufficiency: The decoupling of energy and carbon from human needs, 1975–2005. Ecological Economics, 70(2), 425-433.

Steinberger, J.K., Roberts, J.T., Peters, G.P. and Baiocchi, G. (2012). Pathways of human development and carbon emissions embodied in trade. Nature Climate Change, 2(2), 81-85.

Steinberger, J.K. (2016) Understanding international energy sufficiency: comparing countries in terms of the role of energy in delivering human well-being (unpublished material). Retrieved Jun, 2016 from http://www.demand.ac.uk/wp-content/uploads/2016/03/DEMAND2016_Full_paper_91-Steinberger.pdf

Tester, J.W., Drake, E.M., Driscoll, M.J., Golay M.W. and Peters, W.A. (Eds.) (2005). Sustainable energy: Choosing among options. Cambridge, MA: MIT Press.

UN [United Nations] (2015) Sustainable Development Goals 17 goals to transform our world. Retrieved Jun, 2016 from http://www.un.org/sustainabledevelopment/sustainable-development-goals/

Veenhoven, R. (1995) The cross-national pattern of happiness. Social Indicators Research 34, 33-68

Veenhoven, R. (1996) Happy life expectancy: a comprehensive measure of quality-of-life in nations. Social Indicators Research 39, 1-58

Veenhoven, R. (2005) Apparent quality-of-life in nations: how long and happy people live. Social Indicators Research 71, 61-68.

Vincent, J.R. and Panayotou, T. (1997) Consumption-Challenge to Sustainable Development... or Distraction-Reply. Science 276.5309 (1997): 57-57.

York, R., Rosa, E.A. and Dietz, T. (2003) Footprints on the earth: The environmental consequences of modernity. American Sociological Review: 279-300.

White, L. (1949). Energy and the evolution of culture. In The Science of Culture (pp. 363-93). New York: Farrar, Straus, Giroux.

White, L. (1959). The evolution of culture: The development of civilization to the fall of Rome. New York: McGraw-Hill.

WCED [World Commission on Environment and Development], 1987. Our Common Future. Oxford University Press, New York.

II. Data and Methods

2.1 Summary

In chapter III, a mathematical technique called Data Envelopment Analysis (DEA) has been applied to formulate indices. As a complement, statistical analysis are used to assess holistically the relationship between energy use, environmental stress and several human well-being dimensions. DEA was used to derive comparative performance indices using country data taken from national statistics. These indices were constructed on a multidimensional basis, taking three well-being indices, and energy use and environmental impact indicators.

In chapters IV and V, statistical methods were used to evaluate the concept of energy services as a linkage between energy use and well-being. For this assessment, data was surveyed in households within two regions of one country, and the analyses are based on statistical techniques, which simplify multiple predictors (principal component analysis), verify factors derived (reliability analyses), test for associations (correlations and linear contrasts) and for significant predictors in a model (backward and hierarchical regressions), and elucidate differences attributed to categorical factors (direct comparison of results).

An explanation of the data and methods used is provided below. Further details complementing these explanations are also found in each methodological section in chapters III, IV and V.

2.2 Data and surveys

2.2.1 Country data. For the assessment in chapter III, a sample of forty countries, among the most populous and representative of each continent, was selected. The data for the analysis comprised of the following: Gross Domestic Product (GDP) per capita taken from the World Bank Database (WB, 2016a; 2016b); two well-being indicators: the Human Development Index (HDI) taken from UNDP (2015), and the Subjective Well-being Index[1] (SWB) taken from The Gallup Poll (Gallup-Healthways, 2016); and energy

---

[1] The New Economics Foundation's SWB is a compilation of regional subjective well-being indices pooled together though an exhaustive review of several databases.

and environmental indicators taken from the International Energy Agency statistics (IEA, 2015a; 2015b). Further details on the treatment of these data is provided in section 3.2 of chapter III. Chapter III also features a comparison with previous sustainability indices using other databases detailed within the chapter (section 3.4).

2.2.2 Regional data. To conduct the analyses of chapter IV and V, data was collected through a survey in two regions in Mexico on March 2011. A total sample of 98 questionnaires provided the data. For chapter IV the data was comprised of a subjective well-being index and six energy services measured in a five-point Likert scale. For chapter V, it was comprised of socio-demographic aspects, household characteristics, household equipment and expenditure on five energy types besides the six energy services already used in chapter IV. The survey procedure, its structure and variables are detailed in sections 4.2 and 5.2.

2.3 Data envelopment analysis

DEA is mathematical technique inspired by the construction of efficiency measures to improve productivity. It is one Multiple-Criteria Decision Analysis (MCDA) derived from Operations Research, formally developed by Charnes, Copper and Rhodes (1978).

DEA is a tool to measure productive efficiency. It is applied to similar Decision Making Units (DMU) or organisations, which have activities or processes that can be compared. When such activity of the DMUs is determined by multiple indicators it is particularly useful, as these indicators can be combined together grouped into inputs or outputs. Through an efficiency relationship of these indicators, for each DMU a linear programming model (LP) is constructed, using all the other DMUs as constraints. Solving each model yields the efficiency score of each DMU, setting the best performer as the most efficient. Hence, DEA is sometimes referred to as the "production frontier" or the "best-practice frontier" method in the literature (Cook et al., 2014). It is noteworthy to say that because DEA is a non-parametric technique it allows consideration of any type of indicator, thus it is also a powerful tool to construct "frontier-based" multidimensional performance indices. This is the application being dealt with in chapter III of this thesis.

This following section will explain the general aspects of the mathematical formulation of a DEA model, and the model preferred for the analysis in chapter III. Section 3.2 of chapter III will detail the considerations when applying the specific data set in the model.

2.3.1 DEA formulations.

As mentioned before, the first DEA formulation was developed by Charnes, Copper and Rhodes (1978). Taking the initials of these authors, their model became known as the CCR DEA model in the literature. CCR models can only handle constant returns to scale (CRS), but they are widely applied in the contemporary DEA literature when details about the production function are not well-known (Cullinane et al., 2006). Mathematical sophistication of DEA models has advanced considerably in recent years. Several types of variations to the original models can be found in many of the available reviews (Cook and Seiford, 2009; Emrouznejad et al., 2008). A CCR model is, however, suitable to attain chapter III's analysis needs and has therefore been selected (see section 3.2.4 for details). In the following paragraphs, the formulation of the CCR model is explained.

2.3.1.1 Fractional DEA.

The first step in the formulation of a DEA problem is to identify the number of inputs and outputs of the DMUs under analysis. The problem will normally contain more than one input and output, requiring a mathematical formulation for its solution. Inputs and outputs are divided and then aggregated linearly. These aggregations yield what is known as virtual inputs and outputs (Ramanathan, 2003). Virtual inputs are thus expressed as:

$$\textit{Virtual Inputs} = \sum_{i=1}^{I} u_i x_i \tag{1}$$

where u_i is a weight assigned to input x_i (from i to I, the total number of inputs), and $u_i \geq 0$ (meaning no weights can be negative).

The virtual outputs are:

$$Virtual\ Outputs = \sum_{j=1}^{J} v_j y_j \tag{2}$$

where v_i is the weight assigned to output y_i (from j to J, the total number of outputs), and also $v_j \geq 0$ (meaning no weights can be negative).

Given (1) and (2), the efficiency of a DMU can be expressed mathematically as:

$$Efficiency = E = \frac{Virtual\ Outputs}{Virtual\ Inputs} = \frac{\displaystyle\sum_{j=1}^{J} v_j y_j}{\displaystyle\sum_{i=1}^{I} u_i x_i} \tag{3}$$

In this equation (3) both weights u_i and v_i are not assigned to the DMU. Instead, they are variables to be determined.

The second step involves proposing a mathematical formulation for the efficiency of one DMU under assessment. This DMU is called the reference or base DMU and is restricted to constraints expressing the efficiency values of the other DMUs. Hence, the base DMU efficiency is set as a maximum attainable, subjected to the efficiencies of the others as constraints. The efficiencies of other DMUs should take a value between 0 and 1, and the weights should be restricted to positive numbers. This is expressed mathematically as follows:

$$\max \quad E_m = \frac{(\mathit{Virtual\ Outputs})_m}{(\mathit{Virtual\ Inputs})_m} = \frac{\sum_{j=1}^{J} (v_j y_j)_m}{\sum_{i=1}^{I} (u_i x_i)_m} \tag{4}$$

subject to

$$0 \ \leq \ \frac{\sum_{j=1}^{J} v_{j_m} y_{j_n}}{\sum_{i=1}^{I} u_{i_m} x_{i_n}} \ \leq \ 1 \quad , \quad n = 1, 2, ..., N,$$

$$u_{i_m}, v_{j_m} \ \geq 0 \quad , \quad i = 1, 2, ..., I \quad , \quad j = 1, 2, ..., J.$$

where,

E_m= efficiency of the m^{th} DMU.

(Inputs)

$x_{i_m} = i^{th}$ input of the m^{th} DMU.

$u_{i_m} =$ weight of the i^{th} input of the m^{th} DMU.

$x_{i_n} = i^{th}$ input of the n^{th} DMU.

$i = 1, 2, ..., I$ (I is the total number of inputs).

(Outputs)

$y_{j_m} = j^{th}$ output of the m^{th} DMU.

$v_{j_m} =$ weight of the j^{th} output of the m^{th} DMU.

$y_{j_n} = j^{th}$ output of the n^{th} DMU.

$j = 1, 2, ..., J$ (J is the total number of outputs).

(Others)

$u_{i_m}, v_{j_m} \geq 0$ (weights should be natural numbers).

$n = 1, 2, ..., N$ (N is the total number of DMUs, and n includes m).

The model above is an extended non-linear programming formulation of an ordinary fractional programming problem. Efficiency E_m for the m^{th} DMU is expressed as a relative efficiency to the other DMUs, setting the constraints of this efficiency subject to others. Similar models have to be replicated for each n^{th} DMU to obtain all the relative efficiencies. A transformation from the above fractional programming model to a linear programming model (LP) is advised and can be done as explained below.

2.3.1.2 Output-maximisation Multiplier DEA. To convert the problem in model (4) into a LP, either the numerator or the denominator of the objective function requires normalisation. In addition, the constraints must be simplified to get the LP in the canonical form (Taha, 2007). By normalising the denominator, the outputs are kept to be maximised, and the resulting LP is known as *Output-maximisation Multiplier (OMM) DEA*. The procedure is as follows:

Normalising the denominator in model (4) yields:

$$
\begin{aligned}
&\max \quad z = \sum_{j=1}^{J} (v_j y_j)_m \\
&\text{subject to} \\
&\sum_{i=1}^{I} (u_i x_i)_m = 1, \\
&0 \ \leq \ \frac{\sum_{j=1}^{J} v_{j_m} y_{j_n}}{\sum_{i=1}^{I} u_{i_m} x_{i_n}} \ \leq \ 1 \quad , \quad n = 1,2,...,N, \\
&u_{i_m}, v_{j_m} \ \geq 0 \quad , \quad i = 1,2,...,I \quad , \quad j = 1,2,...,J.
\end{aligned}
\tag{5}
$$

which can be further simplified to:

$$
\begin{aligned}
&\max \quad z = \sum_{j=1}^{J} (v_j y_j)_m && (6)\\
&\text{subject to}\\
&\sum_{i=1}^{I} (u_i x_i)_m = 1,\\
&\sum_{j=1}^{J} v_{j_m} y_{j_n} - \sum_{i=1}^{I} u_{i_m} x_{i_n} \ \leq 0 \quad , \quad n = 1, 2, ..., N,\\
&u_{i_m}, v_{j_m} \ \geq 0 \quad , \quad i = 1, 2, ..., I \quad , \quad j = 1, 2, ..., J.
\end{aligned}
$$

Using linear algebra (Bronson and Costa, 2007), model (6) can also be expressed in its standard matrix form as:

$$
\begin{aligned}
&\max \quad z = Y_m \cdot V_m^T && (7)\\
&\text{subject to}\\
&X_m \cdot U_m^T = 1,\\
&X \cdot U_m^T - Y \cdot V_m^T \geq 0,\\
&V_m, U_m \geq 0.
\end{aligned}
$$

where,

X_m = row vector of inputs of the m^{th} DMU.

Y_m = row vector of outputs of the m^{th} DMU.

U_m = row vector of input weights of the mth DMU.

V_m = row vector of output weights of the mth DMU.

X = matrix of inputs of all the DMUs.

Y = matrix of outputs of all the DMUs.

The matrices X and Y in model (7) have a dimension m x n, where m corresponds to the number of DMUs and n to the number of inputs or outputs respectively.

2.3.1.3 Input-minimization Multiplier DEA. An analogous LP formulation to the OMM DEA explained above is possible by minimising the weighted sum of inputs in model (4) and normalising the numerator of the objective function. This alternative model is known as *Input-minimization Multiplier (IMM) DEA,* represented as:

$$
\begin{aligned}
&\min \quad z' = \sum_{i=1}^{I} (u_i x_i)_m \\
&\text{subject to} \\
&\sum_{j=1}^{J} (v_j y_j)_m = 1, \\
&\sum_{j=1}^{J} v_{j_m} y_{j_n} - \sum_{i=1}^{I} u_{i_m} x_{i_n} \ \leq 0 \quad , \quad n = 1, 2, ..., N, \\
&u_{i_m}, v_{j_m} \ \geq 0 \quad , \quad i = 1, 2, ..., I \quad , \quad j = 1, 2, ..., J.
\end{aligned}
\tag{8}
$$

Model (8) can also be expressed in its standard matrix form as:

$$
\begin{aligned}
&\min \quad z' = X_m \cdot U_m^T \\
&\text{subject to} \\
&Y_m \cdot V_m^T = 1, \\
&X \cdot U_m^T - Y \cdot V_m^T \geq 0, \\
&V_m, U_m \geq 0.
\end{aligned}
\tag{9}
$$

In models 6, 7, 8, and 9 the number of constraints depends on the number of DMUs, while the number of variables depends on the number of inputs or outputs. Thus, when a small number of inputs/outputs and large data sets are analysed, computations can be intensive using any of these forms. The dual models of these formulations invert the variables with the constraints providing better computational efficiency. The following subsections describe these dual formulations.

2.3.1.4 Input-oriented Envelopment DEA. In LP theory, every problem can be stated in a dual form (See Taha, 2007 for a complete demonstration). The OMM DEA (model 6) derived in section 2.3.1.2, when transformed to its dual, is known as *Input-oriented Envelopment (IOE) DEA*. It takes the following form:

$$
\begin{aligned}
&\min \quad \theta_m && (10)\\
&\text{subject to}\\
&\sum_{n=1}^{N} (y_j\lambda)_n \ \geq \ (y_j)_m \quad , \quad j = 1, 2, ..., J,\\
&\sum_{n=1}^{N} (x_i\lambda)_n \ \leq \ \theta_m\,(x_i)_m \quad , \quad i = 1, 2, ..., I,\\
&\lambda_n \ \geq 0 \quad , \quad n = 1, 2, ..., N.
\end{aligned}
$$

where,

θ_m= efficiency of the m^{th} DMU.

(Constraints)

λ_n = dual variable of constraints in the primal (model (6)).

x_{i_m} = i^{th} input of the m^{th} DMU.

y_{j_m} = j^{th} output of the m^{th} DMU.

x_{i_n} = i^{th} input of the n^{th} DMU.

y_{j_n} = j^{th} output of the n^{th} DMU.

$i = 1, 2, ..., I$ (I is the total number of inputs)

$j = 1, 2, ..., J$ (J is the total number of outputs)

$n = 1, 2, ..., N$ (N is the total number of DMUs, and n includes m)

Model (10) can also be expressed in its standard matrix form as:

$$
\begin{aligned}
&\min \quad \theta_m \\
&\text{subject to} \\
&Y^T \cdot \lambda \geq Y_m^T, \\
&\theta_m \cdot X_m^T - X^T \cdot \lambda \geq 0, \\
&\lambda \geq 0.
\end{aligned}
\tag{11}
$$

where

θ_m= efficiency of the m^{th} DMU.

λ = column vector of dual variables of constraints in the primal.

X_m = row vector of inputs of the m^{th} DMU.

Y_m = row vector of outputs of the m^{th} DMU.

X = matrix of inputs of all the DMUs.

Y = matrix of outputs of all the DMUs.

2.3.1.5 Output-oriented Envelopment DEA.

Analogous to the *IOE DEA* transformation described previously, the dual form of the *IMM DEA* is known as *Output-oriented Envelopment (OOE) DEA*, expressed as:

$$
\begin{aligned}
&\max \quad \phi_m \\
&\text{subject to} \\
&\sum_{n=1}^{N} (x_i \mu)_n \;\; \leq \;\; (x_i)_m \quad , \quad i = 1, 2, ..., I, \\
&\sum_{n=1}^{N} (y_j \mu)_n \;\; \geq \;\; \phi_m \, (y_j)_m \quad , \quad j = 1, 2, ..., J, \\
&\mu \;\; \geq 0 \quad , \quad n = 1, 2, ..., N.
\end{aligned}
\tag{12}
$$

where

ϕ_m= efficiency of the m^{th} DMU.

(Constraints)

μ_n = dual variable of constraints in the primal (model (8)).

$x_{i_m} = i^{th}$ inputs of the m^{th} DMU.

$y_{j_m} = j^{th}$ outputs of the m^{th} DMU.

$x_{i_n} = i^{th}$ inputs of the n^{th} DMU.

$y_{j_n} = j^{th}$ outputs of the n^{th} DMU.

$i = 1, 2, ..., I$ (I is the total number of inputs)

$j = 1, 2, ..., J$ (J is the total number of outputs)

$n = 1, 2, ..., N$ (N is the total number of DMUs, and n includes m)

Model (12) can also be expressed in its standard matrix form as:

$$\begin{aligned} &\max \quad \phi_m \\ &\text{subject to} \\ &X^T \cdot \mu \leq X_m^T, \\ &\phi_m \cdot Y_m^T - Y^T \cdot \mu \leq 0, \\ &\mu \geq 0. \end{aligned} \tag{13}$$

where

θ_m= efficiency of the m^{th} DMU.

μ = column vector of dual variables of constraints in the primal.

Y_m = matrix of outputs of the mth DMU.

X_m = matrix of inputs of the mth DMU.

Y = matrix of outputs of all DMUs.

For further details on the simplifications above refer to DEA textbooks (Cooper et al., 2011; 2007; Ramanathan, 2003), where more comprehensive explanations are available.

2.3.2 Multiplier vs. envelopment DEAs. As seen from the mathematical formulations of multiplier (OMM and IMM) and envelopment (IOE and OOE) DEA models, the dual and the primal forms have the objective functions and constraints interchanged. For applications with a large number of DMUs, the dual forms (envelopment DEAs) have the advantage of being computationally more efficient. This is because the number of constraints of the dual form depends on the number of inputs and outputs, whereas in the primal (multiplier DEAs) the number of constraints depends on the number of DMUs. In most DEA problems, a large number of DMUs is under analysis, compared to the number of inputs and outputs. Envelopment programs are thus more computationally efficient and normally preferred. In this thesis, the envelopment forms are primarily used, although the outcomes from both analysis have been compared with the help of computational programs (see section 2.5).

2.3.3 Input vs. output-oriented DEAs. The difference between input (IMM and IOE) or output (OMM and OOE) oriented DEAs is related to estimations of weak efficiency (slacks). These slacks can be obtained by reducing inputs or increasing outputs (Cooper et al., 2007). For such estimations in the analysis of this thesis, the input oriented DEAs are preferred as the desirable outcome is to reduce these inputs (energy consumption and environmental impact) to attain the output (well-being indices).

2.3.4 Slacks. The purpose of calculating weak efficiency is to estimate the reduction in the inputs or the increment in the outputs to achieve an equally efficient performance as the best peer. Thus, weak efficiency or slacks are usually derived from the envelopment DEA models formulated before, because the constraints in these models are related to inputs and outputs (opposed to the multiplier forms, where they relate to the DMUs). When the envelopment model is reduced to its standard form, in the dual formulation these slack variables are added to the constraints. Unrestrictedness in the sign of some constraints can also occur as a result. Detailed explanations about these transformations are available in Taha (2007) and DEA textbooks (Cooper et al., 2011; Cooper et al., 2007; Ramanathan, 2003). In this thesis, the *IOE DEA* form is prefered (over the *OOE DEA*), because as explained above, the desirable outcome is to reduce inputs (energy consumption and environmental impact) to attain the output (well-being indices). The model derived from the transformation is the following:

$$\begin{aligned}
&\min \quad \theta_m - \varepsilon \left(\sum_{i=1}^{I} S_i + \sum_{j=1}^{J} S_j \right) \\
&\text{subject to} \\
&\sum_{n=1}^{N} (y_j \lambda)_n - S_j = \ (y_j)_m \quad , \quad j = 1, 2, ..., J, \\
&\theta_m (x_i)_m - \sum_{n=1}^{N} (x_i \lambda)_n - S_i = 0 \quad , \quad i = 1, 2, ..., I, \\
&\lambda_n, S_j, S_i \ \geq 0 \quad , \quad n = 1, 2, ..., N. \\
&\theta_m \text{ unrestricted}
\end{aligned} \tag{14}$$

which can also be expressed in its matrix form:

$$\begin{aligned}
&\min \quad \theta_m - \sum_{i=1}^{I} S_I - \sum_{j=1}^{J} S_J \\
&\text{subject to} \\
&Y^T \cdot \lambda - S_J^T = Y_m^T, \\
&\theta_m \cdot X_m^T - X^T \cdot \lambda - S_I^T = 0, \\
&\lambda, S_J, S_I \geq 0. \\
&\theta_m \text{ unrestricted}
\end{aligned} \tag{15}$$

where

θ_m= efficiency of the m^{th} DMU.

λ = column vector of dual variables of constraints in the primal.

X_m = row vector of inputs of the m^{th} DMU.

Y_m = row vector of outputs of the m^{th} DMU.

X = matrix of inputs of all the DMUs.

Y = matrix of outputs of all the DMUs.

S_I =row vector of input slacks

S_J =row vector of output slacks

2.4 Statistical analysis

As briefly mentioned in the summary of this chapter, several statistical analyses are used in this thesis.

2.4.1 Simplification of variables with multiple items. In chapters IV and V, some variables with multiple items are condensed into factors using Principal Component Analysis (PCA). This procedure simplifies the total number of predictors in the association analysis conducted in both chapters. To confirm how well a component could condense such concepts encompassing multiple items, the Cronbach's Alpha of each proposed factor is verified (Field, 2009). Afterwards, the PCAs are obtained. Then, the covariance of each element as well as the Kaiser-Meyer-Olkin (KMO) sampling adequacy and variance explained by the components are used to discriminate unnecessary elements. Elements with coefficients less than 0.2 and with sampling adequacy (covariance) lower than 0.5 were singled out (Field, 2009). All this results in the final components, which serve as measures in the association analyses, and also provide information for the discussions based on comparisons among regions (see sections 4.2 and 5.2 for further details).

2.4.2 Association analysis. For chapters III and IV, correlation analyses are used to test for association among variables. In chapter III to find the key factors of nations having higher well-being scores mixed with low energy use and environmental impact, DEA efficiency scores are tested with numeric and ordinal predictors using Pearson and Spearman correlations. ANOVAs and robust measures of ANOVA (Brown–Forsythe tests) are also used in chapter III to test for differences among categories of predictors in nominal scales.

In turn, in chapter IV four correlation coefficients (Pearson, Spearman, Kendall's Tau and Gamma) are used to test for associations between energy services and well-being. Linear Contrasts are also used in chapter IV to test the hypothesis of a linkage between energy services and well-being using mean scores (Abdi and Williams, 2010).

2.4.3 Regression methods. For chapter V, regression methods are used to build a model to multiple energy-related variables as predictors of energy services (Agresti and Finlay, 2009). The variables are grouped into blocks, and backward regressions are first used to clean the blocks from redundant predictors. Next, hierarchical regressions are used to analyse the block contributions and to further test the predictive power of the variables in the model.

Finally, direct comparisons among the results from two regions, elucidate differences attributed to categorical and structural factors.

2.5 Software

Three main computational tools were utilised to conduct the analyses. To formulate and solve the DEA models in chapter III, Microsoft Excel 2007 (See Ramanathan, 2003 and Cooper et al., 2007 for guidance) and a modified version of the Matlab program "DEA Solver Light" (Mathworks, 2003) were used. For the localised statistical analyses in chapters IV and V, the IBM SPSS Statistics 21 software and a statistical tutorial (How2stats, 2013) was used.

2.6 References

Abdi, H. and Williams, L. (2010). Contrast analysis. Encyclopedia of Research Design, 243-251. Chicago.

Agresti, A. and Finlay, B. (2009). Statistical methods for the. social sciences. Pearson International.

Charnes, A., Cooper, W.W. and Rhodes, E. (1978). Measuring the efficiency of decision making units. European Journal of Operational Research, 2(6), 429-444.

Cook, W.D. and Seiford, L.M. (2009). Data envelopment analysis (DEA) – Thirty years on. European Journal of Operational Research, 192(1), 1-17.

Cook, W.D., Tone, K. and Zhu, J. (2014). Data envelopment analysis: Prior to choosing a model. Omega, 44, 1-4.

Cooper, W.W., Seiford, L.M. and Tone, K. (2007). Data envelopment analysis: A comprehensive text with models, applications, references and DEA-solver software. Springer Science and Business Media.

Cooper, W.W., Seiford, L.M. and Zhu, J. (2011). Handbook on data envelopment analysis (Vol. 164). Springer Science and Business Media.

Cullinane, K., Wang, T.F., Song, D.W. and Ji, P. (2006). The technical efficiency of container ports: Comparing data envelopment analysis and stochastic frontier analysis. Transportation Research Part A: Policy and Practice, 40(4), 354-374.

Emrouznejad, A., Parker, B.R. and Tavares, G. (2008). Evaluation of research in efficiency and productivity: A survey and analysis of the first 30 years of scholarly literature in DEA. Socio-economic Planning Sciences, 42(3), 151-157.

Field, A. (2009). Discovering statistics using SPSS. New York: Sage publications.

Gallup-Healthways (2016) Gallup World Poll: Overall life satisfaction index 2012. Retrieved Jul, 2016 from http:// www.well-beingindex.com/

How2stats (2013). SPSS Tutorials. Accessed Apr 22, 2015 from http://www.how2stats.net/p/home.html

IEA [International Energy Agency] (2015a). CO_2 Emissions from Fuel Combustion 2015. Retrieved Jul, 2016 from http://www.iea.org/statistics/topics/CO2emissions/

IEA [International Energy Agency] (2015b). IEA Headline Global Energy Data (2015 edition). Retrieved Jul, 2016 from http://www.iea.org/statistics/ IEA_HeadlineEnergyData_2015.xlsx

Mathworks (2003). DEA Solver Light. Retrieved Apr 22, 2015 from http://jp.mathworks.com/matlabcentral/fileexchange/4150-dea-solver-light

Ramanathan, R. (2003). An introduction to data envelopment analysis: A tool for performance measurement. New York: Sage.

Taha, H.A. (2007). Operations research: an introduction (Vol. 557). Pearson/Prentice Hall.

UNDP [United Nations Development Programme] (2015). Human Development Report 2015: Work for Human Development - Human Development Index. Retrieved Jul, 2016 from hdr.undp.org/sites/default/files/ hdr14_statisticaltables.xls

WB [The World Bank] (2016a). World Bank International Comparison Program Database: GDP, PPP (current international $) 2012 [Series Code: NY.GDP.MKTP.PP.CD]. Retrieved Jul, 2016 from http://data.worldbank.org/

WB [The World Bank] (2016b). World Development Indicators: Population, total 2012 [Series Code: SP.POP.TOTL7]. Retrieved Jul, 2016 from http://data.worldbank.org/

III. Holistic assessment of energy use, environmental stress and human well-being: a country perspective

3.1 Introduction

The premise of taking human well-being as GDP has long been criticised by academic research, claiming that a number of cultural, economic and social aspects are not considered in the economic indicator. It is advised instead to conceive well-being as a multidimensional measure, expandable into subordinates linked with material and non-material aspects. Energy and resources, on the other hand, are utilised to create goods and services for daily life. These are associated with individual well-being directly and indirectly through a series of environmental impacts related to economic activities. Both aspects are crucial to define human sustainability in local and global scales.

Given the complexity, alternative (and multidimensional) well-being measures, energy use and its socio-environmental effects have scarcely been analysed in conjunction. It is difficult to integrate them using a single measure. Thus, as explained in sections 1.2 and 1.3.1, the available perspectives have analysed the link from one or another viewpoint, lacking of a more holistic approach.

3.1.1 Energy-to-well-being analyses. The interest on the energy and well-being link from a macro perspective is present actually in a rather small number of analyses. From these, fewer have focused on how energy use affects alternative well-being indicators. Among them, Mazur and Rosa were probably the first to assess them (Rosa et al., 1981; Mazur and Rosa, 1974). Later followed by further research (Steinberger et al., 2012; Mazur, 2011; Steinberger and Roberts, 2010; Martinez and Ebenhack, 2008; Garcia, 2006; Smil, 2005; Pasternak, 2000). All of them, however, have evaluated the link using central tendency methods, demonstrating repeatedly that there is a logarithmic growth of several well-being measures in relation to increases in energy consumption (see figure 1). One aspect still not clear from these results is how certain countries can achieve higher levels of well-being with lower levels of energy consumption, an area in their two-dimensional plots (figure 1) commonly known as the Goldemberg corner (Steinberger and Roberts, 2010 referring to Goldemberg et al., 1985).

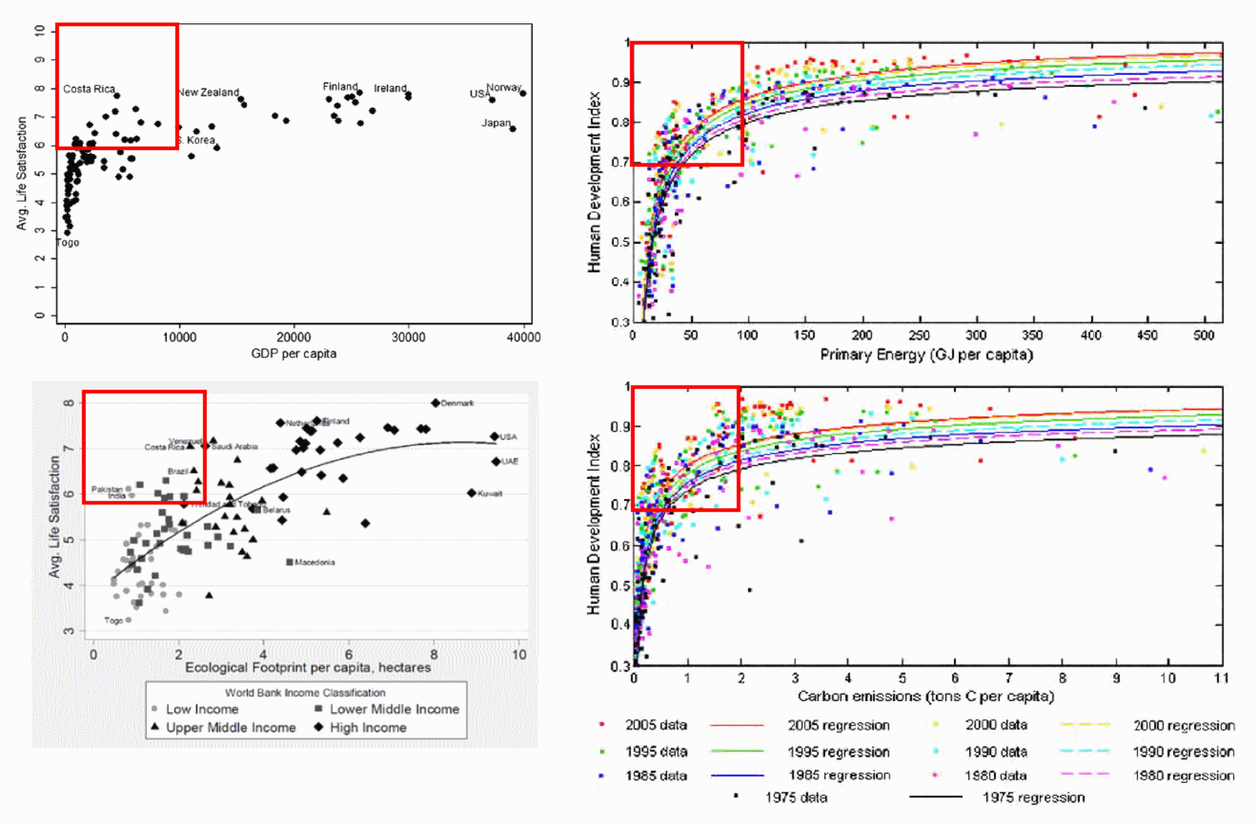


Figure 1 The Goldemberg corner in energy, environmental and well-being indices (Steinberger and Roberts, 2010; Knight and Rosa, 2011; 2009)

For contemporary analysts, the Goldemberg corner is a key element to the sustainability debate, because achieving high levels of well-being with low levels of consumption is the desired outcome of human development. Explanations on what determines such performance is crucial, though still not well understood (Dietz and Jorgenson, 2014; Knight and Schor, 2014; Lamb et al., 2014; Steinberger et al., 2012).

Besides these approaches that have focused directly on the energy-well-being link, there are others which have targeted alternative connections. Dietz and Rosa (1994) were the pioneers to use links between environmental impacts and well-being, for example. Later works have also followed them (Dietz et al., 2012; Knight and Rosa, 2011, 2009; Dietz et al., 2009). This part of the literature considers energy indirectly through environmental consequences, as clearly mentioned in the most recent research (Dietz et al., 2012; Knight and Rosa, 2011, 2009; Dietz et al., 2009).

All these perspectives provide explanations circumscribed to analyses of single indices, but assessments considering multiple indicators are also desirable, because as explained in section 1.3.1, both aspects aggregated together would extend the analyses to connect with further elements in theory in search of explanations of the highest performers. As introduced in section 1.2.1, some engineering approaches have the advantage of handling relationships with multiple indicators, being potentially useful here.

3.1.2 A holistic analysis of energy and well-being. As section 1.2.1 has introduced, a wide range of engineering methods have been brought in transdisciplinary applications. Multiple-Criteria Decision Analyses (MCDA) are one type, which are used to integrate several indicators in a single measure. MCDA techniques were originally used in operations research, but they have increasingly been applied in finance and social science. Data Envelopment Analysis (DEA), in particular, is one MCDA applicable when the purpose is the estimation of comparative performance.

Inspired on ideas to improve productivity, Farrell (1957) was the first to explore DEA almost 60 years ago. Later, it was formally developed by Charnes, Copper and Rhodes (1978). Since then, it has been introduced in a wide range of applications, but fewer works have explored socio-economic aspects (Cook and Seiford, 2009; Emrouznejad et al., 2008).

Nevertheless, DEA is a powerful tool to build multidimensional indices, and some analyses have noticed this potential (Reig-Martinez, 2013; Jurado and Perez-Mayo, 2012; Murias et al.,2006, Zhu, 2001), but almost no attention has been given to dimensions comprising energy use, environmental impacts and well-being (Ramanathan, 2002). Unlike the analysis of the energy-well-being link with regression methods, the DEA approach allows considering environmental, energy and well-being dimensions together, resolving the problem of handling multiple indicators. In addition, the DEA method switch the focus to the Goldemberg corner, because DEA assesses based on comparative performance (see section 2.3).

The only assessment done in this direction is that by Cravioto et al. (2011), which is the first to take multiple well-being measures with energy and environmental indicators (Mariano et al., 2015). Although the analysis yielded two efficiency indices of well-being it did not attempt to analyse the results together in a more holistic assessment. Their results also lacked reference to previous theory and hence did not focus on explanations of performance within the Goldemberg corner.

Thus, given that no approaches on the energy-well-being link have considered multiple DEA-based efficiency indicators in conjunction, and still unclear as to why certain countries can achieve higher levels of well-being with lower levels of energy consumption (the Goldemberg corner), a mixed approach of multiple DEA indices assessed holistically with statistical analyses is proposed to clarify such aspects.

3.1.3 Purpose. The purpose of the present chapter is to analyse the connection between energy use, environmental stress and three well-being indicators at a country-level using a comparative efficiency approach. Crucial elements for paths towards sustainable performance (the Goldemberg corner) are discussed in the light of previous theory and the case of Mexico.

3.2 Method

3.2.1 Data.

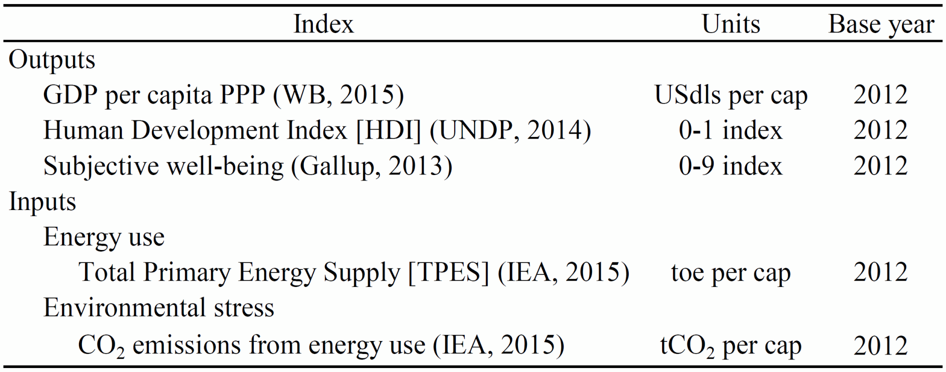
3.2.1.1 Sample data. As mentioned in section 2.2, forty countries of the five continents were selected (table 1). Countries with populations above 1 million of inhabitants with full availability of data for the analysis comprised the sample. This selection procedure took place to include countries with the most reliable databases, and to avoid the dominance of numerous small nations (See Dietz et al., 2007 for details on such consideration). The sample is intended to be symbolical in terms of geography, country size and world cultures.

Out of several economic indicators and well-being indices, table 2 shows the ones selected. Base years and units of measurement are also included in this table. As introduced in section 2.2, one objective well-being index and a subjective one were selected: The Hu-

Table 1 Countries selected for the DEA indices

Africa/Oceania	America	Asia	Europe
Australia	Argentina	China	Bulgaria
Ghana	Brazil	India	France
Morocco	Canada	Indonesia	Germany
New Zealand	Chile	Iran	Greece
Nigeria	Costa Rica	Israel	Italy
South Africa	Jamaica	Japan	Norway
Tanzania	Mexico	Malaysia	Poland
	United States	Philippines	Russia
	Venezuela	Saudi Arabia	Spain
		South Korea	Sweden
		Thailand	Turkey
		Uzbekistan	United Kingdom

Table 2 Well-being, environmental and energy indicators selected for the DEA indices



Index	Units	Base year
Outputs		
GDP per capita PPP (WB, 2015)	USdls per cap	2012
Human Development Index [HDI] (UNDP, 2014)	0-1 index	2012
Subjective well-being (Gallup, 2013)	0-9 index	2012
Inputs		
Energy use		
Total Primary Energy Supply [TPES] (IEA, 2015)	toe per cap	2012
Environmental stress		
CO_2 emissions from energy use (IEA, 2015)	tCO_2 per cap	2012

man Development Index[1] (HDI) and the Subjective Well-being Index[2] (SWB). Both indices are meant to represent complementary ideas as they have a different construction; objective indices describe improvement of observable conditions, which can be closely related to social development, whereas subjective ones indicate how these conditions are perceived by individuals (Smith and Clay, 2010). In relevant literature, it has been reported that both measures have strong correlations (Graham, 2009; Van Praag and Ferrer-i-Carbonell, 2007; Kahneman et al., 1999). Thus, human well-being can be conceived quite similarly with either. In the present study, however, both measures are considered in the search for subtle differences, and GDP per capita[3] is also included as the quintessential indicator of economic development.

Finally, the energy and environmental indicators comprised Total Primary Energy Supply (TPES)[4] and CO_2 emissions from energy use[5] both in per capita figures[6] (table 2).

3.2.2 DEA models. A correlation matrix applied to data selected showed that strong correlations were found between GDP, TPES and CO_2 emissions (all per capita). However, weaker correlations existed between HDI and SWB with both indicators (table 3). Three relations have been selected based on this: first, GDP with TPES and CO_2 emissions (all per capita) to build the "production" DEA model; second, HDI with TPES and CO_2 emissions (both per capita) to build the "development" DEA model; and third, SWB with TPES and CO_2 emissions (both per capita) to build the "well-being" DEA model.

---

[1] HDI comes in a 0-1 scale, where 0 is the lowest development level and 1 the highest. The index is built from the aggregation of Mean Gross National Income, Life Expectancy and Education. HDI data is taken from the Human Development Index Report 2015 (UNDP, 2015).

[2] The subjective well-being index comes in a 0-9 scale, where 0 is the lowest level and 9 the highest. Data is taken from the Gallup World Poll (see Overall Life Satisfaction Index in Gallup-Healthways, 2016).

[3] GDP PPP figures are taken from WB (2016a) and per capita figures are created using the total population reported in WB (2016b).

[4] Total Primary Energy Supply refers to the amount of energy produced and imported without exports and storage changes. It is defined as: indigenous production + imports - exports - international marine bunkers - international aviation bunkers +/- stock changes. Data is taken from IEA (2015c).

[5] CO_2 emissions from energy use refer to the estimates of CO_2 emissions from fuel combustion calculated by the IEA. These estimates include emissions from all reported energy use of fuels, but exclude emissions from non-energy use of fuels. For details on the calculation procedure please refer to IEA (2015b). Data used in this thesis is taken from IEA (2015a).

[6] Per capita figures are created using the total population reported in WB (2016b).

Table 3   Correlations between the selected indices and indicators

	Pearson r				
	1	2	3	4	5
1. GDP per capita PPP	1				
2. Human Development Index (HDI)	.875**	1			
3. Subjective well-being	.660**	.681**	1		
4. Total Primary Energy Supply (TPES)	.880**	.761**	.551**	1	
5. CO_2 emissions	.735**	.698**	.389*	.885**	1
	Spearman ρ				
1. GDP per capita PPP	1				
2. Human Development Index (HDI)	.951**	1			
3. Subjective well-being	.643**	.691**	1		
4. Total Primary Energy Supply (TPES)	.910**	.874**	.552**	1	
5. CO_2 emissions	.786**	.771**	.365*	.899**	1

Notes: * $p < 0.05$, ** $p < 0.01$

Using the DEA formulations detailed in section 2.3, the three models mentioned above were constructed as described below.

3.2.2.1 Production DEA.

The production DEA model is built considering TPES and CO_2 emissions (both per capita) as inputs[7] and GDP per capita as the output. Equation 16 shows the expression for country 1.

---

[7] CO_2 emissions treated as an input represents, in fact, an undesirable output (see Cooper et al., 2011 on treatment of undesirable outputs).

$$\max \quad E_{\mathrm{Prod},1} = [65.4]\,[v_{\mathrm{GDP},1}] \tag{16}$$

subject to

$$\begin{bmatrix} 7.08 & 5.91 \end{bmatrix} \begin{bmatrix} u_{\mathrm{CO_2},1} \\ u_{\mathrm{TPES},1} \end{bmatrix} = 1,$$

$$\begin{bmatrix} v_{\mathrm{GDP},1} \end{bmatrix} \begin{bmatrix} 65.4 \\ 42.6 \\ 51.4 \\ \vdots \\ y_{\mathrm{GDP},40} \end{bmatrix} - \begin{bmatrix} u_{\mathrm{CO_2},1} \\ u_{\mathrm{TPES},1} \end{bmatrix} \begin{bmatrix} 7.08 & 5.91 \\ 17.02 & 5.56 \\ 16.02 & 6.81 \\ \vdots & \vdots \\ x_{\mathrm{CO_2},40} & x_{\mathrm{TPES},40} \end{bmatrix} \leq 0$$

$$v_{\mathrm{GDP}} \quad , \quad u_{\mathrm{CO_2}} \quad , \quad u_{\mathrm{TPES}} \geq 0$$

The expression above is in the form of an Output-maximisation Multiplier DEA Model (see section 2.3 for details), where $E_{\mathrm{Prod},1}$ corresponds to the comparative efficiency; $v_{\mathrm{GDP},1}$ represents the weight of the output (GDP per capita); $u_{\mathrm{CO_2},1}$ the weight of the first input (CO_2 per cap.); and $u_{\mathrm{TPES},1}$ the weight of the second input (TPES per capita). In addition 65.4 corresponds to the output (GDP per capita) in thousands of US dls per capita; 7.08 to the first input (CO_2 per cap.) in tons of CO_2 per capita; and 5.91 to the second input (TPES per capita) in toe per capita. Note that in the constraints corresponding to efficiency equations for each DMU, only the first three are expressed in the equation for simplicity. The last element in these matrices represents the last DMU, when $n = 40$.

The aim of solving this linear programming problem (eq. 16) is to find $v_{\mathrm{GDP},1}$, $u_{\mathrm{TPES},1}$, $u_{\mathrm{CO_2},1}$ such that $E_{\mathrm{Prod},1}$ is maximum. For each country, a similar linear programming problem must be modelled until the 40th country is reached (when $m = n$).

After this, each maximisation model is transformed into the input-oriented envelopment DEA form for two reasons. First, such form is more suitable for computational purposes (see section 2.3 for details), and second, the envelopment model allows for estimation of slacks (how much should inputs be reduced to attain 100% efficiency). Section 3.2.3 provide more details on the formulation of the slacks model.

3.2.2.2 Development DEA. The development DEA model considers HDI as the output, while TPES and CO_2 emissions per capita remain as inputs. The expression for country 1 (equation 17) has a slight change from that in the production DEA (equation 16). The coefficients 0.94, 0.93, 0.91 correspond to the HDI indices for country 1, 2, 3 and so forth until the 40th country is reached ($y_{\mathrm{HDI},40}$). Likewise for the production DEAs, the formulations below were transformed into envelopment models for estimating slacks detailed after section 3.2.3.

$$
\begin{aligned}
&\max \quad E_{\mathrm{Devel},1} = [0.94]\,[v_{\mathrm{HDI},1}] \qquad (17)\\
&\text{subject to}\\
&\begin{bmatrix} 7.08 & 5.91 \end{bmatrix} \begin{bmatrix} u_{\mathrm{CO_2},1} \\ u_{\mathrm{TPES},1} \end{bmatrix} = 1,\\
&[v_{\mathrm{HDI},1}] \begin{bmatrix} 0.94 \\ 0.93 \\ 0.91 \\ \vdots \\ y_{\mathrm{HDI},40} \end{bmatrix} - \begin{bmatrix} u_{\mathrm{CO_2},1} \\ u_{\mathrm{TPES},1} \end{bmatrix} \begin{bmatrix} 7.08 & 5.91 \\ 17.02 & 5.56 \\ 16.02 & 6.81 \\ \vdots & \vdots \\ x_{\mathrm{CO_2},40} & x_{\mathrm{TPES},40} \end{bmatrix} \leq 0\\
&v_{\mathrm{HDI}} \;,\; u_{\mathrm{CO_2}} \;,\; u_{\mathrm{TPES}} \geq 0
\end{aligned}
$$

3.2.2.3 Well-being DEA. Lastly, the third DEA model considers SWB as the output, keeping TPES and CO_2 emissions per capita as inputs. The expression for country 1 results in equation 18, where coefficients 7.7, 7.2, 7 correspond to SWB indices for countries 1, 2, 3, and so on until the 40th country is reached ($y_{\mathrm{SWB},40}$). Likewise done with the production and development DEAs, these maximisation models were later transformed into envelopment ones to estimate slacks, as detailed after in section 3.2.3.

$$
\begin{aligned}
&\max \quad E_{\text{Well\_b},1} = [7.7]\,[v_{\text{SWB},1}] && (18)\\
&\text{subject to}\\
&\begin{bmatrix} 7.08 & 5.91 \end{bmatrix} \begin{bmatrix} u_{\text{CO}_2,1} \\ u_{\text{TPES},1} \end{bmatrix} = 1,\\
&[v_{\text{SWB},1}] \begin{bmatrix} 7.7 \\ 7.2 \\ 7 \\ \vdots \\ y_{\text{SWB},40} \end{bmatrix} - \begin{bmatrix} u_{\text{CO}_2,1} \\ u_{\text{TPES},1} \end{bmatrix} \begin{bmatrix} 7.08 & 5.91 \\ 17.02 & 5.56 \\ 16.02 & 6.81 \\ \vdots & \vdots \\ x_{\text{CO}_2,40} & x_{\text{TPES},40} \end{bmatrix} \leq 0\\
&v_{\text{SWB}} \;\;,\;\; u_{\text{CO}_2} \;\;,\;\; u_{\text{TPES}} \geq 0
\end{aligned}
$$

3.2.3 Slacks. To estimate the necessary improvements (reductions in CO_2 emission and energy consumption) of the inefficient countries, the duals of the models described above were formulated. These were the IOE DEA with slacks variables are in the form of model 15 (see section 2.3 for details on derivation of the general form). Once obtained the efficiencies E_{Prod}, E_{Devel} and $E_{\text{Well-b}}$ from models 16, 17 and 18, these are taken as θ_{Prod}, θ_{Devel} and $\theta_{\text{Well-b}}$ in models 19, 20 and 21 below, in order to estimate the slack variables $S_{\text{GDP,CO}_2}$, $S_{\text{GDP,TPES}}$, $S_{\text{HDI,CO}_2}$, $S_{\text{HDI,TPES}}$, $S_{\text{SWB,CO}_2}$, and $S_{\text{SWB,TPES}}$. All these expressions correspond to country 1, and for each other country a similar linear programming problem must be modelled until the 40th country is reached.

3.2.3.1 Production Slacks (country 1).

$$\min \quad \theta_{\text{Prod},1} - (S_{\text{GDP},\text{CO}_2} + S_{\text{GDP},\text{TPES}}) \tag{19}$$

subject to

$$\begin{bmatrix} 65.4 \\ 42.6 \\ 51.4 \\ \vdots \\ y_{\text{GDP},40} \end{bmatrix}^T \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \vdots \\ \lambda_{40} \end{bmatrix} = \begin{bmatrix} 65.4 \end{bmatrix},$$

$$\theta_{\text{Prod},1} \cdot \begin{bmatrix} 7.08 \\ 5.91 \end{bmatrix} - \begin{bmatrix} 7.08 & 5.91 \\ 17.02 & 5.56 \\ 16.02 & 6.81 \\ \vdots & \vdots \\ x_{\text{CO}_2,40} & x_{\text{TPES},40} \end{bmatrix}^T \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \vdots \\ \lambda_{40} \end{bmatrix} - \begin{bmatrix} S_{\text{GDP},\text{CO}_2} \\ S_{\text{GDP},\text{TPES}} \end{bmatrix} = 0,$$

$$\begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \vdots \\ \lambda_{40} \end{bmatrix}, \begin{bmatrix} S_{\text{GDP},\text{CO}_2} \\ S_{\text{GDP},\text{TPES}} \end{bmatrix} \geq 0 \quad , \quad \theta_{\text{Prod},1} \text{ unrestricted}$$

3.2.3.2 Development Slacks (country 1).

$$\min \quad \theta_{\text{Devel},1} - (S_{\text{HDI},\text{CO}_2} + S_{\text{HDI},\text{TPES}}) \tag{20}$$

subject to

$$\begin{bmatrix} 0.94 \\ 0.93 \\ 0.91 \\ \vdots \\ y_{\text{HDI},40} \end{bmatrix}^T \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \vdots \\ \lambda_{40} \end{bmatrix} = \begin{bmatrix} 0.94 \end{bmatrix},$$

$$\theta_{\text{Devel},1} \cdot \begin{bmatrix} 7.08 \\ 5.91 \end{bmatrix} - \begin{bmatrix} 7.08 & 5.91 \\ 17.02 & 5.56 \\ 16.02 & 6.81 \\ \vdots & \vdots \\ x_{\text{CO}_2,40} & x_{\text{TPES},40} \end{bmatrix}^T \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \vdots \\ \lambda_{40} \end{bmatrix} - \begin{bmatrix} S_{\text{HDI},\text{CO}_2} \\ S_{\text{HDI},\text{TPES}} \end{bmatrix} = 0,$$

$$\begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \vdots \\ \lambda_{40} \end{bmatrix}, \begin{bmatrix} S_{\text{HDI},\text{CO}_2} \\ S_{\text{HDI},\text{TPES}} \end{bmatrix} \geq 0 \quad , \quad \theta_{\text{Devel},1} \text{ unrestricted}$$

3.2.3.3 Well-being Slacks (country 1).

$$\min \quad \theta_{\text{Well-b},1} - (S_{\text{SWB},\text{CO}_2} + S_{\text{SWB},\text{TPES}}) \tag{21}$$

subject to

$$\begin{bmatrix} 7.7 \\ 7.2 \\ 7 \\ \vdots \\ y_{\text{SWB},40} \end{bmatrix}^T \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \vdots \\ \lambda_{40} \end{bmatrix} = \begin{bmatrix} 7.7 \end{bmatrix},$$

$$\theta_{\text{Well-b},1} \cdot \begin{bmatrix} 7.08 \\ 5.91 \end{bmatrix} - \begin{bmatrix} 7.08 & 5.91 \\ 17.02 & 5.56 \\ 16.02 & 6.81 \\ \vdots & \vdots \\ x_{\text{CO}_2,40} & x_{\text{TPES},40} \end{bmatrix}^T \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \vdots \\ \lambda_{40} \end{bmatrix} - \begin{bmatrix} S_{\text{SWB},\text{CO}_2} \\ S_{\text{SWB},\text{TPES}} \end{bmatrix} = 0,$$

$$\begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \vdots \\ \lambda_{40} \end{bmatrix}, \begin{bmatrix} S_{\text{SWB},\text{CO}_2} \\ S_{\text{SWB},\text{TPES}} \end{bmatrix} \geq 0 \quad , \quad \theta_{\text{Well-b},1} \text{ unrestricted}$$

3.2.4 Assumptions. One general assumption when using the previous DEA models is that if one DMU is efficient to obtain outputs from inputs, the others should be able to do it in the same way. Therefore, the formulations assume that all countries are equally capable of obtaining outputs from inputs. There might be external elements inherently creating unfavourable outputs in the DEA efficiency. Thus, the assumption sets the ground for the last part of this chapter (discussion), which has focused on testing predictors to find variables capable of explaining differences in the results.

Another assumption is that energy consumption (TPES per capita) as one of the inputs has a causal effect with the outputs (GDP per capita, HDI and SWB), a valid premise theoretically and empirically (sections 1.1 and 1.2). CO_2 emissions, in turn, represent an undesirable output, which as noted before can technically be treated as an input in these DEA formulations (see Cooper et al., 2011 on treatment of undesirable outputs).

Finally, by using a Charnes, Copper and Rhodes (CCR) model there is an assumption of constant returns to scale (CRS) in the output (response variable) from input gains (explanatory variables). Although it is well known that GDP, HDI and SWB relate in decreasing returns to scale (DRS) to energy consumption (Steinberger et al., 2012; Mazur, 2011; Steinberger and Roberts, 2010; Martinez and Ebenhack, 2008; Garcia, 2006; Smil, 2005; Pasternak, 2000; Rosa et al., 1981, Mazur and Rosa, 1974) and CO_2 emissions (Dietz et al., 2012; Knight and Rosa, 2011, 2009; Dietz et al., 2009), the aim of this analysis is not to consider the DRS over the saturation threshold as "normal". Instead, it is to consider that countries above the threshold actually observe almost no gains in the level of the output at the expense of very high energy consumption or environmental damage. Thus, the assumption of CRS in the DEA model allows a more realistic representation of the deviations from the most efficient peer(s).

3.2.5 Statistical analyses. As already mentioned in section 2.4, to further analyse the efficiency results through numeric and categorical predictors, which might explain the observed differences, four statistical methods have been utilised in the discussion of the results. Pearson and Spearman correlations are used to analyse associations with predictors in numeric and ordinal scales, and ANOVAs are used to test for differences among categories of predictors in nominal scales.

The results are discussed in the light of how the three DEA models correlate with other indices, how elements from theory can predict a higher holistic performance of the indices, and how would more sustainable performance be achieved taking the case of Mexico.

3.3 Results

3.3.1 DEA indices (efficiencies and country ranks). Three countries (Costa Rica, Nigeria and The Philippines) scored the highest efficiency (100%) in the production

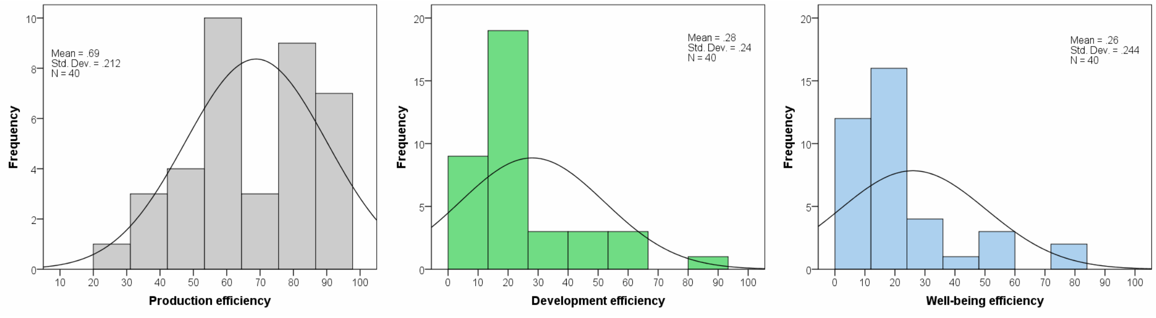


Figure 2 Distributions of production, development and well-being efficiencies

model, and two others (Ghana and Tanzania) in both the development and well-being models (table 4).

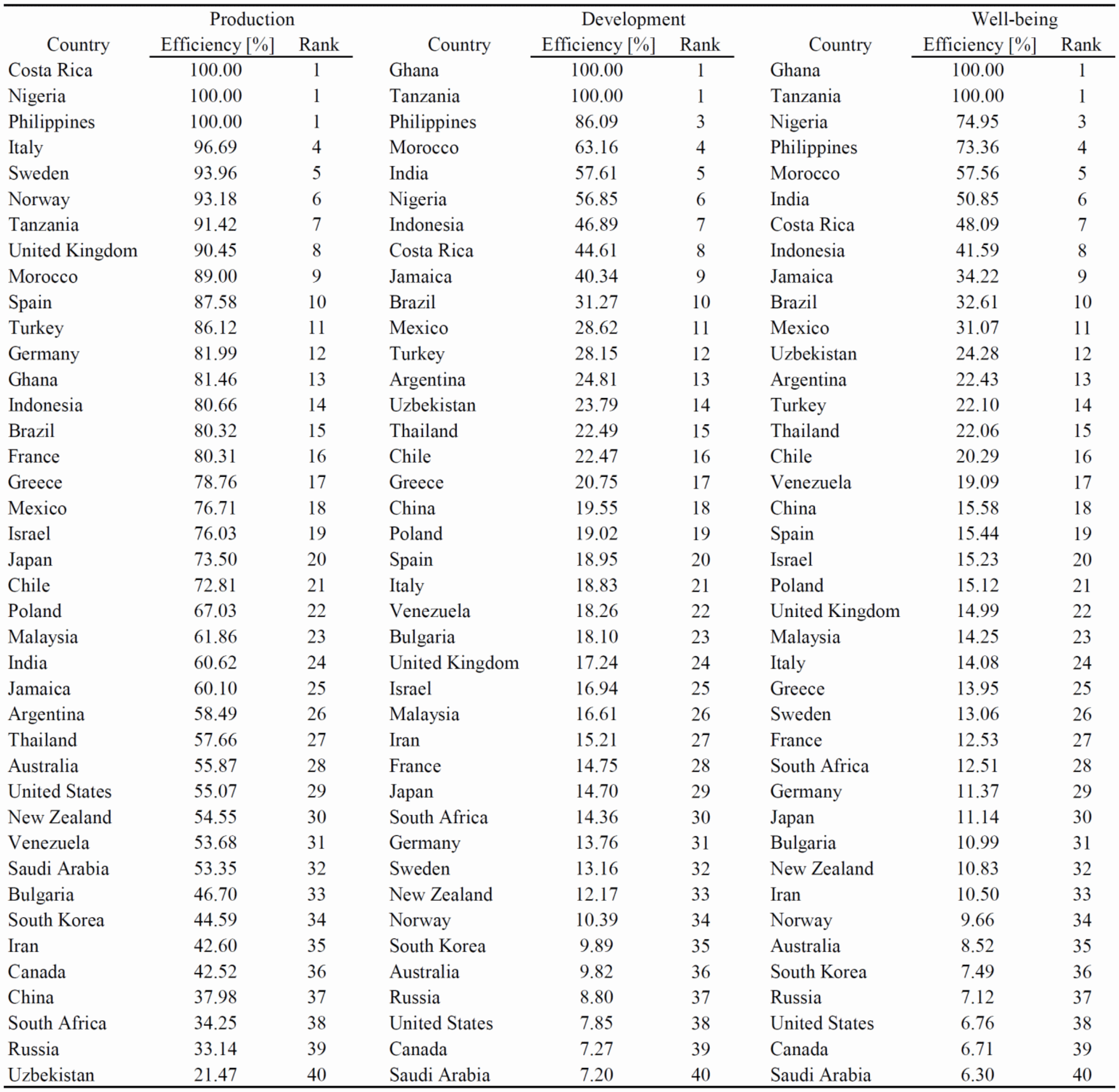
Development and well-being efficiencies seemed highly skewed to the right, whereas production rather skewed to the left (figure 2). In the development and well-being models, nations lying above the 80th percentile were economically developing ones (Tanzania, Ghana, Phillipines, Morocco, India, Nigeria, Indonesia and Costa Rica). In contrast, for production efficiency, the share in such range was rather equal: four developed countries (Italy, Sweden, Norway and UK) and four developing ones (Costa Rica, The Philippines, Nigeria and Tanzania).

Developed countries scored better in production than well-being and development. However, for development and well-being, their outcomes became low, taking places below the 50th percentile (table 4). The worst performers in development and well-being were Saudi Arabia, Canada, United States and Russia, appearing below the 10th percentile. In contrast, Uzbekistan, Russia, South Africa and China and had the worst scores in the production model.

These results confirm the hypothesis that more industrialised countries have lower efficiencies using "alternative" measures of development and well-being in relation to energy use and environmental stress. Yet, they also support the premise that industrialised nations are rather efficient in terms of producing economic wealth.

3.3.2 Slacks. The improvements in terms of TPES and CO_2 reductions (per capita) that inefficient countries should attain to become as efficient as the peers were

Table 4 Production, development and well-being indices: efficiencies and country rankings



	Production			Development			Well-being	
Country	Efficiency [%]	Rank	Country	Efficiency [%]	Rank	Country	Efficiency [%]	Rank
Costa Rica	100.00	1	Ghana	100.00	1	Ghana	100.00	1
Nigeria	100.00	1	Tanzania	100.00	1	Tanzania	100.00	1
Philippines	100.00	1	Philippines	86.09	3	Nigeria	74.95	3
Italy	96.69	4	Morocco	63.16	4	Philippines	73.36	4
Sweden	93.96	5	India	57.61	5	Morocco	57.56	5
Norway	93.18	6	Nigeria	56.85	6	India	50.85	6
Tanzania	91.42	7	Indonesia	46.89	7	Costa Rica	48.09	7
United Kingdom	90.45	8	Costa Rica	44.61	8	Indonesia	41.59	8
Morocco	89.00	9	Jamaica	40.34	9	Jamaica	34.22	9
Spain	87.58	10	Brazil	31.27	10	Brazil	32.61	10
Turkey	86.12	11	Mexico	28.62	11	Mexico	31.07	11
Germany	81.99	12	Turkey	28.15	12	Uzbekistan	24.28	12
Ghana	81.46	13	Argentina	24.81	13	Argentina	22.43	13
Indonesia	80.66	14	Uzbekistan	23.79	14	Turkey	22.10	14
Brazil	80.32	15	Thailand	22.49	15	Thailand	22.06	15
France	80.31	16	Chile	22.47	16	Chile	20.29	16
Greece	78.76	17	Greece	20.75	17	Venezuela	19.09	17
Mexico	76.71	18	China	19.55	18	China	15.58	18
Israel	76.03	19	Poland	19.02	19	Spain	15.44	19
Japan	73.50	20	Spain	18.95	20	Israel	15.23	20
Chile	72.81	21	Italy	18.83	21	Poland	15.12	21
Poland	67.03	22	Venezuela	18.26	22	United Kingdom	14.99	22
Malaysia	61.86	23	Bulgaria	18.10	23	Malaysia	14.25	23
India	60.62	24	United Kingdom	17.24	24	Italy	14.08	24
Jamaica	60.10	25	Israel	16.94	25	Greece	13.95	25
Argentina	58.49	26	Malaysia	16.61	26	Sweden	13.06	26
Thailand	57.66	27	Iran	15.21	27	France	12.53	27
Australia	55.87	28	France	14.75	28	South Africa	12.51	28
United States	55.07	29	Japan	14.70	29	Germany	11.37	29
New Zealand	54.55	30	South Africa	14.36	30	Japan	11.14	30
Venezuela	53.68	31	Germany	13.76	31	Bulgaria	10.99	31
Saudi Arabia	53.35	32	Sweden	13.16	32	New Zealand	10.83	32
Bulgaria	46.70	33	New Zealand	12.17	33	Iran	10.50	33
South Korea	44.59	34	Norway	10.39	34	Norway	9.66	34
Iran	42.60	35	South Korea	9.89	35	Australia	8.52	35
Canada	42.52	36	Australia	9.82	36	South Korea	7.49	36
China	37.98	37	Russia	8.80	37	Russia	7.12	37
South Africa	34.25	38	United States	7.85	38	United States	6.76	38
Russia	33.14	39	Canada	7.27	39	Canada	6.71	39
Uzbekistan	21.47	40	Saudi Arabia	7.20	40	Saudi Arabia	6.30	40

estimated in ranges between 0.07 to 6.2 toe per cap and 0.15 to 15.21 tCO_2 emissions per cap.

3.4 Discussion

3.4.1 DEA indices and previous measures. A small part of the previous literature has reported indices using a DEA measure (section 1.2). This section explores differences and similarities with these indices and with other similar indices of sustainable energy or ecological performance.

3.4.1.1 Previous DEA works. Ramanathan (2002) previously built a DEA model considering CO_2 emissions, energy consumption and GDP all in a per capita basis. He found that India, Tanzania, Sweden and Norway had the highest (100%) efficiency. Cravioto et al. (2011) later build similar three-dimensional DEA models, one taking GDP per capita and another taking HDI, both considering CO_2 emissions with total electricity consumption in a per capita basis. They found that Tanzania (for the HDI model), Costa Rica and Ghana (for the GDP per capita one) attained 100% efficiency.

Analysing how well these results correlate with the obtained DEA indices, Table 5 shows that the production model had a mid-range correlation with Ramanathan's model, and a considerably higher one with the GDP-based model by Cravioto et al. (2011). Weak correlations were observed between both the development and the well-being models with Ramanathan's outcomes, but higher ones with the HDI results by Cravioto et al. (2011). The generally higher correlations with the results by Cravioto et al. (2011) could be explained by three aspects: first, the countries in sample were the same; second, data has only 5 years of time difference; and third, electricity consumption and TPES (both per capita) are highly correlated ($r = 0.854, p < 0.01$). In contrast, the model by Ramanathan used a larger set of countries and the data is more than 10 years older.

Given this, the number of peers under analysis might influence outcomes, being advisable to consider as much units as possible. In cases when data availability is an issue, rather acceptable approximations might be reached with small samples. In addition, efficiencies might change in time, deserving to consider time series to gain robustness.

Finally, indistinct use of electricity consumption and TPES might be acceptable, but it should be carefully considered especially when countries with very low percentage of access to electricity are under study.

Table 5 Correlation matrix between DEA indices and previous sustainability indices

	Spearman r							
	1	2	3	4	5	6	7	8
1. Production model	1							
2. Development model	0.47**	1						
3. Well-being model	0.49**	0.97**	1					
4. GDP model (Ramathan 2002)	0.54**	0.18	0.24	1				
5. GDP model (Cravioto, 2009)	0.86**	0.56**	0.59**	0.67**	1			
6. HDI model (Cravioto, 2009)	0.44**	0.91**	0.90**	0.33	0.62**	1		
7. Happy plante index	0.24	0.29	0.35*	0.11	0.25	0.27	1	
8. Ecological Footprint	0.1	0.82**	0.81**	0.13	0.27	0.83**	0.23	1

*Notes: * p < 0.05, ** p < 0.01*

3.4.1.2 Other indices. Two well-known indices from the literature are compared with the DEA indices to observe similarites or differences. First, the Ecological Footprint, which is a performance index measuring the size of environmental impact of nations with respect to the earth's resources (Rees, 1992; data from NEF, 2016). Second, the Happy Planet Index (HPI) by the New Economics Foundation (NEF, 2016), which is a composite index comprised of subjective well-being, ecological footprint and economic activity.

Table 5 shows that production efficiency did not correlate above weak levels with any of these indices, but development and well-being showed high correlations with the Ecological Footprint, suggesting that the DEA scores may indirectly represent similar information to that reported by an environmental capacity index[8]. Surprisingly, the correlations with HPI resulted moderate, indicating that there are differences in the construction that are strongly reflected in the outcomes. HPI is a measure that has been criticised for the arbitrary allocation of weight in their dimensions (Abdallah et al., 2009), and it might be that because the DEA-based indices allocate their weights based on the comparison to the best performer available, these resolve the problem giving a more objective outcome.

---

[8] Capacity here refers to environmental capacity, i.e. the measurement of the impact on environmental resources from a given lifestyle as measured by the ecological footprint.

3.4.2 Higher holistic performance. In this section, the efficiency indices are discussed in the light of elements from previous theory and with respect to increases in energy use and environmental damage. It should be noted that the discussions hereafter assume that the cross-sectional sample under study follows a predictable dynamic behaviour between the outcomes observed. Naturally, unexpected outcomes might be observed in reality as any static model has such a limitation.

3.4.2.1 Energy use and environmental damage. CO_2 emissions and TPES (both per capita) do not seem to predict accurately production efficiency, but a clear exponential decrease was observed in both production and well-being with respect to increases in CO_2 emissions and TPES. Figure 3 graphically confirms this and the strong correlations between both efficiencies in table 5 reaffirms this. Given these results, it might be plausible to consider that development and well-being efficiencies are equivalent and different to production efficiency.

Based on the graphs and all the previous analyses, it can be concluded that being more efficient to produce economic utility in terms of energy consumption and environmental stress does not correlate with objective human advancement or higher levels of human well-being. This finding is not only relevant by itself, but also on its implications in policy, which will be brought into discussion later in this chapter.

3.4.2.2 Elements from theory. To evaluate how the efficiency in the three models is influenced by elements mentioned in theory (section 1.2), this last section will verify the cross-sectional results of energy-environmental DEA indices in the light predictors grouped under the following classification: geographic, demographic and socio-cultural.

Geography. Theory on sustainable environmental consumption and well-being has propounded that the most crucial geographical elements affecting the relationship between well-being and environmental damage are type of climate (Van de Vliert, 2009; Rehdanz and Maddison, 2005) and region (Engelbrecht, 2009; Heliwell et al., 2009; Inglehart et al., 2008; Inglehart and Klingemann, 2000). This section explores such ar-

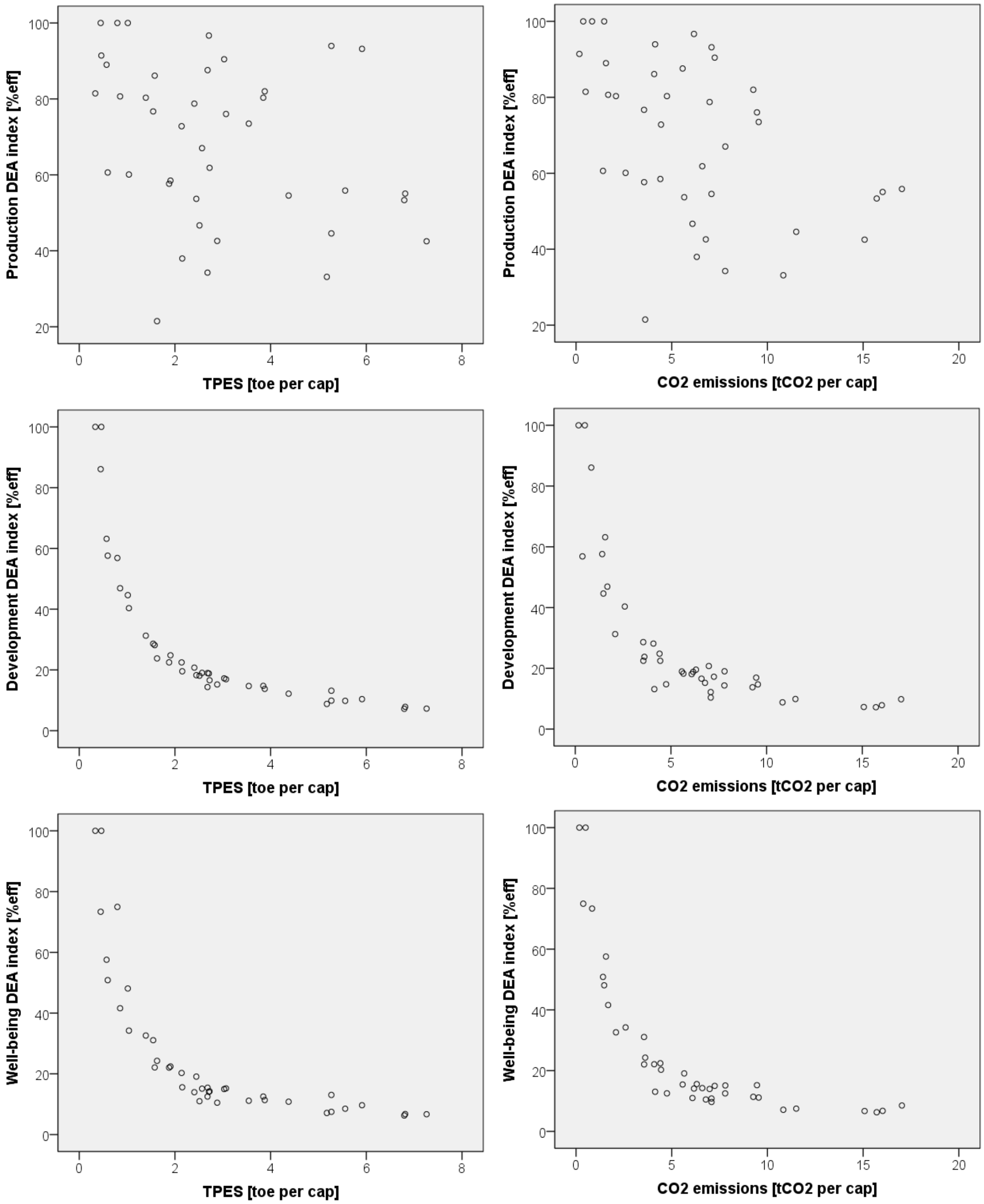


Figure 3 Production, development and well-being efficiency in relation to total primary energy supply and CO_2 emissions from energy use

guments in the light of the DEA indices as efficiency measures of energy, environmental stress and well-being.

Climate. Using a climate classification by the CIA's World Factbook section on climate (CIA, 2015a)[9], differences among climates on production, development and well-being efficiencies were evaluated. A one-way between groups ANOVA was performed to compare the impact of climate on the three DEA indices. Based on the adopted classification of 5 groups ("temperate", "temperate/subartic", "tropical", "diverse" and "arid"), there was a statistically significant differences in all measures [$F(4,35) = 3.892$, $p = 0.01$ for production efficiency, $F(4,35) = 4.545$, $p < 0.005$ for development efficiency and $F(4,35) = 4.628$, $p < 0.004$ for well-being efficiency].

Figure 4 shows how production efficiency appeared higher for countries with "temperate", "tropical" and a mixed "temperate-subartic" climate (above 70%), whereas for development and well-being efficiencies, "tropical" climate appeared above the others (20% difference with "diverse" the next closest classification). Overall the results suggest that climate might be an influential factor.

The results, however, do not clearly support a theory advocating for colder climates related to less life satisfaction (Van de Vliert, 2009; Rehdanz and Maddison, 2005), despite colder climates observed lower scores (subarctic and temperate) in the development and well-being model. In general, it can be said instead that arid climates tend to report lower scores, although it is not clear if this is because of high changes of temperature during the day or extreme seasonal change.

Given these results, it seems plausible to attain a higher holistic performance regardless of the type of climate, although climate differences explained by the selected factor could fall short to represent them accurately. Other geographical variables may be taking equally important roles to determine temperatures in local settlements (elevation, precipitation, etc.), which could be subject for further research.

---

[9] Data taken from the same source.

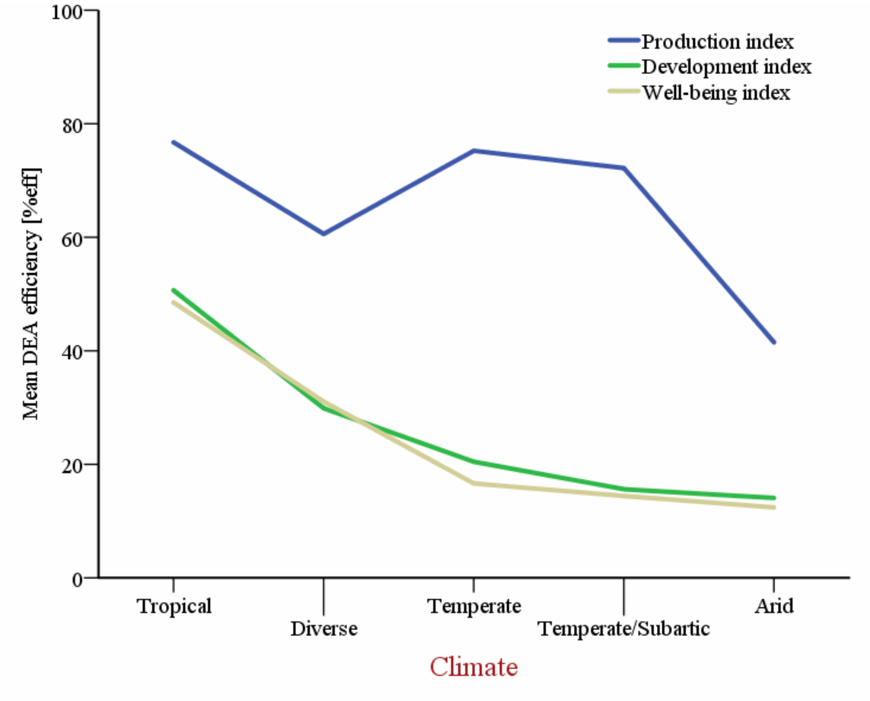


Figure 4 Production, development and well-being efficiency by type of climate

Region. Using the classification of countries in regions by the UN (2015a)[10], a one-way between groups ANOVA was performed to compare the impact of region on the three DEA indices. Based on the adopted classification (13 groups: "Africa (central)", "Africa (north)", "Africa (south)", "America (central-Caribbean)", "America (north)", "America (south)", "Asia (east)", "Asia (south-southeast)", "Asia (west-central)", "Europe (east)", "Europe (north)", "Europe (west)", "Oceania"), there was a statistically significant difference in all three measures [$F(12,27) = 2.859$, $p = 0.011$ for production efficiency, $F(12,27) = 7.478$, $p < 0.001$ for development efficiency and $F(12,27) = 12.31$, $p < 0.001$ for well-being efficiency].

As observed in figure 5, production efficiency in Europe (north and west) and Africa (central and north) were the most efficient (above 80%), closely followed by parts of America (central and the Caribbean) and Asia (south and southeast) (both at 70-80%). In contrast, development and well-being showed higher levels more clearly in Central and North

---

[10] Data taken from the same source.

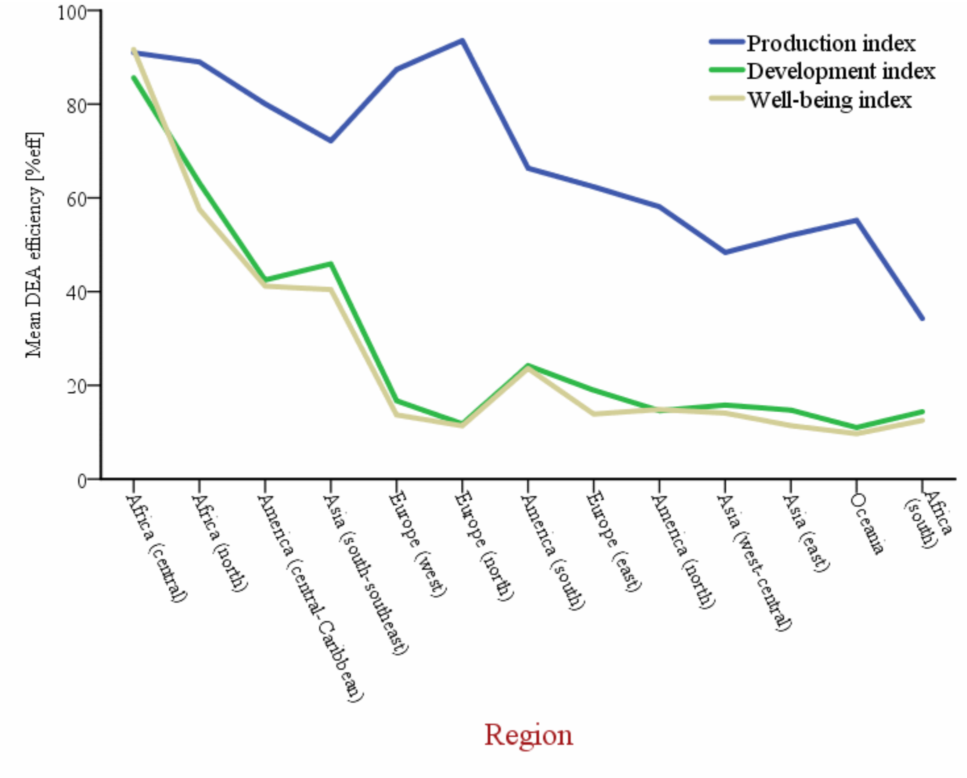


Figure 5 Production, development and well-being efficiency by region

Africa (60-80%), South-Southeast Asia (40-50%) and Central America and the Caribbean (40-50%).

Based on this, the results partly support a constant in research findings: that Latin America (LA) reports higher life satisfaction (Engelbrecht, 2009; Heliwell et al., 2009; Inglehart et al., 2008; Inglehart and Klingemann, 2000). Even in these multidimensional measures and considering them holistically this might hold, but it should be noted that Central Africa and south and southeast Asia also reported similar high scores. It is also noteworthy to mention that within LA, countries in Central American and the Caribbean report higher performance compared to South American ones.

Demographics. In terms of demographic predictors, theory suggests that several aspects may affect the relation between energy, environmental stress and well-being. However, the most crucial seem to be affluence levels (Mol and Spaargen, 2004; Grossman and Kreuger, 1995; Rice, 2008; Gould et al., 2004) and country size

(Tausch, 2011; Schumacher, 1973). The age of the population is also hypothesised to create differences. Thus, in the light of the DEA indices these demographic aspects are evaluated to search for differences.

Affluence. Taking a poverty index[11] as the reciprocal proxy for affluence levels resulted in almost no correlation with productive efficiency ($\rho = 0.010$) and strong correlations with development and well-being ($\rho = 0.757, p < 0.01$ and $\rho = 0.747, p < 0.01$). The possitive direction of these results suggests that being more affluent is related to less efficiency levels of development and well-being.

These results disprove the arguments by The Ecological Modernisation Theories (Mol and Spaargen, 2004; Grossman and Kreuger, 1995) that advocate for economic growth as the solution to environmental damage. Instead, there is support for the treadmill of production theory (Rice, 2008; Gould et al., 2004), in which affluence is related with decreases in efficient resource utilisation and increased environmental damage. The reason may be that more affluent societies become commoditised or ineffective in satisfying their needs. Taken holistically, these indices would suggest that enhancing well-being through consumption or energy abundant lifestyles among the poorest most probably would come with inefficient performance.

Country size. The predictor chosen to represent country size was total population[12] from which a very weak negative correlation was found in the three models ($\rho = -0.015$ -production-; $\rho = 0.132$ -development-; $\rho = 0.114$ -well-being-). These results show no clear support to the hypothesis that smaller countries have better performance (Schumacher, 1973), nor bigger ones (Tausch, 2011). Country size do not seem to effectively influence a higher holistic performance.

Age. Following, the median age of the population[13] was tested, from which a relationship was only found with development and well-being efficiency ($\rho =$

---

[11] This index is the percentage of the population living under 2 usdls a day as measued by the UN and OECD. Data is published by The World Bank (WB, 2015).

[12] Data taken from The World Bank (WB, 2016b).

[13] Data from the UN database (UN, 2015b).

0.005 -production-; $\rho = -0.583$ -development-; $\rho = -0.638$ -well-being-). These outcomes clearly suggest that a country with older population associates with lower performance in development and well-being, while taken holistically, aging in a country may have on one side negative effects on well-being performance but a possitive one in terms of production. The possitive effect, however, is almost negligible.

Socio-cultural aspects. Finally, among the socio-cultural aspects theorised to create differences, the following seem to be the most important to consider: sustainable consumption, community participation and social capital (Seyfang, 2009; Jackson, 2005, Manno, 2002). For this purpose, it is assumed that a more balanced lifestyle could reflect on elements related to community participation and increases in social capital. Thus, a predictor of work-life balance is proposed for the assessment.

It is not mentioned in theory if there are notable differences among cultures in the way they attain well-being levels from environmental resources, but part of this section explores this by holistically examining the three DEA indices in terms of language and religion.

Work-life. Taking the metric of work-life balance by the OECD[14], it seems to relate in opposite directions and less to development and well-being efficiencies ($\rho = -0.105$ and $\rho = -0.094$) than production efficiency ($\rho = 0.496$). On one hand and to our surprise, these results contradict the common understanding that increases in leisure time come with less productivity. It appears that, on the contrary, high productive efficiency is not only feasible but also related to having more leisure time. As for development and well-being, it is also surprising that higher well-being efficiency did not relate as strongly with more leisure time, and as a matter of fact in opposite direction. This probably suggests that if leisure time increase without alternative activities to engage with, leisure time does not necessarily reflect on effective satisfaction of needs.

---

[14] This index corresponds to the time devoted to leisure and personal care as published by the OECD (OECD, 2015).

Language. The language family classification in the CIA's World Factbook (CIA, 2015b)[15] was used to examine the impact of language on the DEA indices. The analysis consisted of a one-way between groups ANOVA to compare the results of 7 groups in the classification ("Afro-Asiatic", "Altaic", "Austronesian", "Daic", "Indo-European", "Niger-Kordofanian" and "Sino-Tibetan"). Statistically significant differences were found in development [$F(6,33) = 3.734$, $p = 0.006$] and well-being efficiency [$F(6,33) = 3.757$, $p = 0.006$], but not in production efficiency [$F(6,33) = 0.956$, $p = 0.47$].

Figure 6 shows that Niger–Kordofanian languages (spoken in Ghana, South Africa and Tanzania), followed by Austronesian languages (spoken in Indonesia, Malaysia and the Philippines) and Afro-Asiatic languages (spoken in Israle, Morocco, Saudi Arabia and Nigeria) scored higher in development and well-being efficiencies compared to the others. Although production efficiency did not show a significant difference among groups, a similar result was observed only adding the Indo-European languages to the "more efficient" group. These outcomes partially support that countries from Central and North Africa, as well as Southeast Asia can attain higher levels of performance, arguing for a cultural effect on higher efficiency outcomes.

Religion. Lastly, countries were analysed by religious beliefs first using the Pew Research Center's Religious Diversity Index[16]. All models seemed to have weak correlations with the index, although homogenous countries tended to report slightly higher scores in development and well-being efficiencies compared to production ($\rho = -0.056$ -production-, $\rho = -0.353$ -development- and $\rho = -0.275$ -well-being-).

Religiously homogeneous countries were further analysed for differences. Using the information on the distributions of religious groups within each country by the Pew Research Center (PRC, 2015), a religion classification was made. It was comprised of 6 groups ("Hindu", "Mixed", "Christian", "Muslim", "Buddhist" and "Jewish"). In spite of this, it was difficult to conduct an ANOVA test on this predictor as some groups only had one

---

[15] Data is also taken from here.

[16] Based on percentages of affiliated members in the total population of a country, this index creates a metric of religious diversity in a 0-1 scale, where 1 is the most diverse and 0 the most homogeneous case (PRC, 2015).

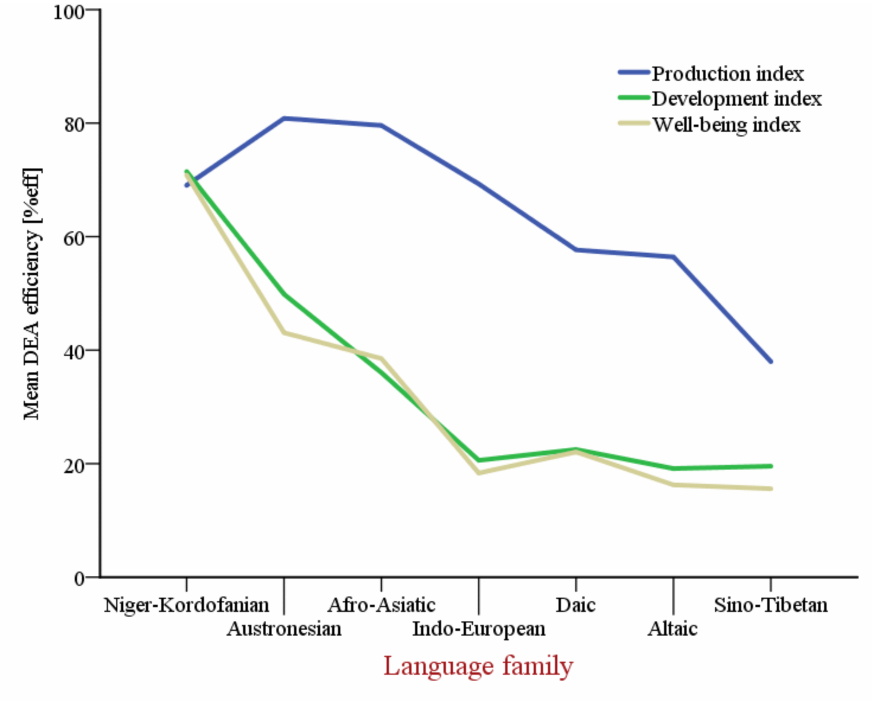


Figure 6 Production, development and well-being efficiency by language group

sample. Hence, graphical examination of ANOVA curves was the most adequate procedure for analysis.

As seen in figure 7, the Hindu religion outscored the rest of religious groups in development and well-being efficiencies (50-60%), whereas followers of the Jewish religion reported the highest production efficiency (>75%). The outcomes support the existence of a more efficient performance of certain countries with a homogeneous religious belief, although not as clear holistically (mixed belief scored above certain homogenous groups). Provided a more definite result, it would be plausible to consider that, in general, certain religious practices might associate with higher performance. Cultures as seen by religion indeed have effects on holistic performance.

3.5 Sustainable development for inefficient countries

The discussion on how to attain a sustainable performance can be divided between countries that still have to substantially improve well-being levels at the expense of the expansion of consumption and those that have to substantially reduce their energy con-

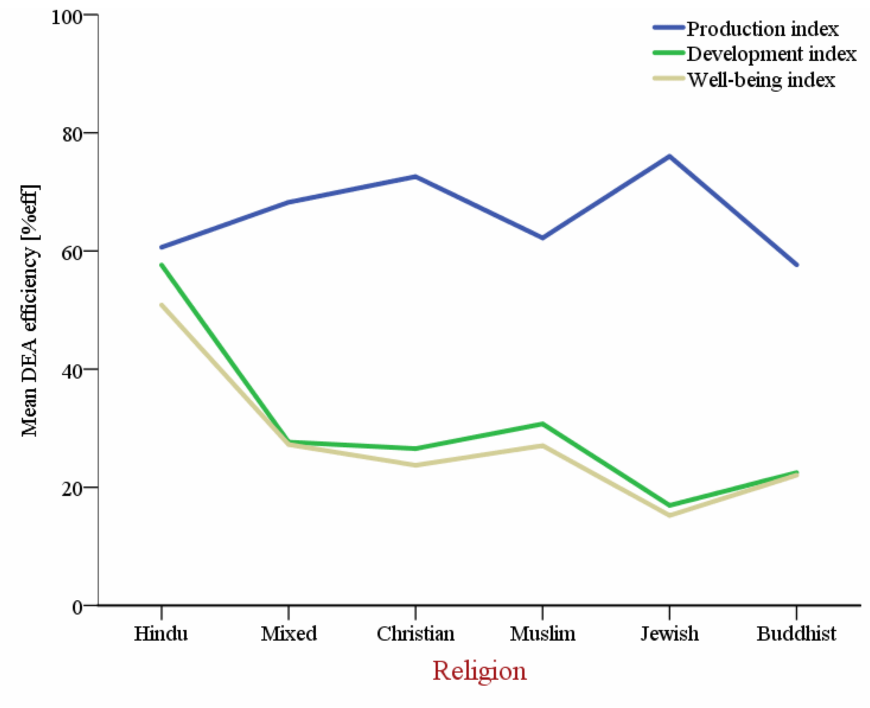


Figure 7 Production, development and well-being efficiency by religious group

sumption and environmental impact. These groups will be called "countries below the threshold" and "countries above the threshold" of energy and environmental consumption.

3.5.1 Countries below the threshold. These countries could target increases in economic activity to enhance development and well-being levels, as it was found that up to a certain energy consumption level (1 toe per cap) with its associated environmental impact (2.5 tCO_2 per cap.) efficiencies did not dropped beyond 50%. However, the countries within this range are few and other aspects are equally advisable. In particular, an alternative development path considering less focus on increasing total energy supply or economic growth, and instead considering the geographical, demographic and cultural features of the country.

First, countries should consider their local geographical features. It was observed that arid climates scored low in all measures, thus if within the countries there are regions with extreme seasonal changes and high need for energy consumption for cooling or heating, the country should target better technologies for living in these settings to attain more sustainable development.

Countries should also be aware that aging in the population is an issue that might yield negative outcomes in sustainable development. A balance in the cohorts of age within the population should be targeted.

Importance given to traditional values through certain practices may increase efficiency (e.g. religion). Increasing leisure time might also be a good instrument to attain more sustainable development, as this seemed highly compatible with higher production efficiency. Thus, increasing leisure time and promoting participation in recreational, artistic or sport activities would come in hand. It is noteworthy to say that such measures would also demand creating the required infrastructure, because as discussed before, leisure time increase without alternative activities to engage with does not necessarily reflect on effective satisfaction of needs (less strong correlations with development and well-being efficiency). In sum, incentives among the agents involved in such changes are also needed.

3.5.2 Countries above the threshold. For these countries, efficient use of energy is at a higher level, although there is still room for improvement by using cleaner energy sources and more efficient consumption. Demographic aspects to consider might be the aging of the society, for which negative outcomes would be expected. Increases in affluence should not be aimed at all.

In contrast, cultural aspects are of more importance. Less focus on materialism is desired and more balanced lifestyles that could bring about more efficient outcomes. With this respect, better work-life balance might come in hand, although more leisure time does not necessarily reflect on higher holistic well-being as seen by the holistic outcomes on affluence. Increasing leisure is undoubtedly the most important element to attain better efficiencies for countries above the threshold, but avoiding commoditisation or ineffective satisfaction of needs. Hence, promoting participation in recreational, artistic or sport activities with real options to engage with under a prospective better work-life balance. Similarly to countries below the threshold, this would obviously mean creating the necessary capacity for such activities as well as incentives among the agents involved in such a change.

3.6 Holistic assessment of sustainable development in Mexico

The case of Mexico is of particular interest in this study, given that this analysis is a macro perspective complementing the subsequent analyses of chapter IV and V. Mexico is a country holding within great differences in geography, demographics and cultural environments located in the LA region, which is associated with higher performance (section 3.4.2.2). Nevertheless, Mexico reported rather poor scores in development and well-being efficiency (28.62 % and 31.07 % respectively) and not as high in production efficiency (76.71 %). Some countries with a similar cultural background reported lower scores in the three measures (Venezuela, Chile and Argentina), whereas other countries consistently scored higher (Costa Rica and Brazil). Only Spain reported a contrasting outcome between production (being above Mexico) and development and well-being (below Mexico).

Given this, it might be plausible to consider Mexico well within countries above the threshold, expecting holistic increases in its efficiency levels considering a set of aspects. First, alternative development path considering less focus on increasing total energy supply or economic growth are already needed, and geographical, demographic and cultural features of the country demarcate targets in such direction.

Geographically, the northern particularly set in arid climates might follow extreme seasonal changes and high need for energy consumption for cooling or heating. Thus, better technologies for living in this region are crucial to attain more sustainable development. Coastal and south regions might need to consider similar energy consumption needs. However, the central plateau, in which more than 60% of the population lives, might be less concerned about this fact as it has a temperate climate during the whole year.

The total population and its age structure do not seem to be of concern, as no risk of an ageing population is foreseeable. However as seen in figure 8, there is a slight reduction of cohorts between 5-9 years, which has been compensated in the last years (cohorts in 0-4 years).

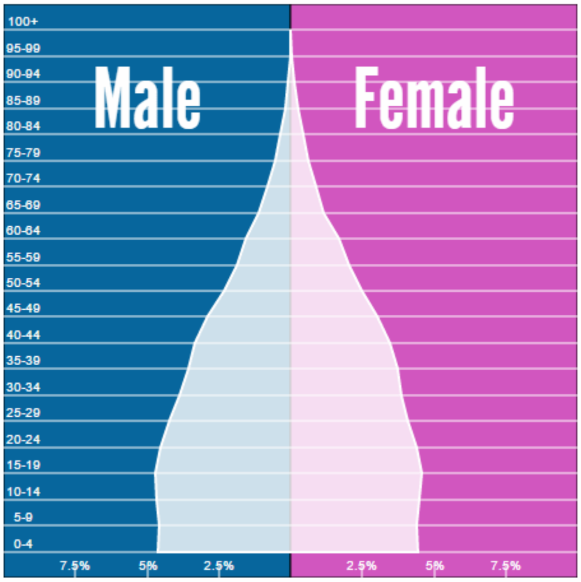


Figure 8 Mexican population pyramid, 2016 (PP, 2016)

On the other hand, despite the multicultural settings within the country, the homogeneity of values in the Mexican population might support that no great differences in terms of the importance given to aspects that contribute to a high quality of life exist. Homogeneous language and religious belief (85% Catholics), as well as high importance given to family and social relations are among the cultural traits that account for this homogeneity among members of its population.

Nevertheless, according to the Organisation for Economic Co-operation and Development (OECD), Mexicans have the most average annual working hours. The average Mexican work up to 450 hours more than an average American every year, earning less than a fifth of the pay. All in all, 29 percent of Mexicans work more than 50 hours every week with average working hours per year adding up to 2,237 (McCarthy, 2015). Although there seems to be plenty of room for increasing income levels given these facts, increasing work-life balance undoubtedly seems the most important element to attain better efficiencies for Mexico. Such should be attained in careful observance of avoiding commoditisation or ineffective satisfaction of needs as suggested by the scores in other countries in North America (USA: 7.85% -development-, 6.76% -well-being-, 55.07% -production-; Canada: 7.27%, 6.71%, 42.52%, respectively). Hence, as prescribed above, promoting participation in recreational, artistic or sport activities might come in hand under a prospective better work-life balance with real options to engage with, mixed with necessary capacity for such activities and incentives among the agents involved. All these aspects have not been addressed in the National Development Plans (Energía, 2012; Federal, 2012), but should be considered as important aspects in future policy decision making.

3.7 Conclusions

The connection between energy use, environmental stress and three well-being indicators at a country-level using a comparative efficiency approach yielded the following results:

First, from all the analysed countries, three (Costa Rica, Nigeria and The Philippines) scored highest in the DEA-based production efficiency model, which used GDP per capita, TPES and CO_2 emissions (both per capita) in a comparative-efficiency approach. In turn, two countries (Ghana and Tanzania) reported the highest performance in the DEA-based development and well-being efficiency models, which utilised the Human Development Index and a subjective well-being index accordingly with the same indicators of energy use and environmental stress. The most industrialised countries reported better performance in production than in development and well-being. The worst performers for development and well-being efficiency were Saudi Arabia, Canada, United States and Russia, whereas Uzbekistan, Russia, South Africa and China scored the lowest in production efficiency. All these countries reported performance below the 10th percentile in each correspoding model.

In order to become as efficient as the best peers, the reductions of inefficient countries were estimated in ranges between 0.15 to 15.21 tCO_2 emissions per cap, and 0.07 to 6.2 toe per cap.

Second, the efficiency indices of development and well-being demonstrated a similar graphical pattern and correlated with the Ecological Footprint, while production did not correlate above weak levels with any previous sustainability index. Given this, the DEA-based indices of development and well-being are suggested to indirectly represent indicators of ecological capacity.

In terms of crucial elements for paths towards sustainable performance (the Goldemberg corner) in the light of previous theory and the case of Mexico, the following can be concluded:

Overall, higher development and well-being efficiency associated with tropical climates, specific regions, religious groups and language groups, younger populations, reduced affluence levels and better work-life balance. In contrast, higher production efficiency was strongly associated to higher work-life balance, mixed climates and specific regions.

Mexico seems to be well within those countries above a hypothetical threshold of inefficient performance (76.71 % -production-, 28.62 % -development-, 31.07 % -well-being-), suggesting to consider less focus on increasing energy consumption or economic growth, and a refocus on alternative paths to attain a more sustainable performance. Geographically, only some regions in the country (the north, coasts and the south) might need to consider a higher level of energy consumption than average for cooling or heating, and thus better technologies to improve energy efficiency on such end-uses. However, increasing work-life balance undoubtedly seems the most important element to improve the DEA results of Mexico, given that on one hand such factor is associated with positive gains and on the other, it is reported that Mexico has the highest average annual working hours in the OECD. Promoting participation in recreational, artistic or sport activities might come in hand under a prospective policy for increased hours for leisure. These options of activities to engage with are needed among the population together with the necessary infrastructure for such activities and incentives among the agents involved. All these aspects should be considered important in future policy decision making.

3.8 References

Abdallah, S., Thompson, S., Michaelson, J., Marks, N., Steuer, N. (2009) The Happy Planet Index 2.0: Why good lives don't have to cost the Earth.

Charnes, A., Cooper, W.W. and Rhodes, E. (1978). Measuring the efficiency of decision making units. European Journal of Operational Research, 2(6), 429-444.

CIA [Central Intelligence Agency] (2015a). The World Factbook - Climate. Retrieved May, 2015 from https://www.cia.gov/library/publications/the-world-factbook/fields/2059.html

CIA [Central Intelligence Agency] (2015b). The World Factbook - Languages. Retrieved May, 2015 from https://www.cia.gov/library/publications/the-world-factbook/fields/print_2098.html

Cook, W.D. and Seiford, L.M. (2009). Data envelopment analysis (DEA) – Thirty years on. European Journal of Operational Research, 192(1), 1-17.

Cooper, W.W., Seiford, L.M. and Zhu, J. (2011). Handbook on data envelopment analysis (Vol. 164). Springer Science & Business Media.

Cravioto, J., Yamasue, E., Okumura, H. and Ishihara, K.N. (2011). Performance analysis between well-being, energy and environmental indicators using data envelopment analysis. In Zero-Carbon Energy Kyoto 2010 (pp. 49-55). Springer Japan.

Dietz, T. and Jorgenson, A.K. (2014). Towards a new view of sustainable development: human well-being and environmental stress. Environmental Research Letters, 9(3), 031001.

Dietz, T. and Rosa, E.A. (1994). Rethinking the environmental impacts of population, affluence and technology. Human Ecology Review, 1,277-300.

Dietz, T., Rosa, E.A., and York, R. (2007) Driving the human ecological footprint. Frontiers in Ecology and the Environment 5.1: 13-18.

Dietz, T., Rosa, E.A. and York, R. (2009). Environmentally efficient well-being: Rethinking sustainability as the relationship between human well-being and environmental impacts. Human Ecology Review, 16(1), 114-123.

Dietz, T., Rosa, E.A. and York, R. (2012). Environmentally efficient well-being: Is there a Kuznets curve? Applied Geography, 32(1), 21-28.

Emrouznejad, A., Parker, B.R. and Tavares, G. (2008). Evaluation of research in efficiency and productivity: A survey and analysis of the first 30 years of scholarly literature in DEA. Socio-economic Planning Sciences, 42(3), 151-157.

Energía, Secretaria de (2012) Estrategía nacional de energía 2013-2027. México.

Engelbrecht, H. (2009) Natural capital, subjective well-being, and the new welfare economics of sustainability: Some evidence from cross-country regressions. Ecological Economics 69.2: 380-388.

Farrell, M.J. (1957). The Measurement of Productive Efficiency. Journal of the Royal Statistical Society, Series A, General 120 (III), 253–281.

Federal, Administración Pública (2012). Plan nacional de desarrollo 2013-2018. México.

Gallup-Healthways (2016) Gallup World Poll: Overall life satisfaction index 2012. Retrieved Jul, 2016 from http:// www.well-beingindex.com/

Garcia, M. (2006). An Introduction Linking Energy Use and Human Development. Energy for Human Development, Report 1.

Graham, C. (2009). Happiness around the world: The paradox of happy peasants and miserable millionaires. Oxford University Press.

Goldemberg, J., Johansson, T.B., Reddy, A.K.N. and Williams, R.H. (1985). Basic needs and much more with one kilowatt per capita. Ambio, 14(4–5), 190–200.

Gould, K.A., Pellow, D.N. and Schnaiberg, A. (2004) Interrogating the treadmill of production everything you wanted to know about the treadmill but were afraid to ask. Organization & Environment 17.3: 296-316.

Grossman, G.M. and Krueger, A.B. (1994) Economic growth and the environment. National Bureau of Economic Research, No. w4634.

Helliwell, J.F., Barrington-Leigh, C.P., Harris, A., Huang, H. (2009) International evidence on the social context of well-being. National Bureau of Economic Research, Working Paper 14720.

IEA [International Energy Agency] (2015a). CO_2 Emissions from Fuel Combustion 2015. Retrieved Jul, 2016 from http://www.iea.org/statistics/topics/CO2emissions/

IEA [International Energy Agency] (2015b). CO_2 Emissions from Fuel Combustion 2015 Highlights. Retrieved Jul, 2016 from https://www.iea.org/publications/freepublications/ publication/CO2EmissionsFromFuelCombustionHighlights2015.pdf

IEA [International Energy Agency] (2015c). IEA Headline Global Energy Data (2015 ed.). Retrieved Jul, 2016 from http://www.iea.org/statistics/IEA_HeadlineEnergyData_2015.xlsx

Inglehart, R. and Klingemann, H. (2000) Genes, culture, democracy, and happiness. Culture and subjective well-being: 165-183.

Inglehart, R., Foa, R., Peterson, C. and Welzel, C. (2008) Development, freedom, and rising happiness: A global perspective (1981–2007). Perspectives on psychological science 3.4: 264-285.

Jackson, T. (2005) Live better by consuming less?: is there a "double dividend" in sustainable consumption? Journal of Industrial Ecology 9.1-2 (2005): 19-36.

Jurado, A. and Perez-Mayo, J. (2012). Construction and evolution of a multidimensional well-being index for the Spanish regions. Social Indicators Research, 107(2), 259-279.

Kahneman, D., Diener, E. and Schwarz, N. (Eds.) (1999).Well-being: The foundations of hedonic psychology. New York: Russell Sage Foundation.

Knight, K.W. and Rosa, E.A. (2009). The environmental costs of life satisfaction: A cross-national empirical test. In Workshop of the Sustainable Research and Action Network (SCORAI). Clark University Worcester, MA.

Knight, K.W. and Rosa, E.A. (2011). The environmental efficiency of well-being: A cross-national analysis. Social Science Research, 40(3), 931-949.

Knight, K.W. and Schor, J.B. (2014). Economic growth and climate change: A cross-national analysis of territorial and consumption-based carbon emissions in high-income countries. Sustainability, 6(6), 3722-3731.

Lamb, W.F., Steinberger, J.K., Bows-Larkin, A., Peters, G.P., Roberts, J.T. and Wood, F.R. (2014). Transitions in pathways of human development and carbon emissions. Environmental Research Letters, 9(1), 014011.

Manno, J. (2002). Commoditization: consumption efficiency and an economy of care and connection. In: Princen, Thomas, Maniates, Michael, Conca, Ken (Eds.), Confronting Consumption. The MIT Press, Cambridge, MA, pp. 23–42.

Mariano, E.B., Sobreiro, V.A. and do Nascimento Rebelatto, D.A. (2015). Human development and data envelopment analysis: A structured literature review. Omega, 54, 33-49.

Martinez, D.M. and Ebenhack, B.W. (2008). Understanding the role of energy consumption in human development through the use of saturation phenomena. Energy Policy, 36(4), 1430-1435.

Mazur, A. and Rosa, E. (1974). Energy and lifestyle: Cross-national comparison of energy consumption and quality of life indicators. Science, 1(86), 607-610.

Mazur, A. (2011). Does increasing energy or electricity consumption improve quality of life in industrial nations? Energy Policy, 39(5), 2568-2572.

McCarthy, Niall (2015). These Countries Have The Most Annual Working Hours. Forbes Magazine, Business section (Apr 21, 2015).

Mol, A.P.J. and Spaargaren, G. Ecological modernization and consumption: a reply. Society and Natural Resources 17.3: 261-265.

Murias, P., Martinez, F. and De Miguel, C. (2006). An economic wellbeing index for the Spanish provinces: A data envelopment analysis approach. Social Indicators Research, 77(3), 395-417.

NEF [New Economics Foundation] (2016) Happy Planet Index. Retrieved Jun 2016 from http://www.happyplanetindex.org/data/

OECD [Organisation of Economic Cooperation and Development] (2015). Better Life Index Dataset: Time devoted to leisure and personal care. Retrieved May, 2015 from http://stats.oecd.org

Pasternak, A. (2000). Global energy futures and human development: A framework for analysis (rep. no. UCRL-ID-140773: 1–25). Lawrence Livermore National Laboratory, California (USA).

PP [Population Pyramid] (2016). Population Pyramids of the World from 1950 to 2100 - Mexico 2016. Retrieved Jun 17, 2016 from http://populationpyramid.net/mexico/2016/

PRC [Pew Research Center] (2015). Religion and public life. Retrieved May, 2015 from http://www.pewforum.org/2014/04/04/religious-diversity-index-scores-by-country/

Rees, W.E. (1992). Ecological footprints and appropriated carrying capacity: what urban economics leaves out. Environment and Urbanization, 4(2), 121-130.

Rice, J. (2008) Material consumption and social well-being within the periphery of the world economy: An ecological analysis of maternal mortality." Social Science Research 37.4: 1292-1309.

Rosa, E., Keating, K.M. and Staples, C. (1981). Energy, economic growth and quality of life: A cross-national trend analysis. In International Congress on Applied Systems Research and Cybernetics.

Ramanathan, R. (2002). Combining indicators of energy consumption and CO_2 emissions: a cross-country comparison. International Journal of Global Energy Issues, 17(3), 214-227.

Rehdanz, K. and Maddison, D. (2005) Climate and happiness. Ecological Economics 52.1: 111-125.

Reig-Martínez, E. (2013). Social and economic wellbeing in Europe and the Mediterranean Basin: Building an enlarged Human Development Indicator. Social Indicators Research, 111(2), 527-547.

Schumacher, E. F. (1973). Small is beautiful; economics as if people mattered. New York: Harper & Row.

Seyfang, G. (2009) The new economics of sustainable consumption. Minería transnacional, narrativas del desarrollo y resistencias sociales. Buenos Aires: Biblos (2009).

Smil, V. (2005). Energy at the crossroads: Global perspectives and uncertainties. Cambridge, MA: MIT press.

Smith, C.L. and Clay, P.M. (2010). Measuring subjective and objective well-being: Analyses from five marine commercial fisheries. Human Organization, 69(2), 158-168.

Steinberger, J.K. and Roberts, J.T. (2010). From constraint to sufficiency: The decoupling of energy and carbon from human needs, 1975–2005. Ecological Economics, 70(2), 425-433.

Steinberger, J.K., Roberts, J.T., Peters, G.P. and Baiocchi, G. (2012). Pathways of human development and carbon emissions embodied in trade. Nature Climate Change, 2(2), 81-85.

Tausch, A. (2011) Costa Rica, superstar? some reflections on the global drivers and bottlenecks of the happy planet index. Some Reflections on the Global Drivers and Bottlenecks of the Happy Planet Index.

UN [United Nations] (2015a). United Nations Database: Composition of macro geographical (continental) regions, geographical sub-regions, and selected economic and other groupings. Retrieved May, 2015 from http://unstats.un.org/unsd/methods/m49/m49regin.htm#ftnb

UN [United Nations] (2015b). United Nations Database: Population median age (years). Retrieved May, 2015 from https://data.un.org

UNDP [United Nations Development Programme] (2015). Human Development Report 2015: Work for Human Development - Human Development Index. Retrieved Jul, 2016 from hdr.undp.org/sites/default/files/ hdr14_statisticaltables.xls

Van de Vliert, E. (2008) Climate, affluence, and culture. Cambridge University Press.

Van Praag, B.M.S. and Ferrer-i-Carbonell, A. (2007). Happiness quantified: A satisfaction calculus approach. Oxford University Press.

WB [The World Bank] (2015). The World Bank Database: Poverty headcount ratio at $2 a day (PPP) (% of population). Retrieved May, 2015 from http://databank.worldbank.org.

WB [The World Bank] (2016a). World Bank International Comparison Program Database: GDP, PPP (current international $) 2012 [Series Code: NY.GDP.MKTP.PP.CD]. Retrieved Jul, 2016 from http://data.worldbank.org/

WB [The World Bank] (2016b). World Development Indicators: Population, total 2012 [Series Code: SP.POP.TOTL7]. Retrieved Jul, 2016 from http://data.worldbank.org/

Zhu, J. (2001). Multidimensional quality-of-life measure with an application to Fortune's best cities. Socio-Economic Planning Sciences, 35(4), 263-284.

IV. Energy services at households and human well-being

4.1 Introduction

Despite the vast literature that exists on human well-being, descriptions from the energy use perspective are rare. Isolating energy from other elements is difficult, because the relationship is determined by many factors. Approaches controlling these factors are greatly needed, and the few potentially useful ones have scarcely been studied.

As mentioned in section 1.3.2, energy services (ES) is one of the few concepts that could act as a linkage between energy use and human well-being. The first articles mentioning ES were published during the 1980s (Reister and Devine, 1981; Kahane, 1991). Later, ES have echoed in more recent works (Sovacool, 2011a; Norgard, 2000; Jonsson et al., 2011).

Despite this, ES appear far less in academic literature, when compared to other similar concepts. End-uses of energy, for example, is a closely related notion mentioned more often, yet usually confused with ES. According to different authors, end-uses of energy refer to "the content of primary energy supplied to the consumer at the point of end-use" (Sovacool, 2011a), thus being physical quantities. Energy services, in contrast, are broader notions encompassing these end-uses and further elements. ES can therefore be thought of specific benefits for human satisfaction or well-being largely connected with energy use.

Unfortunately, as mentioned earlier, analysts have repeatedly attributed characteristics of end-uses on ES. Reister and Devine (1981), for example, defined ES as "a measure of a service provided to ultimate consumers by their own use of energy in any of its forms...". As they state it: "energy services should be measured in units of work, of heat at various temperatures...", they believed that such an explanation qualifies them as "surrogates of satisfaction... experienced when human wants are fulfilled via the direct use of energy". Hass et al. (2008) and Wirl (1995) regarded ES more as a demand force, expressed by a bivariate concept encompassing energy and technology. Although the idea seems closer to the notion of "benefits for human well-being", their view also assumes ES to be equal to end-uses in terms of measurement. Finally, Kahane (1991) believed that more efficiency gains could be attained by taking a broader view of the energy system, and that quality of life is made up by ES. Yet, similarly to the other authors, he equates them to end-uses in terms of measurement.

The latest literature brings ES closer to real well-being surrogates, at least conceptually. Norgard (2000) and Jonsson et al. (2011), for example, recognise more clearly that ES are placed between end-uses and human welfare, and that they are the last quantifiable link in the energy chain. Considering that end-uses should be efficiencies of a given activity per amount of energy, it is still not clear how ES could be quantified as surrogates of well-being. For Modi et al. (2006) and Sovacool (2011a), ES are also surrogates of human satisfaction, considering them "benefits that energy carriers produce for human well-being". They recognise a multidimensional nature of ES (figure 9), but also do not provide any clear system for their measurement.

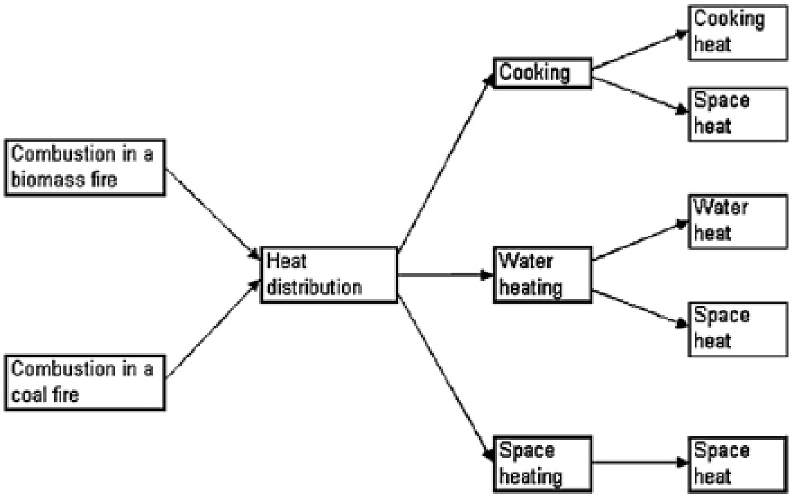


Figure 9 Multidimensional relationship of heat-related household energy services (Howells et al., 2005 in Sovacool, 2011a)

As suggested by these remarks, taking ES and end-uses interchangeably is not accurate, given that both represent related yet different notions. End-uses should be acknowledged as a physical or efficiency measure, while ES should be taken in a scale able to represent them as real surrogates of human well-being.

4.1.1 Energy services and well-being. Provided that ES could be analysed as a well-being surrogate connected with energy use, one concern for research is how accurately can ES actually be such a surrogate, and another how these would correlate with end-uses and other factors.

As previously explained in section 1.1, the energy-well-being link is crucial for human sustainability. Disciplinary research, largely from social scientists, has made great progress on describing what factors correlate with different well-being indices, but little attention has been given to ES or other energy-related surrogates. This could be a more straightforward and useful approach.

ES as surrogates of well-being might also become a tool for policy design, because they could help to analyse the effectiveness of specific policies related to energy-use, devices and practises aimed to enhance overall human well-being. In addition, they might shed light on ways to increase well-being levels, while reducing consumption through end-uses of energy. The household sector perspective is crucial here, as households are often considered the final users of energy consumed from the other sectors (Jonsson et al., 2011; Moll et al., 2005 in Sovacool, 2011a). But because ES is a research topic still largely unexplored, the assumption that ES can act as a well-being surrogate is the first crucial issue. Past studies of ES measured in ways closer to a well-being dimension are nonexistent and the few approaches suggesting a similar measurement are disconnected with such concerns (Romero et al., 2013).

4.1.2 Purpose. Corresponding to the first part of the household-level assessment of the connection between human well-being and energy use, this chapter's purpose is first, to measure energy surrogates of human well-being denoted by (six) energy services at Mexican households quantified in a satisfaction scale; and second, to analyse their correlations with an index of overall life satisfaction by income group in order to assess the adequacy of energy services as linkages between human well-being and energy use.

4.2 Method

4.2.1 Case Study. As already mentioned in this chapter's introduction, given that the measurement of ES has never been studied, ES data had to be obtained through a survey directly conducted in households. Well-being scores, although available nationally

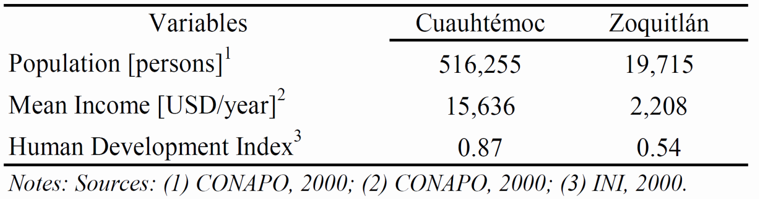
Figure 10 Location of Zoquitlán and Cuauhtémoc

in many cases (Gallup, 2014), also had to be surveyed with ES to have both data taken simultaneously for the analysis.

In selecting regions to carry out the survey, Latin America seemed to be suitable, because countries within are not only comparatively less studied, but also interesting given that research has reported that high well-being scores mixed with rather low energy consumption is found in the region (Cravioto et al., 2011; Knight and Rosa, 2011; Dietz et al., 2009; Mazur, 2011; Steinberg and Roberts, 2010). Furthermore, to control for culture and climatic conditions, we looked for a culturally homogeneous country with similar geography. Under these considerations Mexico was selected, for it is representative of Latin America and contains multiple locations with different income levels that still can keep culture, climate and geography alike.

Within Mexico, based on the information published in national statistics (CONAPO, 2000; INI, 2000), two sites from the Mexican central plateau were chosen. This simplified the analysis, because both regions do not present drastic seasonal climate differences. The first, Cuauhtémoc, is one of the sixteen boroughs in Mexico City and the second, Zoquitlán, is a rural community to the southwest of Mexico City in the highlands of the state of Puebla (figure 10). Both lie at around 2000 m over sea levels and have temperate climate (type Cwb in the Köppen classification), but Cuauhtémoc is an urban district with most of its population in upper-middle income levels, while Zoquitlán is a rural community with lower socio-economic conditions (table 6). These differences are also observed through their HDI levels, which provide a ground for comparison of regions in different levels of objective well-being levels, related to the findings reported in the previous chapter.

Table 6 Socioeconomic profiles of surveyed locations: Zoquitlán and Cuauhtémoc



Variables	Cuauhtémoc	Zoquitlán
Population [persons][1]	516,255	19,715
Mean Income [USD/year][2]	15,636	2,208
Human Development Index[3]	0.87	0.54

Notes: Sources: (1) CONAPO, 2000; (2) CONAPO, 2000; (3) INI, 2000.

4.2.2 Data collection. As briefly explained in section 2.2, the data was collected in March 2011, using an interviewed survey conducted in randomly selected households. The obtained sample consisted of 98 questionnaires: 40 from Zoquitlán and 58 from Cuauhtémoc.

4.2.3 Questionnaire.

4.2.3.1 Well-being measures. As explained in section 3.2, well-being measures are divided into objective and subjective groups. This study follows the common subjective scale proposed by Veenhoven for measuring life satisfaction (LS) (WDH, 2015; Veenhoven, 2010; Veenhoven and Hagerty, 2006). Such consideration allows for comparisons with ES, which are taken using a similar scale. The item used in the questionnaire is measured in a five-point Likert scale as follows:

> Taking into account everything, how satisfied or dissatisfied you are currently with your life as a whole?

1 ———— 2 ———— 3 ———— 4 ———— 5

Dissatisfied Satisfied

4.2.3.2 Energy services. Considering the ES literature review outlined in section 1.3.2 and referred to in this chapter's introduction, six ES among the most relevant in importance (Sovacool, 2011a; Modi et al., 2006) were selected. These included: communications, entertainment, food preservation, illumination, temperature regulation and transport, all measured in a five-point Likert scale. The question used to retrieve the level of satisfaction with each of these ES was the following:

> In a five-point scale, rate how satisfied or dissatisfied you are currently with the following ES at home?
> (1 being very dissatisfied and 5 very satisfied) _______________

4.2.3.3 Other variables. The survey also included other variables not used here, but further explained and considered in the analysis of chapter V. A sample of the questionnaire can be found in appendix B.

4.2.4 Analysis methods.

4.2.4.1 Simplification of ES. As explained in section 2.4, a Principal Component Analysis (PCA) is used to condense ES together into a single index. Following the considerations for element discrimination already detailed (see section 2.4), this procedure serves first, to prepare ES in a single measure for a subsequent association analysis between ES and LS; and second, to test for associations among ES to relate them with previously reported theories (Sovacool, 2011a; Sovacool, 2011b; Modi et al., 2006).

4.2.4.2 ES-LS association analyses. Two statistical methods already mentioned in section 2.4 are conducted to verify the associations between ES and LS. First, correlations valid for numeric (Pearson R) and ordinal scales (Spearman Rho, Kendall Tau, Gamma), and linear contrasts, a test of hypothesis of a linear linkage between ES and LS using the mean scores in the scales.

These results are complemented with a final discussion on ES used as well-being surrogates, in addition to the limitations of the case study.

4.3 Results

4.3.1 Energy services and well-being survey results by income group. As expected, households in Cuauhtémoc were confirmed to have better general physical conditions than households in Zoquitlán (figure 11). Surprisingly, however, this difference reflected only in some ES.

Figure 11 Household conditions in Zoquitlán and Cuauhtémoc

First of all, Cuauhtémoc reported mean scores one point above Zoquitlán in entertainment, and differences were less noticeable for transport and communications (0.8 above). For illumination, food preservation and temperature regulation the differences were even less noticeable (only 0.5 points higher - see ES in figure 12).

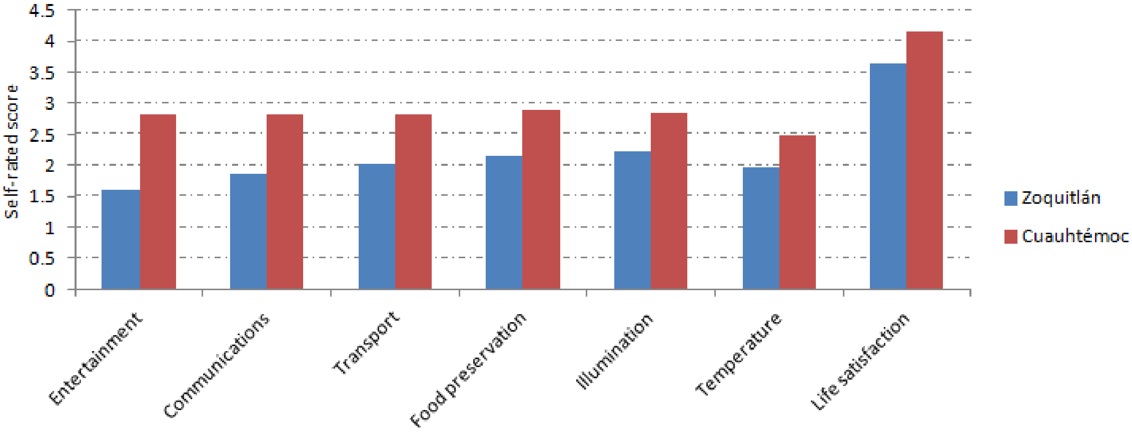
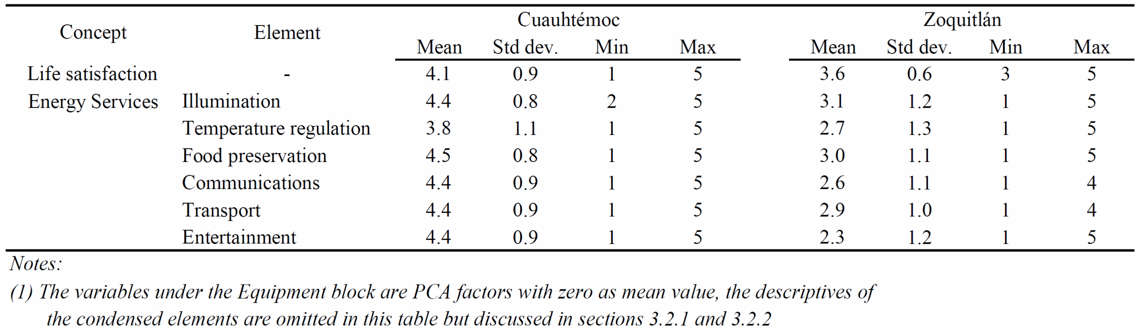


Figure 12 Energy services and life satisfaction. Mean scores by region.

In terms of LS, both regions also showed slight changes, but compared to ES, Cuauhtémoc and Zoquitlán seemed even more comparable (see LS in figure 12).

In terms of data distributions, more differences were noticeable. ES in Cuauhtémoc were found to be skewed to the left, concentrating on higher frequencies in the upper ends of the scale (very satisfied / satisfied), whereas normal or in some cases distributions slightly skewed to the right were found in Zoquitlán, meaning that ES tended to lie more in the center (see figures 13, 14, 15). LS scores on the contrary, showed left-skewed results in both regions, concentrating frequencies clearly above the center of the scale. It should be noted however, that despite this similarity, in Cuauhtémoc higher number of "satisfied / very satisfied" answers were found over "regular" (76% against 24%), whereas in Zoquitlán both resulted rather equal (43% for regular and 57% for satisfied). Another unexpected result regarding LS was that nobody answered "unsatisfied" in Zoquitlán, even though the region has considerably lower income levels. In contrast, in Cuauhtémoc a couple of "unsatisfied" and "very unsatisfied" answers were found, in spite of the wealthier conditions of households. Table 7 shows a summary of selected statistics of the data.

Table 7 Descriptive statistics of surveyed data on energy services and life satisfaction



Concept	Element	Cuauhtémoc				Zoquitlán			
		Mean	Std dev.	Min	Max	Mean	Std dev.	Min	Max
Life satisfaction	-	4.1	0.9	1	5	3.6	0.6	3	5
Energy Services	Illumination	4.4	0.8	2	5	3.1	1.2	1	5
	Temperature regulation	3.8	1.1	1	5	2.7	1.3	1	5
	Food preservation	4.5	0.8	1	5	3.0	1.1	1	5
	Communications	4.4	0.9	1	5	2.6	1.1	1	4
	Transport	4.4	0.9	1	5	2.9	1.0	1	4
	Entertainment	4.4	0.9	1	5	2.3	1.2	1	5

Notes:

(1) The variables under the Equipment block are PCA factors with zero as mean value, the descriptives of the condensed elements are omitted in this table but discussed in sections 3.2.1 and 3.2.2

4.3.2 Energy services components by income group. In addition to the individual comparisons of ES reported above, to test how ES are integrated into a single concept, the results of the PCA on ES are presented here. Similarly to the analyses of ES individually, both regions showed differences in the components obtained: In Zoquitlán, the six ES were reduced into two components; whereas in Cuauhtémoc, they became a single one.

The two components in Zoquitlán divided most of the ES clearly. Only food preservation had to be later introduced arbitrarily based on a slightly better consistency with one of the components (see table 8). The first component was comprised of "temperature",

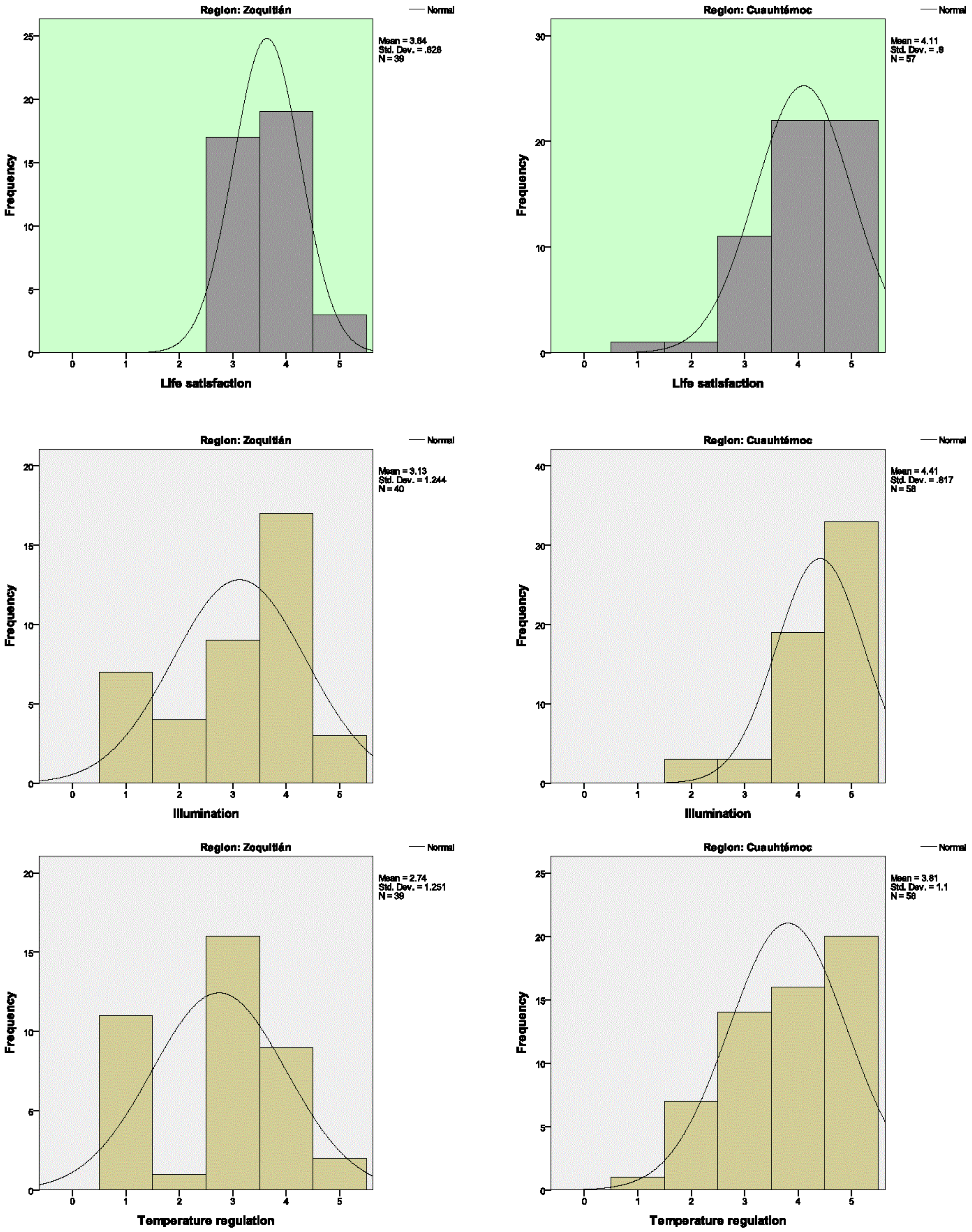


Figure 13 Energy services and life satisfaction. Histograms and distributions by region (1/3).

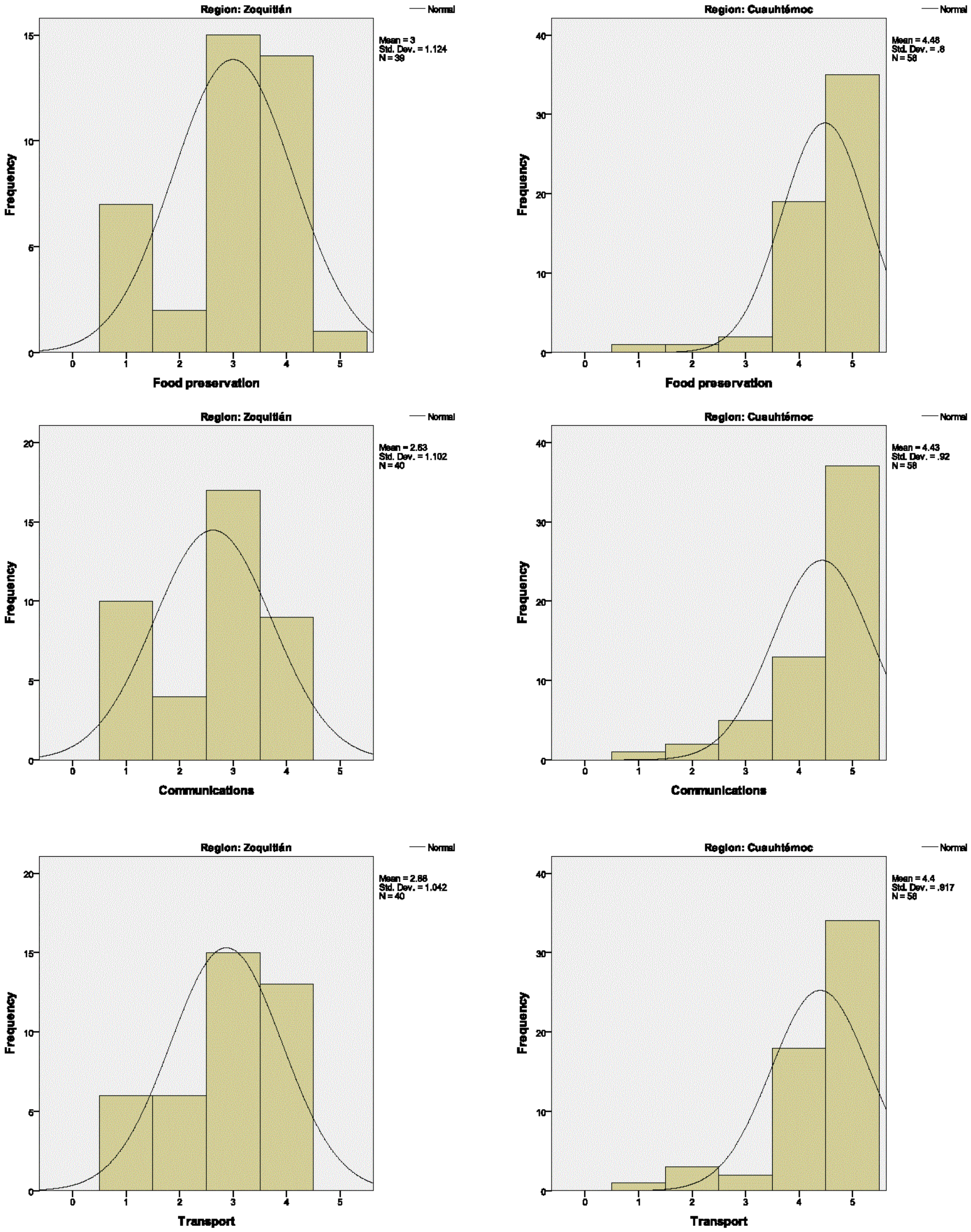


Figure 14 Energy services and life satisfaction. Histograms and distributions by region (2/3).

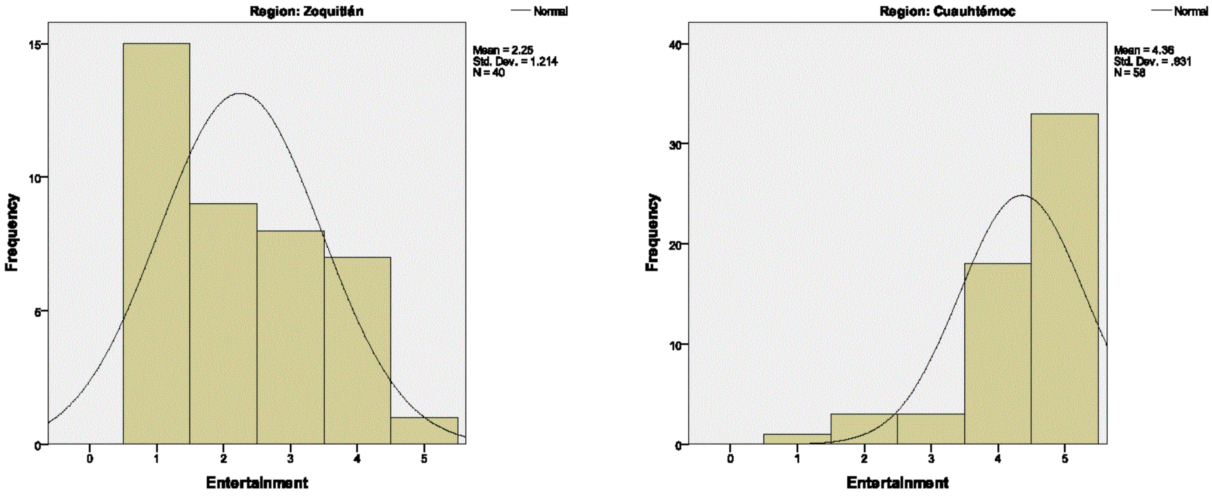


Figure 15 Energy services and life satisfaction. Histograms and distributions by region (3/3).

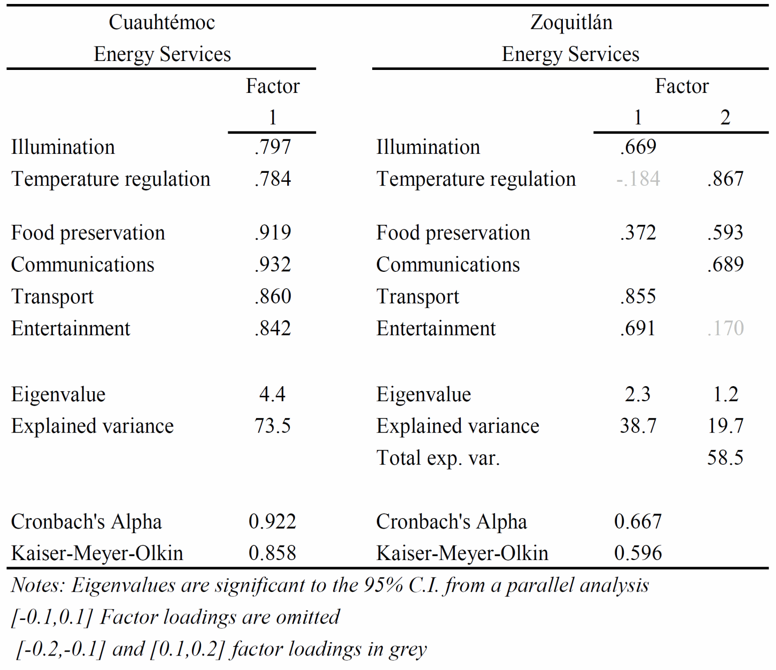
"food preservation", and "communications"; the second, "illumination", "transport" and "entertainment". The results suggested that for lower incomes some ES might be more fundamental for daily living, compared to others less essential. Hypothesising such hierarchical order, these components were labelled "primary ES" and "secondary ES".

In contrast, ES merged together into a single component in Cuauhtémoc, demonstrating that as income increases, both primary and secondary ES can be assimilated into a single unique factor.

Overall, these findings suggest that PCAs might capture the user preference on certain ES, which evolves as income increases. The ES preference shifts from being multiple-hierarchical in lower incomes to more horizontal as income increases.

Both sections above (4.3.1 and 4.3.2) support that income differences are reflected more clearly in ES than in LS. However, how well can ES predict an increase in LS or the nature of such relation is another concern. Related literature has constantly found a decreasing returns to scale between LS and many material indicators (Mazur, 2011; Steinberg and Roberts, 2010; Knight and Rosa, 2011, 2009; Dietz et al., 2009; Martinez and Ebenhack, 2008; Pasternak, 2000; Mazur and Rosa, 1974). However it is not clear if ES and LS might have a similar relationship or can be regarded as closer concepts. As introduced in section 2.4 (and further explained in section 4.2.4), the association analyses in the following section will shed light on such concerns, and test how close are energy surrogates of well-being to overall life satisfaction. In addition, with these initial results the use of non-parametric statistical tools described before is further justified, given the nature of the distributions found in the data (figures 13, 14 and 15).

Table 8 Principal component analyses on energy services



Cuauhtémoc Energy Services		Zoquitlán Energy Services		
	Factor		Factor	
	1		1	2
Illumination	.797	Illumination	.669	
Temperature regulation	.784	Temperature regulation	-.184	.867
Food preservation	.919	Food preservation	.372	.593
Communications	.932	Communications		.689
Transport	.860	Transport	.855	
Entertainment	.842	Entertainment	.691	.170
Eigenvalue	4.4	Eigenvalue	2.3	1.2
Explained variance	73.5	Explained variance	38.7	19.7
		Total exp. var.		58.5
Cronbach's Alpha	0.922	Cronbach's Alpha	0.667	
Kaiser-Meyer-Olkin	0.858	Kaiser-Meyer-Olkin	0.596	

Notes: Eigenvalues are significant to the 95% C.I. from a parallel analysis
[-0.1,0.1] Factor loadings are omitted
[-0.2,-0.1] and [0.1,0.2] factor loadings in grey

4.3.3 Relationship between energy services and well-being. For the correlation analyses following this section, LS and ES were treated as both quantitative and ordinal variables. As explained in section 4.2.4, four types of correlations are used to test for associations (Pearson R, Spearman Rho, Kendall Tau, Gamma).

4.3.3.1 ES and LS categorical data corrections. Complementing the correlation analyses, linear contrast analyses verify the existence of a linear trend between LS and ES scores, treating both variables in categorical-ordinal scales. In these analyses, ES is the explanatory variable and LS the dependent one, and LS must have at least two samples in each of the five-point categories encompassing ES. According to the descriptive statistics of section 4.3.1 (table 7), LS scores tended to show very little variation. Thus, for some ES categories only few LS responses were found, or even worsened when the sample was separated into regions (detail in table 9). Thus, for convenience a correction in the scale of ES took place, when used in a regional basis.

ES were corrected from the original 5-point scale into a 3-point scale, in which the classifications corresponding to "very dissatisfied" and "dissatisfied" were consolidated together into a group called "negative"; the category "regular" was converted to "neutral"; and lastly, "satisfied" and "very satisfied" were grouped into a "positive" category. Besides its inherent convenience in the analysis, a spearman correlation of 0.997 ($p < 0.01$) of such metric with the original suggested it to be statistically valid. Hereafter, ES will refer to this reduced 3-point scale.

Table 9 Life satisfaction by categorical levels of energy services

	Life satisfaction					
Illumination	very dissatisfied	dissatisfied	regular	satisfied	very satisfied	Total
very bad	0	0	3	4	0	7
	0%	0%	43%	57%	0%	100%
bad	0	1	3	3	0	7
	0%	14%	43%	43%	0%	100%
regular	0	0	6	5	1	12
	0%	0%	50%	42%	8%	100%
good	0	0	10	14	11	35
	0%	0%	29%	40%	31%	100%
very good	1	0	6	15	13	35
	3%	0%	17%	43%	37%	100%
Total	1	1	28	41	25	96
	1%	1%	29%	43%	26%	100%

	Life satisfaction					
Communications	very dissatisfied	dissatisfied	regular	satisfied	very satisfied	Total
very bad	0	0	4	6	0	10
	0%	0%	40%	60%	0%	100%
bad	0	1	3	2	0	6
	0%	17%	50%	33%	0%	100%
regular	0	0	9	11	2	22
	0%	0%	41%	50%	9%	100%
good	0	0	5	9	7	21
	0%	0%	24%	43%	33%	100%
very good	1	0	7	13	16	37
	3%	0%	19%	35%	43%	100%
Total	1	1	28	41	25	96
	1%	1%	29%	43%	26%	100%

	Life satisfaction					
Temperature regulation	very dissatisfied	dissatisfied	regular	satisfied	very satisfied	Total
very bad	0	0	7	5	0	12
	0%	0%	58%	42%	0%	100%
bad	0	1	5	1	1	8
	0%	13%	63%	13%	13%	100%
regular	0	0	8	14	7	29
	0%	0%	28%	48%	24%	100%
good	0	0	4	14	6	24
	0%	0%	17%	58%	25%	100%
very good	1	0	4	6	11	22
	5%	0%	18%	27%	50%	100%
Total	1	1	28	40	25	95
	1%	1%	30%	42%	26%	100%

	Life satisfaction					
Transport	very dissatisfied	dissatisfied	regular	satisfied	very satisfied	Total
very bad	0	0	5	1	1	7
	0%	0%	71%	14%	14%	100%
bad	0	1	5	3	0	9
	0%	11%	56%	33%	0%	100%
regular	0	0	6	10	1	17
	0%	0%	35%	59%	6%	100%
good	0	0	7	14	8	29
	0%	0%	24%	48%	28%	100%
very good	1	0	5	13	15	34
	3%	0%	15%	38%	44%	100%
Total	1	1	28	41	25	96
	1%	1%	29%	43%	26%	100%

	Life satisfaction					
Food preservation	very dissatisfied	dissatisfied	regular	satisfied	very satisfied	Total
very bad	0	0	3	4	1	8
	0%	0%	38%	50%	13%	100%
bad	0	1	2	0	0	3
	0%	33%	67%	0%	0%	100%
regular	0	0	9	7	1	17
	0%	0%	53%	41%	6%	100%
good	0	0	6	15	10	31
	0%	0%	19%	48%	32%	100%
very good	1	0	8	14	13	36
	3%	0%	22%	39%	36%	100%
Total	1	1	28	40	25	95
	1%	1%	30%	42%	26%	100%

	Life satisfaction					
Entertainment	very dissatisfied	dissatisfied	regular	satisfied	very satisfied	Total
very bad	0	0	7	8	1	16
	0%	0%	44%	50%	6%	100%
bad	0	1	7	4	0	12
	0%	8%	58%	33%	0%	100%
regular	0	0	3	6	2	11
	0%	0%	27%	55%	18%	100%
good	0	0	7	10	7	24
	0%	0%	29%	42%	29%	100%
very good	1	0	4	13	15	33
	3%	0%	12%	39%	46%	100%
Total	1	1	28	41	25	96
	1%	1%	29%	43%	26%	100%

Table 10 Life satisfaction and energy services correlation analyses

ES	LS (total sample)							LS low income (Zoquitlán)						LS high income (Cuauhtémoc)					
	t	r	r	g	mean		rank	t	r	r	g	mean		t	r	r	g	mean	
1. Transport	0.36 **	0.40 **	0.37 **	0.50	0.41	med	1	0.16	0.18	0.16	0.25	0.19	weak	0.22	0.24	0.34 *	0.35	0.29	weak
2. Entertainment	0.33 **	0.39 **	0.35 **	0.46	0.38	med	2	-0.02	-0.02	-0.01	-0.03	-0.02	-	0.27 *	0.30 *	0.38 **	0.42	0.34	med
3. Temperature	0.31 **	0.36 **	0.33 **	0.43	0.36	med	3	0.14	0.16	0.17	0.22	0.17	weak	0.27 *	0.30 *	0.29 *	0.37	0.31	med
4. Communications	0.31 **	0.35 **	0.32 **	0.43	0.35	med	4	0.02	0.02	0.05	0.03	0.03	-	0.16	0.18	0.27 *	0.27	0.22	weak
5. Illumination	0.27 **	0.31 **	0.29 **	0.39	0.31	med	5	0.05	0.05	0.07	0.07	0.06	-	0.14	0.16	0.25	0.22	0.19	weak
6. Food preservation	0.24 **	0.28 **	0.25 *	0.35	0.28	weak	6	0.02	0.02	-0.05	0.03	0.01	-	0.04	0.04	0.20	0.07	0.09	-
ES components																			
7. Primary ES	0.30 **	0.37 **	0.34 **		0.33	med		0.04	0.05	0.08		0.06	-	0.17	0.20	0.28 *		0.22	weak
8. Secondary ES	0.34 **	0.42 **	0.38 **		0.38	med		0.08	0.09	0.10		0.09	-	0.24 *	0.28 *	0.38 **		0.30	med
9. General ES	0.32 **	0.40 **	0.38 **		0.37	med		0.03	0.03	0.10		0.05	-	0.20	0.24	0.33 *		0.26	weak

Notes: * $p < 0.05$, ** $p < 0.01$

4.3.3.2 ES-LS correlation analyses and linear contrasts. LS associated positively to ES in all the correlation analyses, taking the data from both regions together (table 10 LS (total sample)). These correlations, ranging from 0.3 - 0.4 levels, proved that from a wide income range perspective, a positive association existed between ES and LS. In addition, a significant linear increase was observed in LS when analysed by ES level (figures 16 and 17).

It seems plausible that ES and LS positively correlate, as satisfaction with services provided by end-uses might reflect well on human life satisfaction. Yet, by looking closely at the results and comparing the findings by region, some unexpected outcomes were also observed.

Firstly, although the ES-LS association exists, it is not equally prevalent in every ES, suggesting that some energy-related well-being surrogates may have a limited predictive power on LS. This could mean that other aspects might well contribute to attain higher life satisfaction levels and could possibly be targeted without obsessive focus on improving all ES.

Regional examinations also suggest that income may influence the associations between ES and LS. The correlation coefficients did not increase when the sample was divided by region and instead became less apparent in comparison to being taken together. Moreover, as table 10 confirms, there was a remarkable difference between lower and higher incomes, challenging the rationale of most of the literature; namely, that increased energy use correlates more strongly with overall well-being levels among the poor. It is common belief that as income increases it reflects in better end-uses of energy and ultimately in higher LS. Yet, this unexpected dissociation between ES and LS in the lower incomes and the progressive associations as income increase, suggests that energy surrogates on well-being play an important part of life satisfaction only from middle income levels on.

Additionally, the results considering the ES components of “primary ES”, “secondary ES” and “general ES” in connection to LS confirm the previous, because among higher-income households (Cuauhtémoc), “secondary ES” correlated more strongly with LS than

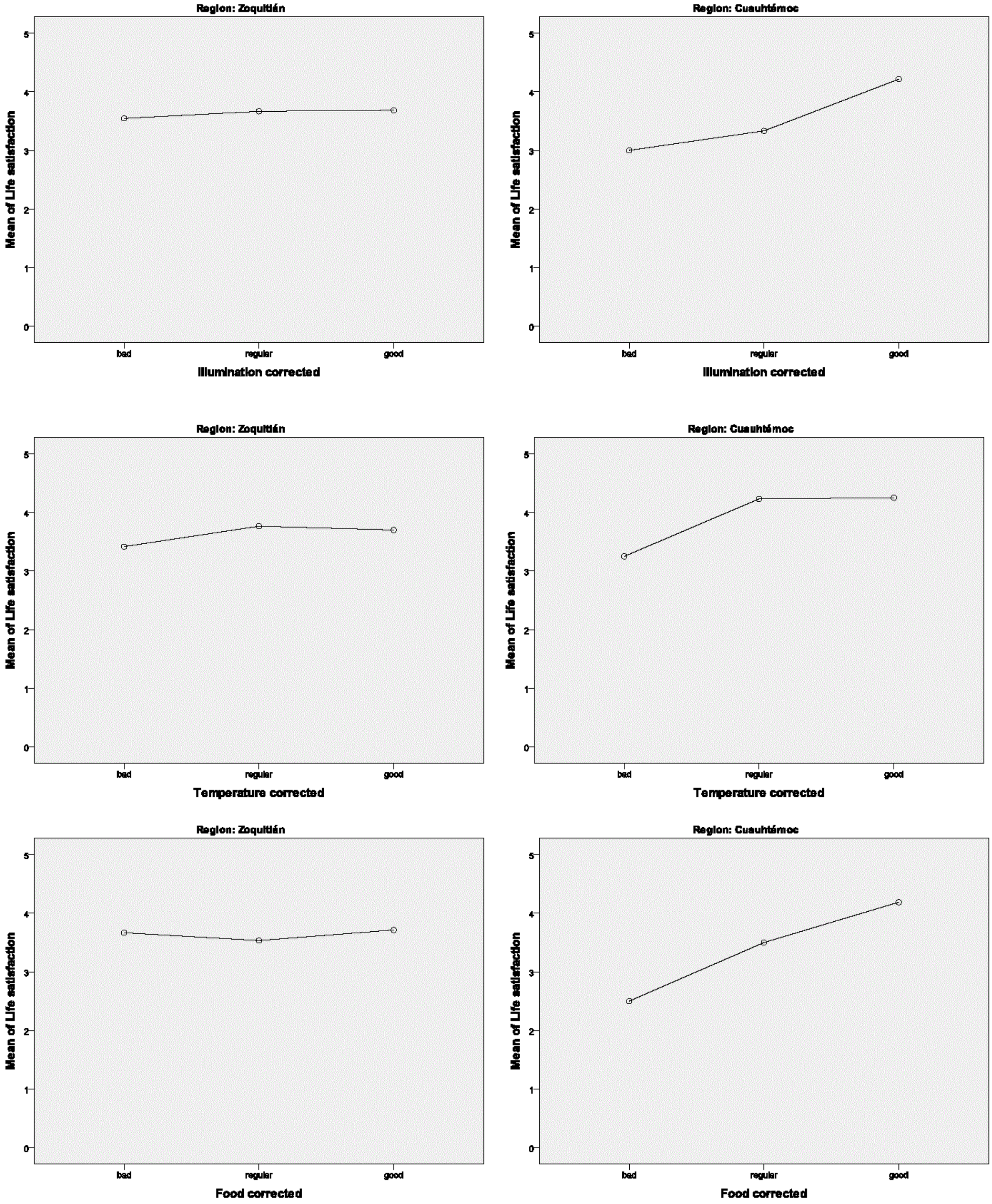


Figure 16 Energy services and life satisfaction. Linear contrast analyses (1/2).

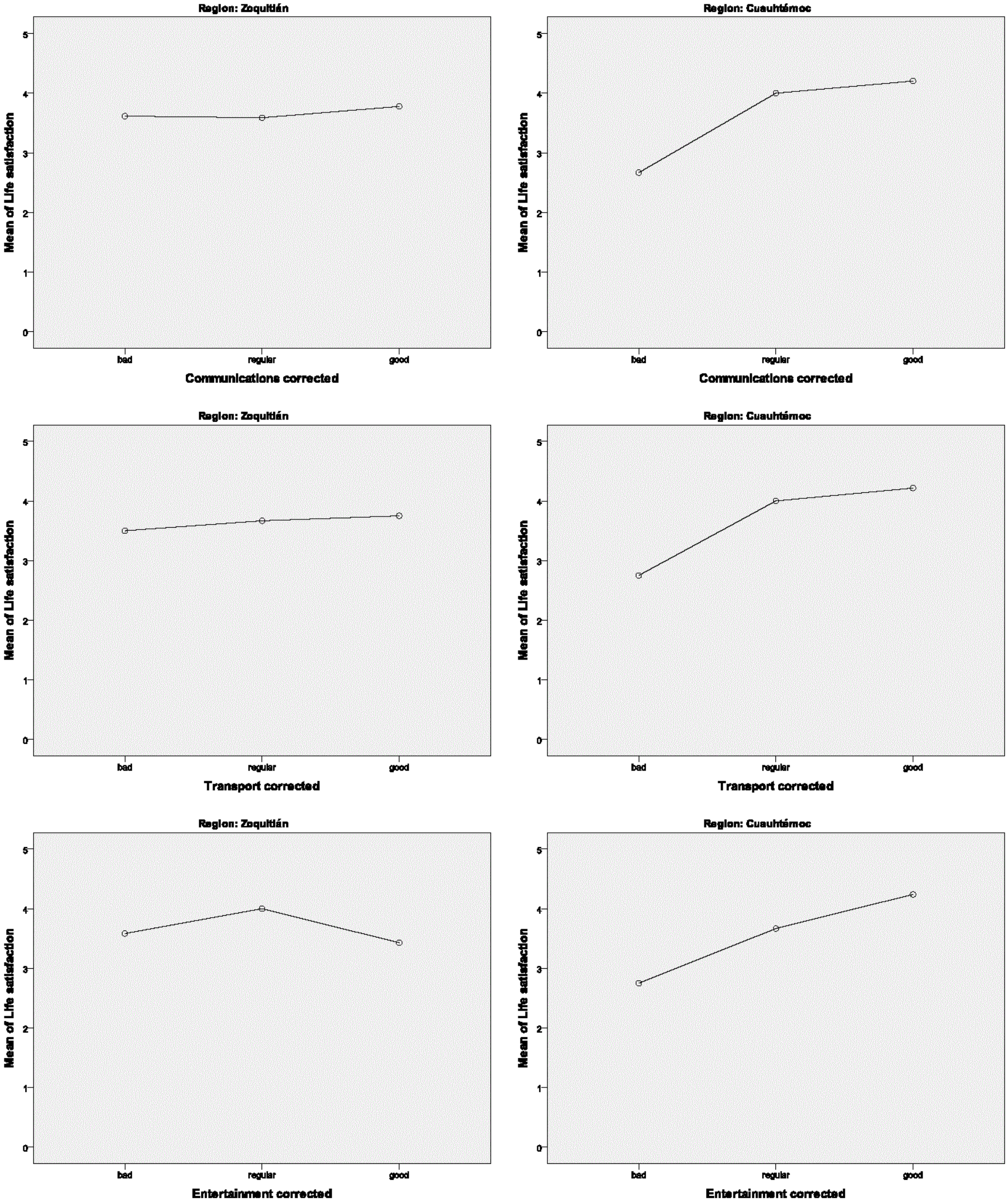


Figure 17 Energy services and life satisfaction. Linear contrast analyses (2/2).

"primary ES", whereas for lower incomes (Zoquitlán), both remained virtually dissociated (table 10).

Lastly, the linear contrast analyses did not clearly support the existence of returns to scale unlike it has constantly been found with energy use and other material predictors (Mazur, 2011; Steinberg and Roberts, 2010; Knight and Rosa, 2011, 2009; Dietz et al., 2009; Martinez and Ebenhack, 2008; Pasternak, 2000; Mazur and Rosa, 1974). A statistically significant linear trend was indeed found in the wide range of incomes, but it was not observed whatsoever for lower incomes and actually seemed to diminish from middle income levels on (figures 16 and 17).

4.4 Discussion

It should be noted that hereafter the discussions on a dynamic change between the data surveyed are elaborated under the assumption that the cross-sectional sample taken follows that behaviour. In reality unexpected outcomes might be observed as any static model has such a limitation.

4.4.1 Implications of the Mexican findings on well-being and energy services theory.

Human well-being is broad concept influenced by multiple social and individual aspects. There is evidence that health (physical and mental), lifestyle (employment, marital status, social relations, religion), political (governance, social capital) and economic (income) factors affect well-being levels (Diener and Seligman, 2004; Van Praag and Ferrer-i-Carbonell, 2007; Kahneman et al., 1999). As energy use is involved in all of these aspects, energy services are often hypothesised to be crucial to achieve life satisfaction (Haas et al., 2008). However, the previous results point to the belief that when circumscribing to the benefits produced by energy within households such association is not as strong as expected, being actually less apparent among low incomes, and slightly increasing from middle-incomes on.

The poor connection between ES and LS among lower incomes suggests instead that other aspects might enhance LS more effectively, especially among the lowest incomes. Evidently, low income families constantly find ways to enhance their LS levels through any of the aforementioned alternative predictors. Only once a middle income level is reached the linkage between energy surrogates of well-being and LS appear, because probably more concern is placed on energy services in households and the influence of relative wealth considered in a wider scope of comparison (Sovacool, 2011a). This fact could probably reflect stronger concerns about convenience, comfort or cleanliness as some of the literature has suggested (Cravioto et al., 2014; Sovacool, 2011a), or early patterns of social signalling or conspicuous consumption from easier access to material goods (this behaviour is more typical among high income households according to Sovacool, 2011a).

4.4.1.1 Life satisfaction and individual energy services in Mexican households.

There is no previous theory on which ES are the most relevant to LS, but some elements from each of the ES under study could be recognised as more important than others. In the previous section it was noted that ES in general shifted from middle income level, but some ES were linked more strongly to LS than others, regardless of the effects of income change.

First, little difficulties seemed to be found to preserve food in these regions, either because of particular patterns of consumption (low amounts of stored food) or because favourable climatic conditions allowed it. This might explain why food preservation did not seem to be relevant at all for LS.

Illumination and communications followed food preservation in importance, but still they were the least relevant among the remaining ES. A marked difference between incomes allowed for a clarification on what both ES might represent, i.e. for the wealthier, illumination and communications seemed somehow more relevant compared to the poor.

Probably the most important ES for LS in both income groups were transport and temperature regulation, and although even more important when income is increased, both of these services correlated more strongly to higher LS levels.

Finally, the most irregular ES was entertainment, which strongly differed among regions. Although not correlated with LS in lower incomes, it correlated even more strongly than others among higher incomes. This might be because as income increases, entertainment is probably more developed inside households, in contrast to low incomes where it might be sought outside the house, and thus not connected to LS.

This study on energy surrogates of well-being seemed to support theory on ES as reported in previous literature. For example, transport and temperature regulation were the most relevant ES for increasing life satisfaction levels regardless of the income group. Energy consumption for transport has been believed to contribute directly to having a varied life more than other energy consumption at households (Poortinga et al., 2004). By income groups, among the lowest levels, survival determines ES, and fuel wood is most important for cooking and regulating temperature (Sovacool, 2011b). According to the results, temperature regulation was one relevant ES for LS in Zoquitlán (more so for lower incomes). For middle incomes, convenience, comfort and cleanliness are the most important concerns of ES choices (Sovacool, 2011b). Indeed, based on the results, entertainment became relevant in Cuauhtémoc (besides temperature regulation and transport), supporting such hypothesis. Finally, communication, socialisation or personal identity seems to be the main concerns among higher incomes (Sovacool, 2011b), which are determined similarly to middle income groups but on levels necessary for more extravagant lifestyles, such as energy for swimming pools or exotic vehicles (sport cars, yachts, jets, etc.). The results do not contradict this fact, although the sample did not isolate high incomes from middle ones.

4.4.1.2 Basic vs. less essential energy services in Mexican households.

Despite the observed distinction between “primary ES”, “secondary ES” and “general ES” per income group, the preference given to each ES appeared rather inconsistent with the ES that actually best enhanced LS levels.

According to section 4.3.2, the preference to increase ES in middle-higher income households seemed horizontal, but not all of these ES had the same effects on LS. Food preservation, although probably the least consistent element in the “general ES” component, was found to correlate positively with the other five ES. The same was observed for illumination and communications, which did not have as strong effects on LS as transport, entertainment and temperature regulation.

For lower incomes, on the other hand, basic ES (“primary ES”) were expected to match ES improving LS most strongly, but results were not consistent with this. Higher "temperature regulation" levels correlated with higher "food preservation" and "communications", while "transport" did similarly with "entertainment" and "illumination". In addition, "temperature regulation" was placed within basic ES, but "transport" in less basic ones ("secondary ES"). Although transport and temperature regulation demonstrate strong links to LS, other elements seemed to improve within households inconsistently with the hierarchical order.

In sum, as economic development takes place or income increases, human needs could gradually shift, creating more concern about ES in households, reflected on the ES-LS correlation. ES improvement choices, however, do not always result in LS maximisation. Some ES enhance LS more than others, but individual's choices might not be consistent with this, suggesting that there might be other elements involved in the decision process. Further analysis are needed to shed light on such preferences and how other material aspects might generate differences (Cravioto et al., 2014) to fully understand life satisfaction through energy services and energy consumption.

4.5 Conclusion

Six energy services (communications, entertainment, food preservation, illumination, temperature regulation and transport) measured in a 5-point likert scale and overall human well-being measured as life satisfaction were surveyed in Mexican households of two locations (Zoquitlán and Cuauhtémoc). Correlations between these two measures ranged between 0.3 - 0.4. By dividing the sample into regions, it was observed that in the lower-income one (Zoquitlán) the correlations reduced to weaker levels (0 - 0.1), whereas in the middle-income one (Cuauhtémoc) levels ranged between 0.2 - 0.3. By energy service, transport and temperature regulation seemed the most important to enhance well-being in both regions. Entertainment was only found to be relevant in the middle-income setting, and illumination, communications and food preservation seem the least important in both locations.

Using principal component analyses on the six energy services point to support the premise that preference given to energy services shifts from a hierarchical one (in Zoquitlán) to a more horizontal (in Cuauhtémoc) as income increases, but such preference did not seem consistent with energy services that were more strongly correlated with human well-being. Thus, improvements of energy services seemed to occur in blocks comprising relevant and rather irrelevant elements for higher well-being levels.

These findings put forward the hypothesis that energy use and well-being may not be linked equally strong through energy services at all income levels. Energy services as a linkage between energy use and well-being might be more important at middle incomes compared to lower and higher ones.

4.6 References

CONAPO [Comisión Nacional de Población] (2000). XII Censo general de población y vivienda (XII General census on population and households). INEGI, Aguascalientes, México.

Cravioto, J., Yamasue, E., Okumura, H. and Ishihara, K.N. (2011). Performance analysis between well-being, energy and environmental indicators using data envelopment analysis. In Zero-Carbon Energy Kyoto 2010 (pp. 49-55). Springer Japan.

Cravioto, J., Yamasue, E., Okumura, H. and Ishihara, K.N. (2014). Energy service satisfaction in two Mexican communities: A study on demographic, household, equipment and energy related predictors. Energy Policy, 73, 110-126.

Diener, E. and Seligman, M.E. (2004). Beyond money toward an economy of well-being. Psychological Science in the Public Interest, 5(1), 1-31.

Dietz, T., Rosa, E.A. and York, R. (2009). Environmentally efficient well-being: Rethinking sustainability as the relationship between human well-being and environmental impacts. Human Ecology Review, 16(1), 114-123.

Gallup (2014) State of Global Well-Being: 2014 Country Well-Being Rankings report. Gallup World Poll.

Haas, R., Nakicenovic, N., Ajanovic, A., Faber, T., Kranzl, L., Müller, A. and Resch, G. (2008). Towards sustainability of energy systems: A primer on how to apply the concept of energy services to identify necessary trends and policies. Energy Policy, 36(11), 4012-4021.

Howells, M.I., Alfstad, T., Victor, D.G., Goldstein, G. and Remme, U. (2005). A model of household energy services in a low-income rural African village. Energy Policy, 33(14), 1833-1851.

INI [Instituto Nacional Indigenista] (2000) Índices de desarrollo humano por municipio 2000 (HDI indices by municipality 2000). INI, México D.F.

Jonsson, D.K., Gustafsson, S., Wangel, J., Höjer, M., Lundqvist, P. and Svane, Ö. (2011). Energy at your service: Highlighting energy usage systems in the context of energy efficiency analysis. Energy Efficiency, 4(3), 355-369.

Kahane, A. (1991). New perspectives for energy efficiency and system optimization. Energy Policy, 19(3), 199-201.

Kahneman, D., Diener, E. and Schwarz, N. (Eds.) (1999).Well-being: The foundations of hedonic psychology. New York: Russell Sage Foundation.

Knight, K.W. and Rosa, E.A. (2011). The environmental efficiency of well-being: A cross-national analysis. Social Science Research, 40(3), 931-949.

Knight, K.W. and Rosa, E.A. (2009). The environmental costs of life satisfaction: A cross-national empirical test. In Workshop of the Sustainable Research and Action Network (SCORAI). Clark University, Worcester, MA.

Martinez, D.M. and Ebenhack, B.W. (2008). Understanding the role of energy consumption in human development through the use of saturation phenomena. Energy Policy, 36(4), 1430-1435.

Mazur, A. (2011). Does increasing energy or electricity consumption improve quality of life in industrial nations? Energy Policy, 39(5), 2568-2572.

Mazur, A. and Rosa, E. (1974). Energy and lifestyle: Cross-national comparison of energy consumption and quality of life indicators. Science, 1(86), 607-610.

Modi, V., McDade, S., Lallement, D. and Saghir, J. (2006). Energy services for the millennium development goals. New York: Energy Sector Management Assistance Programme, United Nations Development Programme. UN Millennium Project and The World Bank.

Moll, H.C., Noorman, K.J., Kok, R., Engström, R., Trone-Holst, H. and Clark, C. (2005). Pursuing more sustainable consumption by analyzing household metabolism in European countries and cities. Journal of Industrial Ecology, 9(1-2), 259-275.

Norgard, J.S. (2000). Models of energy saving systems: The battlefield of environmental planning. International Journal of Global Energy Issues, 13(1), 102-122.

Pasternak, A. (2000). Global energy futures and human development: A framework for analysis (rep. no. UCRL-ID-140773: 1–25). Lawrence Livermore National Laboratory, California (USA).

Poortinga, W., Steg, L. and Vlek, C. (2004). Values, environmental concern, and environmental behavior: A study into household energy use. Environment and Behavior, 36(1), 70-93.

Reister, D.B. and Devine, W.D. (1981). Total costs of energy services. Energy, 6(4), 305-315.

Romero, R.A., Bojórquez, G., Corral, M., Gallegos, R. (2013). Energy and the occupant's thermal perception of low-income dwellings in hot-dry climate: Mexicali, México. Renewable Energy, 49, 267-270.

Sovacool, B.K. (2011a). Conceptualizing urban household energy use: Climbing the "Energy Services Ladder". Energy Policy, 39(3), 1659-1668.

Sovacool, B.K. (2011b). Security of energy services and uses within urban households. Current Opinion in Environmental Sustainability, 3(4), 218-224.

Steinberger, J.K. and Roberts, J.T. (2010). From constraint to sufficiency: The decoupling of energy and carbon from human needs, 1975–2005. Ecological Economics, 70(2), 425-433.

Veenhoven, R. (2010). Google thought: What makes people happy? (Oct 26, 2010 online lecture). Accessed Mar 2015 from https://www.youtube.com/watch?v=JsmRw7a_1fM

Veenhoven, R. and Hagerty, M. (2006). Rising happiness in nations 1946–2004: A reply to Easterlin. Social Indicators Research, 79(3), 421-436.

Van Praag, B.M.S. and Ferrer-i-Carbonell, A. (2007). Happiness quantified: A satisfaction calculus approach. Oxford University Press.

WDH [World Database of Happiness] (2015). Continuous register of research on subjective appreciation of life. Erasmus University Rotterdam. Retrieved from https://personal.eur.nl/veenhoven/Pub2000s/2004f-full.pdf

Wirl, F. (1995). Impact of regulation on demand side conservation programs. Journal of Regulatory Economics, 7(1), 43-62.

V. Energy services and demographic, household, equipment and energy related predictors

5.1 Introduction

As previously described throughout this thesis (sections 1.3.2 and 4.1), energy services (ES) are one crucial linkage to understand the connection between energy use and human well-being. It has been demonstrated that ES measured in a satisfaction scale can act as well-being surrogates, representing the benefits from energy use at households (chapter IV). However, several aspects of ES are still unexplored. Besides how ES connect with overall well-being (the matter of study in the previous chapter), how ES connect with material consumption through end-uses (or further elements) is another crucial issue. This chapter is devoted to explore such concern, based entirely on the published work by Cravioto et al. (2014).

As already explained (sections 1.3.2 and 4.1), ES is a rather new concept, few times mentioned in the literature, but often misinterpreted for closely related ideas. Several studies have confused ES with end-uses of energy (Sovacool, 2011a and 2011b; Jonsson et al., 2011; Hass et al., 2008; Modi et al., 2006; Norgard, 2000; Wirl, 1995; Kahane, 1991; Reister and Devine, 1981). And they have assumed that measuring ES in money, heat, work or temperature can act as surrogates of satisfaction. Such a premise is not accurate, given that is known that decouplings exist between material indicators and various measures of well-being or life satisfaction (Pasternak, 2000; Mazur, 2011; Steinberg and Roberts, 2010; Mazur and Rosa, 1974). ES need to actually reflect energy surrogates of well-being feasible only through the use of a real satisfaction scale (chapter IV).

On the other hand, ES are end-uses of energy mixed with further elements (Sovacool, 2011a and 2011b), making the relationship between material consumption and ES another important aspect for study. This link with material predictors has recently drawn more interest than the ES-well-being link, but is still exploring the essential interactions. Within the small available literature, probably the pioneering study by Sovacool (2011a) has been the most important, where several aspects of ES among urban income groups were compared. Sovacool observed that as income increases, there were changes in three

ES-related aspects, namely, higher direct and indirect energy consumption, diverse factors driving energy use and lesser number of ES within the households. He labelled his findings "the energy service ladder hypothesis", but since no real satisfaction scale was used on any of the references in his study, it remains an interesting premise for investigation.

Besides theory, ES also point to act as a powerful policy tool (Modi et al., 2006). ES can bring to light how overall well-being gains come solely from energy related surrogates, as well as how these surrogates improve solely from increased energy (or other material) consumption. In other words, ES act as a two-way linkage in the energy-well-being link, controlling for other non-energy related aspects. As demonstrated by chapter IV, ES can even isolate the energy benefits outside the households. Thus, the study of ES from this material perspective is particularly useful to inform sustainable energy use paths focused on household energy consumption, as well as welfare and development policies focused on commodities (e.g. equipment acquisition or newer technology).

5.1.1 Purpose. Corresponding to the second part of the household-level asessment of the connection between human well-being and energy use, this chapter is aimed at analysing how seventeen demographic and material predictors can explain gains on (six) energy services (illumination, temperature regulation, food preservation, communications, transport and entertainment) taken as energy surrogates of human well-being.

5.2 Method

5.2.1 Data collection and questionnaire. As explained in sections 2.2 and 4.2.2, the necessary data was obtained through a survey directly conducted in Mexican households. The two Mexican communities selected had different income levels suitable for the needs of the analysis. The data was collected in March 2011, simultaneously with that for chapter IV. The final sample comprised 40 questionnaires from Zoquitlán and 58 from Cuauhtémoc.

Besides the six ES (illumination, temperature regulation, food preservation, communications, transport and entertainment) measured in the 5-point Likert scale (see section

4.2.3 for details), five complementary sections retrieved through the same survey were utilised in this chapter. These sections comprised the following:

1. Socio-demographic information such as gender, age, occupation, and other aspects of individual consumption (purchase rate of goods, food and mobile ownership),
2. Household characteristics including age, size (number of members), type of house, materials (wall, ceiling, floor) and number of rooms,
3. Household equipment, such as the number of appliances and how long ago were they purchased (see table 11 for the list of appliances considered), and
4. Average monthly payment of energy (types included: electricity, gas, fuelwood, charcoal and petrol).

The questionnaire used to retrieve the information can be found in appendix B.

Table 11 Surveyed household appliances

Air conditioner	Fan (electric)	Microwave oven	Stove (gas)
Blender	Gas tank	Motorcycle	Teapot (electric)
Boiler	Hairdryer	Oven	Toaster (electric)
Bulbs	Heater (electric)	Phone	TV
Car	Heater (gas)	Printer	Videogames
Computer	Heater (other)	Radio	Videoplayer
DVD	Heating system	Refrigerator	Washing machine
Extractor	Iron	Stove (electric)	Water pump

5.2.2 Energy services predictors and classification by blocks. After screening the data, explicit predictors and blocks of predictors were built for the analysis.

A first block called “demographics” included socio-demographic profiles of the household. This comprised gender, age, family type, maternity, job status and affluence of the respondent. “Gender”, “age” and “job status” were taken as reported in the survey, while “family type”, “maternity” and “affluence” were variables constructed from the data. “Family type” and “maternity” were classifications based on the details of the members living in the household, while “affluence” was a component created through a Principal Component Analysis (PCA) on five related variables (possession of mobile phone and car, clothes purchasing rate, number of clothes owned and household occupancy[1]). “Affluence” as conceived through this approach is a proxy of how wealthy the respondent is, because the actual income levels could not be asked directly to the participants. As will be observed later (section 5.3.2.4), this metric was quite homogeneous within each region, justifying the comparison of locations to understand the effect of large income differences.

A second block called “household characteristics” included six predictors related to features in the house. These were “household age”, “type” and “occupancy”, as well as wall, “ceiling” and “floor materials”, all taken as provided in the survey.

A third block called “household equipment” included two concepts: the number of household appliances and the type of technology. As both predictors encompassed a large number of elements, they were also obtained through PCAs. The first one, “household appliances”, condensed the number of available appliances, and the second, “household technology”, the average age of these appliances. “Household technology” was assumed to be positively correlated with the actual appliance technology.

Lastly, a fourth block called “energy” comprised three predictors derived from the average consumption of five energy types. The energy consumption was first estimated by converting the reported monthly expenditures on electricity, gas, fuelwood, charcoal and petrol into energy amounts, using household size and the factors in table 12. Then, the predictors were reduced to components through PCAs, yielding the concepts of “modern energy”, “traditional energy” and “petrol”. Table 13 summarises all these variables and blocks.

5.2.3 Simplification of variables with multiple items. As explained in the previous section, PCAs were used to simplify variables with multiple items. In some cases this procedure used data from the total sample, while in others it used the regional samples. For “affluence”, the PCA took the total data because a more realistic wealth measure could be captured using the whole sample. In contrast, for “household appliances”, “household technology” and “energy” the data was taken by region, to stress the deviations from the mean reported in each location. The procedures to conduct the PCAs were detailed

---

[1] “Household occupancy” is defined as the number of persons per room in the household.

Table 12 Energy conversion factors

Fuel	Unit	Price Cuauhtémoc [MX pesos]	 Zoquitlán [MX pesos]
Electricity	1 kWh	0.62	0.62
Gas	1 kg	10.2	10.2
Charcoal	1 kg	12	12
Fuelwood	1 m^3	N/A	361
Petrol	1 litre	7.06	7.06

Note: These factors were calculated using information in Quiroz-Carranza (2010), CFE (2011), PEMEX (2014), and De la Cruz (2011).

Table 13 Energy services and predictors

Block	Explanatory variables: Elements	Variable type	Variable	Response variable: Elements	Variable type
Demographics	Gender	Nominal	Energy Services[3]	Illumination	Ordinal
	Age	Continuous		Temperature regulation	Ordinal
	Family type	Nominal		Food preservation	Ordinal
	Maternity	Nominal		Communications	Ordinal
	Job status	Nominal		Transport	Ordinal
	Affluence[1]	Continuous		Entertainment	Ordinal
Household characteristics	Household age	Continuous			
	Household type	Nominal			
	Occupancy	Continuous			
	Wall material	Nominal			
	Ceiling material	Nominal			
	Floor material	Nominal			
Equipment[2]	Household appliances	Continuous			
	Household technology	Continuous			
Energy[2]	Electricity, gas, fuelwood, charcoal and petrol	Continuous			

Notes:

(1) Affluence is a component condensing the information on mobile phone and car possession, clothes purchasing rate, number of clothes owned and household occupancy.

(2) The components of household equipment and energy consumption are continous variables.

(3) ES are treated as a continuous variable when all its elements are reduced to components by PCA.

in section 2.4 and have been already conducted for ES in chapter IV. The resulting ES components of chapter IV and the ones obtained here are used in the subsequent multiple regression analyses briefly explained in section 2.4 and detailed below.

5.2.4 Predictor discrimination by block. Once blocks were defined, the next step consisted in selecting the most significant elements. This helped to keep parsimony in the association analysis between ES and its predictors. The process entailed a backward regression of the predictors within the block, and a hierarchical regression to verify explained variance and fit when several predictors were significant.

5.2.5 Block analysis. After selecting the significant predictors by block, the contribution of each block on ES was analysed. Thus, a further hierarchical regression analysis using the significant predictors by block was performed. "Demographics" was first introduced in the regression model, followed by "household characteristics", "equipment" and "energy". Following, the blocks' final contributions (in terms of beta weights, model fit and variance) were analysed, assuming that by introducing them in the stated order, their unique contribution is controlled. Figure 18 graphically represents the energy-well-being link, and the section under investigation (ES).

Lastly, to elucidate the effects attributable to large income differences a comparison between locations of the previous regressions was done. This comparison was based on how predictors with multiple elements were condensed by the PCAs, and on how the links between ES and their predictors changed.

5.3 Results

5.3.1 Descriptive statistics. As reported in section 4.3, households in Cuauhtémoc reported higher ES scores and better general conditions than households in Zoquitlán. This difference was also observed for household equipment, energy consumption and affluence. Table 19 in appendix A presents a summary of the descriptive statistics of the surveyed data.

5.3.2 Simplification of variables with multiple items.

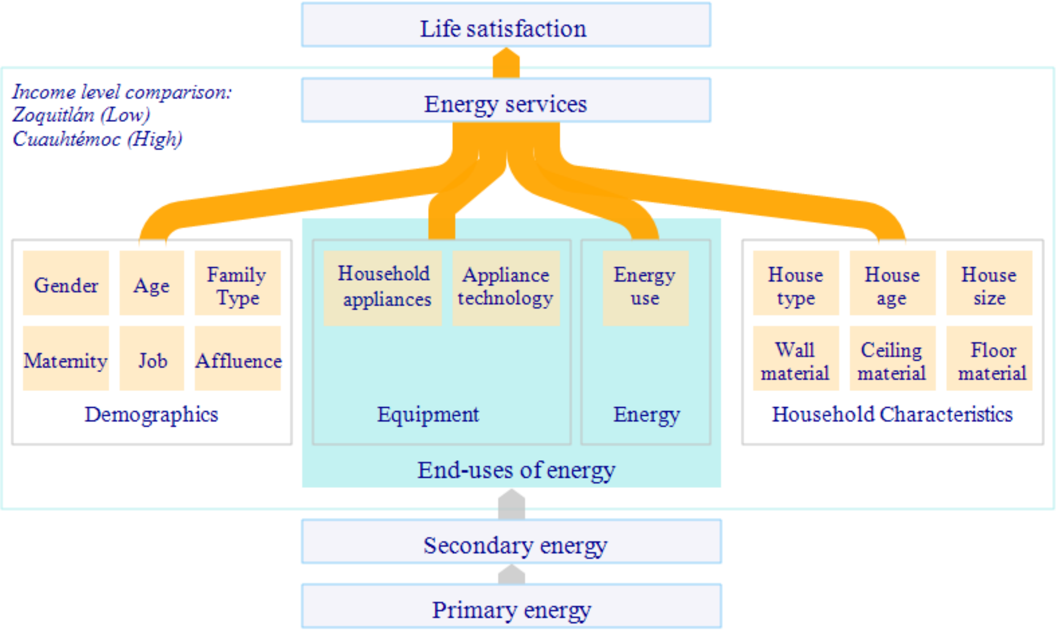


Figure 18 Energy services and its predictors within the energy-to-well-being chain

5.3.2.1 Household appliances. The average appliance saturation level was above 80 percent among households in Cuauhtémoc, compared to 50 percent in Zoquitlán. The observable difference on appliance's possession rates retrieved through the survey coincided with recent studies, which report more appliance penetration among higher income groups (Rosas et al., 2010). However, a closer inspection on the data, particularly through the PCA results, showed that household appliances seemed to vary not only in number, but also on their role from the user's perspective. While in Cuauhtémoc the PCA solution yielded two significant eigenvalues, in Zoquitlán it yielded three (see table 20 in appendix A for the detailed loadings), and although the variance explained by region was equivalent, there were differences in the number and grouping of the appliances within the components. We hypothesise that such variation reflects how some appliances might be more important than others, and such perception might change as affluence levels increase (section 5.4 provides a more detailed discussion). Thus, appliances essential for daily living are considered within the first component, followed by appliances relatively less essential in the second, and appliances more associated with luxury in the third (only observed in Zoquitlán).

For subsequent regression analyses, the scales above needed some statistical improvements (low number of list-wise samples, reliability coefficients, sampling adequacy and explained variance). Thus, following the procedure of element discrimination described in sections 2.4 and 5.2.3, a final two-component solution in both regions was obtained, comprising the more general concepts of “basic” and “secondary” appliances (see table 21, appendix A for the detailed loadings). These new components merged secondary and luxury items in Zoquitlán, and had only slight differences from the originals in Cuauhtémoc, but for both sites they improved statistical performance, resulting in better predictors for the regressions.

5.3.2.2 Household technology. In contrast to household appliances, both regions summarised household technology in a single component, without the need of any discrimination procedures. Such information included nine elements for Cuauhtémoc and five for Zoquitlán (detailed loadings in table 23, appendix A).

5.3.2.3 Energy consumption. Three variables were obtained from the PCAs in this block. Gas and electricity use were reduced into one component (in both locations), labelled “modern energy”. Fuelwood and charcoal were grouped in another (only available in Zoquitlán), labelled “traditional energy”. Petrol use did not seem to fit well in neither, thus it was treated separately.

Although the concepts summarised by the two obtained components seemed rather heterogeneous[2], they accurately represented the variation in energy use (see constituent’s variance in table 24, appendix A). Thus, were considered adequate for the regressions.

5.3.2.4 Affluence. Lastly, the variables associated with lifestyle created the “affluence” metric. As explained in section 5.2.2, these included five elements: possession of mobile phone and car, the frequency of clothing purchases, number of clothes owned and household occupancy, which summarised together seemed barely satisfactory from

---

[2] In statistical terms this meant that the elements showed lower consistency in the obtained PCA components.

the statistical standpoint[3]. Hence, to improve the component, the clothing purchase rate variable was removed and a more consistent result was obtained (see table 25 in appendix A for detailed loadings). This final "affluence" component could summarise better the concepts encompassed[4].

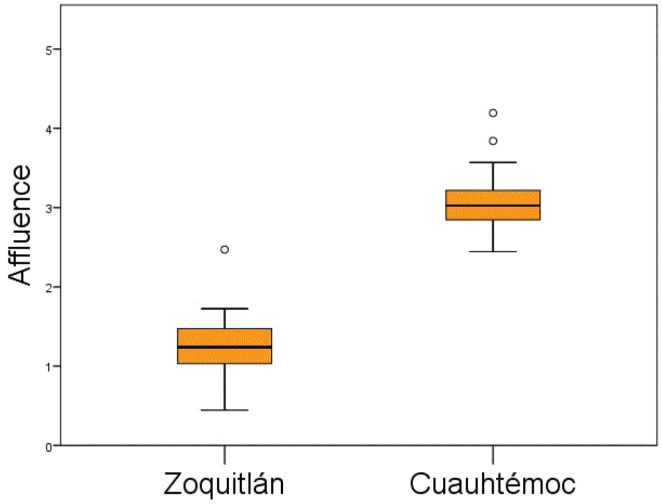


Figure 19 Affluence by region

It is noteworthy to mention here that, even though the metric is useful as a control for affluence effects within each location, the component resulted quite homogeneous within the regions (figure 19). Thus, the subsequent comparison of ES regression models between regions is justified, assuming that any observed differences are attributable to this affluence (income) gap, given that geographical and cultural factors are already controlled with the sample selection.

5.3.3 Predictor discrimination by block.

5.3.3.1 Demographics. Different by region, two significant parameters from the demographics block best explained ES. For Zoquitlán, "maternity" and "family type",

---

[3] It was a single-factor PCA solution, which although combined most elements in acceptable sampling adequacies (above 0.6 except for clothes purchasing rate), it showed a slightly low internal consistency (alpha=0.517).

[4] The internal consistency of the new metric was 0.871 and a KMO sampling adequacy of 0.788, well above the acceptable limit of 0.5 (Field, 2009).

strongly associated to “primary” and “secondary ES” respectively (table 14). For “primary ES”, households with children reported higher levels than those without them, whereas higher “secondary ES” were observed among persons living by themselves compared to nuclear families (figure 20). In addition, “affluence” did not seem to strongly correlate to any of both ES, indicating that small differences in the prosperity of lifestyles among the less affluent might poorly reflect in ES improvement at home.

For Cuauhtémoc, in contrast, “age” and “affluence” were the most relevant predictors (table 14). For age, large variations of “ES” scores were found in the ranges of 10 to 40 year old respondents, while among older ones “ES” scores became more homogeneous (figure 21). The same was observed for “affluence”, having less “ES” variance among the higher scores (figure 5.4). Also, because this model could considerably explain the “ES” observed (26 percent of the variance), all indicated that contrary to less affluent families, among higher incomes, lifestyle prosperity better reflected in the ES used at home. As will be later confirmed, for Cuauhtémoc this block took the largest predictive power, greatly controlling for the others.

5.3.3.2 Household characteristics.

For household characteristics, clear differences between regions were observed again, both in terms of the most important predictors and their predictive power.

For “primary ES” in Zoquitlán, four predictors reported strong positive associations, but only “household age” and “wall material” remained within the block after simplifying (backward regression in table 15). Better materials used for walls positively correlated with these ES, while older houses showed higher scores than newer ones (figure 22).

For “secondary ES”, in turn, two predictors were strongly correlated. However, only “household occupancy” remained relevant to these ES (table 15). As most scores of occupancy concentrated in the lower ranges, and the few higher ones observed lower “secondary ES”, this association was negative (figure 23). In addition, the total predictive power from this parameter seemed smaller compared to that attained by the predictors

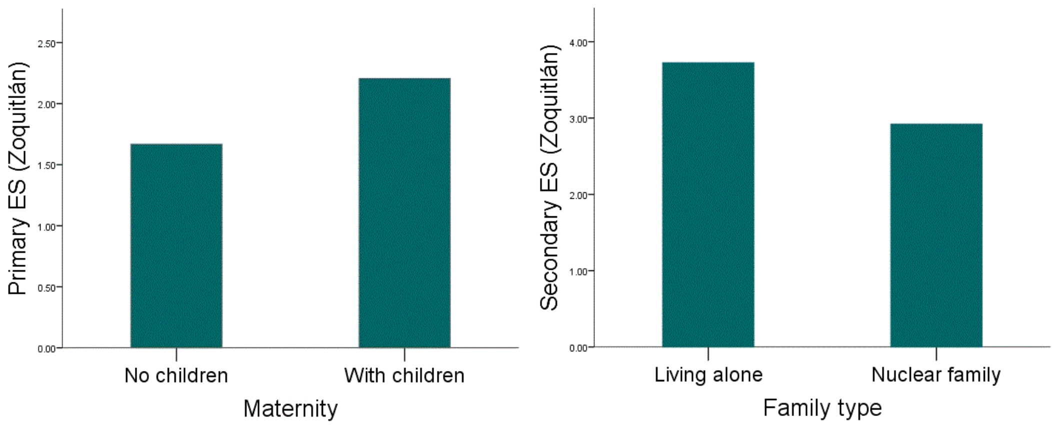


Figure 20 Maternity and primary ES, family type and secondary ES in Zoquitlán.

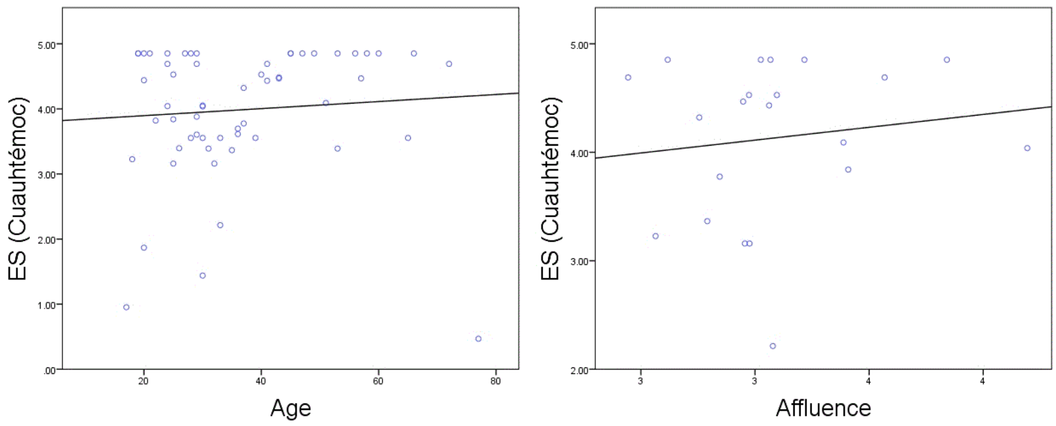


Figure 21 Age, affluence and ES in Cuauhtémoc

Table 14 Standardised regression coefficients for demographics and energy services

Regression	Zoquitlán				Cuauhtémoc		
	Primary ES		Secondary ES		ES (single)		
	β	p	β	p	β	p	
Simultaneous							
Age	0.15	0.49	0.04	0.83	0.65	0.03	*
Sex	0.12	0.58	0.01	0.97	0.17	0.49	
Family type	-0.07	0.75	-0.31	0.15	-0.13	0.61	
Maternity	0.27	0.20	-0.11	0.58	-0.15	0.58	
Job stat	-0.15	0.47	-0.11	0.58	-0.24	0.37	
Affluence	-0.07	0.73	-0.12	0.57	0.39	0.16	
Reduced							
Age	-	-	-	-	0.52	0.03	*
Sex	-	-	-	-	-	-	
Family type	-	-	-0.33	0.07	-	-	
Maternity	0.24	0.21	-	-	-	-	
Job stat	-	-	-	-	-	-	
Affluence	-	-	-	-	0.29	0.19	
Model Fit (reduced)	R^2	Adj R^2	R^2	Adj R^2	R^2	Adj R^2	
	0.06	0.02	0.11	0.08	0.26	0.18	
ANOVA (reduced)	F	p	F	p	F	p	
	1.64	0.21	3.49	0.07	3.14	0.07	
Sample size (n)	30		30		21		

*Notes: * $p < 0.05$, ** $p < 0.01$*

on "primary ES" (table 15). Thus, household characteristics seemed to strongly reflect on essential ES of less affluent households, with basic improvements as the most effective.

In Cuauhtémoc, on the other hand, the strongest predictor was "floor material" (table 15), but unlike Zoquitlán most households reported "high-end" type floorings, yielding small ES gains from further improvements (figure 24). In addition, because this model could not predict "ES" well enough as that of "primary" or "secondary ES" (table 15), this suggested that enhancing household characteristics among higher incomes is less effective to reflect in ES gains.

5.3.3.3 Household equipment. For household equipment, the availability of commodities in general seemed more relevant than the technology used, but the ability to predict ES gains by such parameters reduced as income increased.

On one hand, "basic" and "secondary appliances" in Zoquitlán appeared positively related to "primary ES" fairly equally (β=0.3 and 0.4 respectively), while "household tech-

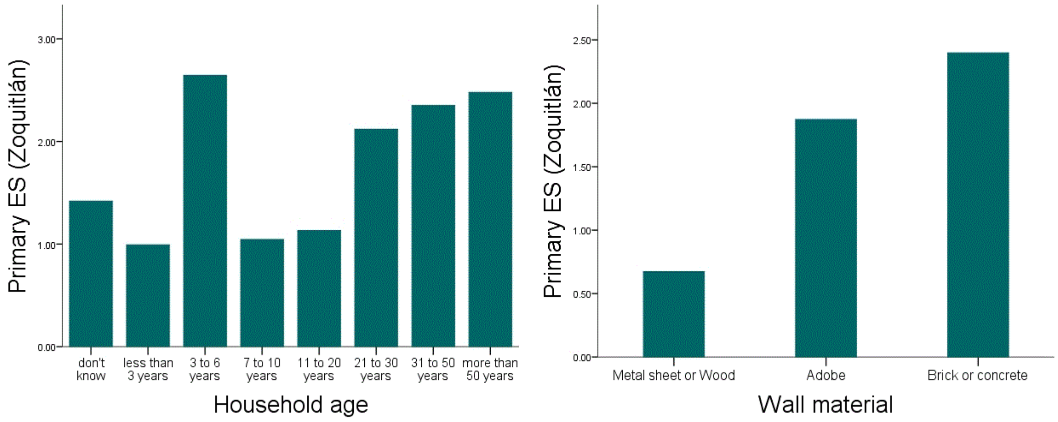


Figure 22 Household age, wall material and primary ES in Zoquitlán

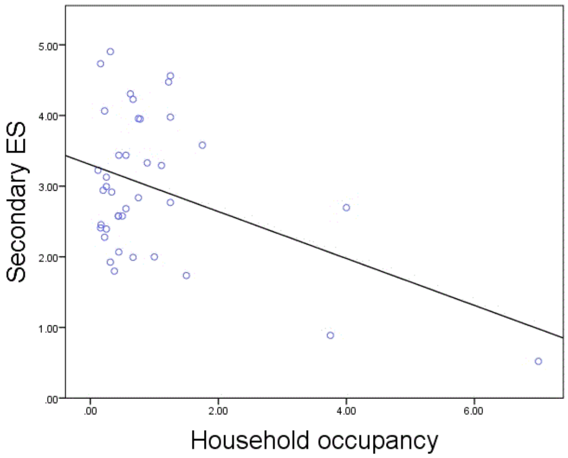


Figure 23 Household occupancy and secondary ES in Zoquitlán

nology" was negatively associated. In contrast, "secondary ES" were positively related to better technology, rather than just the appliances in the house. The peculiar result suggests that among the low income households, simply by having more home appliances greatly improves the satisfaction with basic ES, but better technology may not have such effect, whereas for less basic ES the opposite holds. Additionally, both predictors reduced to a single significant element using backward regressions ("secondary appliances" for "primary ES" and "household technology" for "secondary ES"), but the predictive power was markedly larger for "primary ES" (table 16). This confirmed that improving the availability of appliances better reflected in ES, rather than improvements in the technology used.

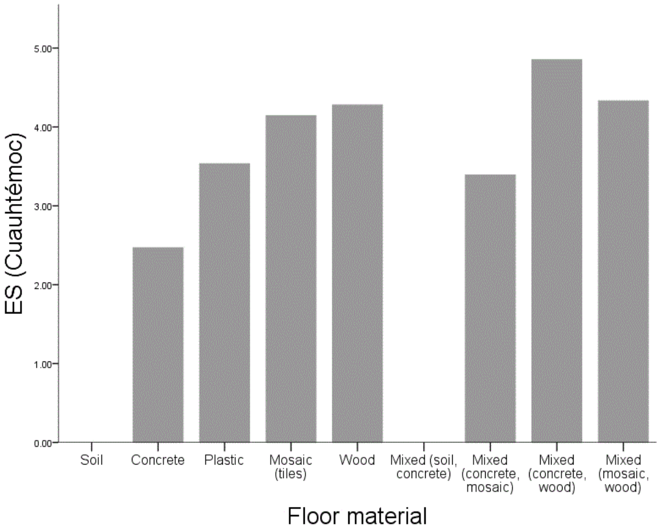


Figure 24 Floor material and ES in Cuauhtémoc

On the other hand, in Cuauhtémoc "basic appliances" and "household technology" showed minimal correlation with "ES", but "secondary appliances" were moderately associated (table 16). Accordingly, the backward regression confirmed that "secondary appliances" was the only important parameter in the block, but with less predictive power than the previously observed in Zoquitlán (table 16).

All these findings imply that policy aiming to increase appliance acquisition should target less affluent income groups and particularly those related to essential ES, whereas technology should be targeted for the secondary ES of these income groups. For more affluent households, such measures would simply not reflect well on ES gains. Yet, careful treatment should be given to all these aspects, as they might be controlled by any of the other blocks already analysed. As will be observed in section 5.3.4, this holds for the case under study.

5.3.3.4 Energy consumption. The first noticeable difference from this block was that all energy types -"traditional energy" (fuelwood and charcoal), "modern energy" (electricity and gas) and "petrol"- were used in households from Zoquitlán, whereas households from Cuauhtémoc basically used "modern energy". Additionally, a negative correlation between "modern energy" and "traditional energy" was observed in Zoquitlán,

Table 15 Standardised regression coefficients for household characteristics and energy services

Regression										Hierarchical Regression			
	Zoquitlán						Cuauhtémoc				Zoquitlán		
	Primary ES			Secondary ES			ES (single)				Primary ES		
	β	p		β	p		β	p			β	p	
Simultaneous										Step 1			
Household age	0.37	0.01	*	-0.02	0.91		-0.09	0.55		Wall material	0.39	.015	*
Household occupancy	0.25	0.06		-0.56	0.01	**	-0.14	0.34		R^2	0.15	.015	*
Household type	-0.02	0.44		-0.05	0.79		-0.10	0.53		Step 2			
Wall material	0.39	0.01	**	0.07	0.71		-	-		Wall material	0.44	0.00	**
Ceiling material	0.43	0.00	**	-0.21	0.33		-0.12	0.38		Household age	0.42	0.00	**
Floor material	-0.08	0.31		0.05	0.78		0.36	0.01	*	DR^2	0.06	.004	**
Reduced										R^2	0.33	.001	**
Household age	0.42	0.01	**	-	-		-	-					
Household occupancy	-	-		-0.42	-2.85	**	-	-					
Household type	-	-		-	-		-	-					
Wall material	0.44	0.00	**	-	-		-	-					
Ceiling material	-	-		-	-		-	-					
Floor material	-	-		-	-		0.35	0.01	**				
Model Fit (reduced)	R^2	Adj R^2		R^2	Adj R^2		R^2	Adj R^2					
	0.33	0.29		0.18	0.16		0.12	0.11					
ANOVA (reduced)	F	p		F	p		F	p					
	8.49	0.00	**	8.10	0.01	**	7.49	0.01	**				
Sample size (n)	38			38			56						

*Notes: * p < 0.05, ** p < 0.01*

Table 16 Standardised regression coefficients for household equipment and energy services

Regression	Zoquitlán						Cuauhtémoc	
	Primary ES			Secondary ES			ES (single)	
	β	p		β	p		β	p
Simultaneous								
Basic appliances	0.29	0.09		-0.48	0.03	*	0.01	0.85
Secondary appliances	0.42	0.02	*	0.08	0.71		0.32	0.16
Household technology	-0.49	0.01	*	0.46	0.04	*	0.08	0.83
Reduced								
Basic appliances	-	-		-	-		-	-
Secondary appliances	0.48	0.00	**	-	-		0.32	0.13
Household technology	-	-		0.35	0.12		-	-
Model Fit (reduced)	R^2	Adj R^2		R^2	Adj R^2		R^2	Adj R^2
	0.23	0.21		0.13	0.08		0.10	0.06
ANOVA (reduced)	F	p		F	p		F	p
	10.81	0.00	**	2.72	0.12		2.46	0.13
Sample size (n)	36			21			24	

*Notes: * p < 0.05, ** p < 0.01*

suggesting the so-called energy ladder hypothesis[5]. Yet, as will be discussed in section 5.4.1, this aspect might only hold for general energy use, and not when observed through specific ES.

As for the associations within the block, the shifts from "traditional" to "modern energy" had a positive effect on "primary ES" in Zoquitlán, while "petrol" had a stronger positive association with "secondary ES" (table 17). This difference may be explained by the fact that temperature regulation and food conservation are improved with the use of electricity and/or gas, while transport and entertainment are more related to petrol through the use of personal vehicles.

For Cuauhtémoc, on the other hand, increased use of "petrol" strongly associated to "ES" gains, more than "modern energy" (table 17), which meant that higher energy consumption from the increased use of vehicles and appliances reflected somewhat proportionally in ES gains.

Finally, the predictive power of the models were drastically different by region (model fit in table 17), suggesting that as income increases energy consumption becomes less accurately to predict ES. Policy should carefully consider this; on one hand, more energy consumption seems not effective to increase ES from middle incomes on, and although energy consumption seems to reflect well on ES gains in early stages of economic development, it is still not clear if other more structural aspects (equipment, household characteristics, etc.) affect these gains. As will be observed in section 5.3.4, these aspects are also controlled by other blocks.

5.3.4 Block analysis. The final regression considering all the previously selected parameters confirmed that clear regional differences existed on predictive power and composition of the blocks explaining ES gains. First, in Cuauhtémoc, "demographics" largely explained the gains, followed by "household characteristics", "energy", and "equipment" (the latter almost unable to predict ES). In Zoquitlán, "primary ES" appeared largely explained by "household characteristics", but more modestly by the other blocks, while

---

[5] The energy ladder hypothesis states that households substitute traditional energy with modern energy as their economic status increase (Hosier and Dowd, 1987).

Table 17 Standardised regression coefficients for energy consumption and energy services

	Regression								
	Zoquitlán						Cuauhtémoc		
	Primary ES			Secondary ES			ES (single)		
	β	p		β	p		β	p	
Simultaneous									
Modern energy	0.52	0.01	**	-0.05	0.81		0.20	0.23	
Petrol	-0.11	0.52		0.31	0.18		0.36	0.04	*
Traditional energy	-0.62	0.00	**	0.17	0.47		-	-	
Reduced									
Modern energy	0.52	0.00	**	-	-		-	-	
Petrol	-	-		0.28	0.20		0.39	0.02	*
Traditional energy	-0.60	0.00	**	-	-		-	-	
Model Fit (reduced)	R^2	Adj R^2		R^2	Adj R^2		R^2	Adj R^2	
	0.52	0.47		0.08	0.03		0.16	0.13	
ANOVA (reduced)	F	p		F	p		F	p	
	10.64	0.00	**	1.76	0.20		5.87	0.02	*
Sample size (n)	23			23			34		

	Hierarchical Regression		
	Zoquitlán		
	Primary ES		
	β	p	
Step 1			
Modern Energy	0.42	.035	*
R^2	0.17	.035	*
Step 2			
Modern Energy	0.52	0.00	**
Traditional Energy	-0.56	0.00	**
DR^2	0.30	.002	**
R^2	0.47	.001	**

*Notes: * $p < 0.05$, ** $p < 0.01$*

"secondary ES" were explained rather similarly by "demographics" and "household characteristics" but less by "energy" and "equipment".

Considering all the blocks, the final predictive power was equivalent for the three models, but this changed markedly controlling for demographics. As table 18 shows, the largest reduction was observed in Cuauhtémoc, followed by "secondary ES" and lastly "primary ES" in Zoquitlán (compare R^2 and tot var. controlling for demographics).

In addition, as already reported in the previous section, the predictors within blocks were different. "Primary ES" gains in Zoquitlán seemed related to "essential" household features in the first place, followed by appliances and energy use, whereas "secondary ES" were positively associated to technology and petrol use. For Cuauhtémoc, in contrast, the significant parameters could explain comparatively narrower ES gains[6], brought about by aspects commonly associated with luxury, e.g. affluence above the average, luxurious household features (e.g. wooden floors) and abundant energy consumption.

Lastly, as the blocks were introduced in the model, a reduction of explained variance was observed. For Zoquitlán, the supposedly large predictive power by "energy" and "household equipment" (sections 5.3.3.4 and 5.3.3.3) dropped substantially when con-

---

[6] These factors explained mean ES scores above 4 in the 5 point scale used.

trolling for “household characteristics” and “demographics”, being these blocks actually the most important in the model. For Cuauhtémoc, a similar result was observed as the contributions from “household characteristics”, “equipment” and “energy” reduced when controlling for “demographics”.

All these results suggest that if policy aims to enhance essential ES of the less affluent, the higher gains might actually come from structural aspects of households rather than from household equipment or energy consumption. Only for the less essential ES of this income group, technology might be effective, whereas for more affluent households, ES gains, in general, become narrower. Thus, technology substitution in low income households targeted by many countries should be carefully considered, and should be mixed with strategies for the reduction of consumption among middle/higher income ones. Such implications are further discussed in the following section.

5.4 Discussion

As mentioned in the previous chapter, it should be noted hereafter that discussions on the dynamic change based on the data surveyed are elaborated under the assumption that the cross-sectional sample follows that behaviour. In reality unexpected outcomes might be observed as any static model has such a limitation.

5.4.1 Implications on theory: "the energy service ladder".

The regional differences found in this study seem to validate the recently conceptualised "ES ladder" hypothesis (Sovacool, 2011a). The dynamics described in such theory state that, controlling for other factors (geography, climate, culture, etc.), an increase in economic status is associated with changes in several energy-related concepts, fundamentally:

- The number of ES in households
- The energy types and indirect energy (embodied energy) used, and
- The driving factors of ES gains.

This section is devoted to explore such arguments based on the previously analysed differences between incomes focusing on:

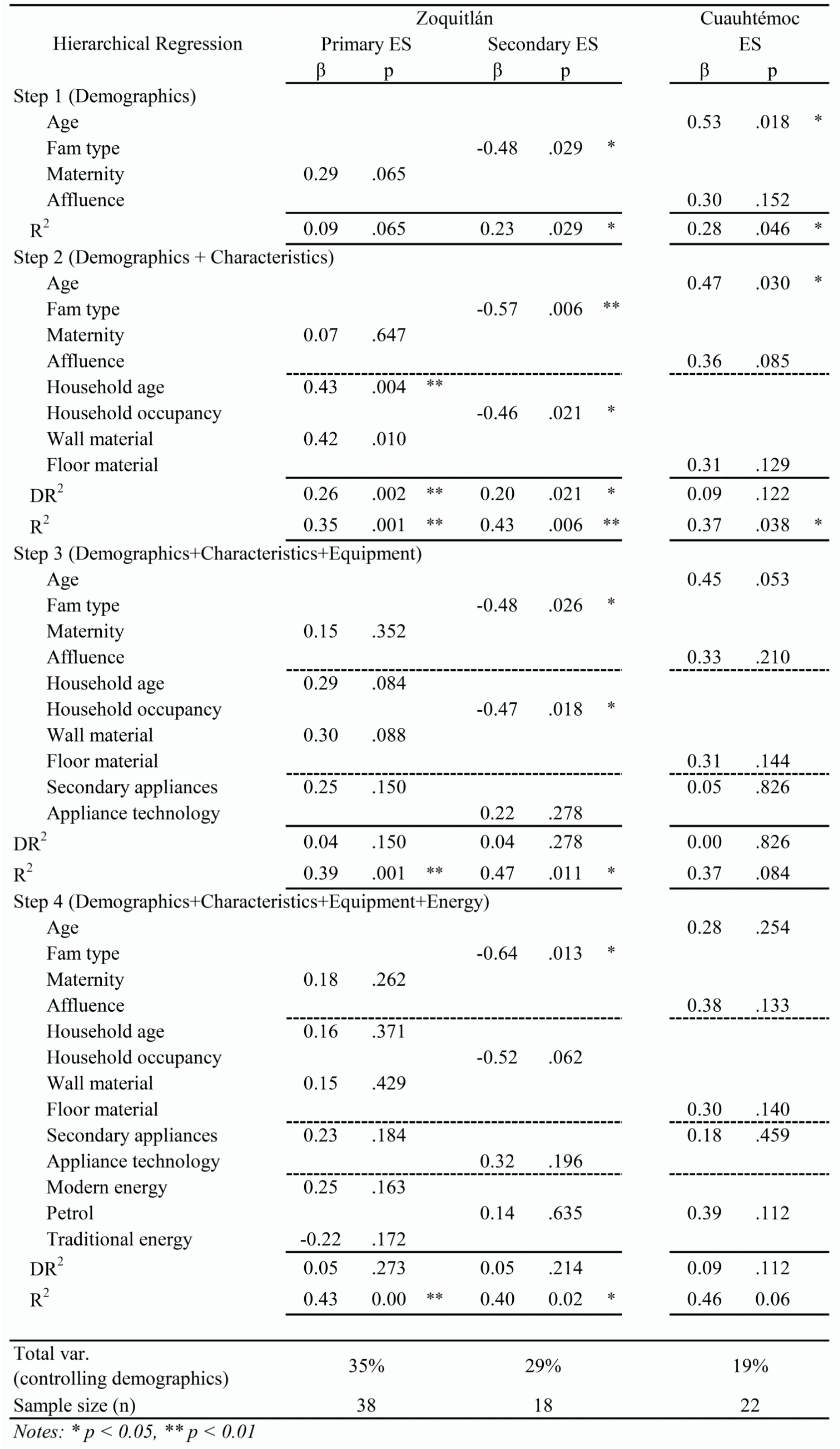
a) How ES and its predictors were summarised through the PCAs, and

b) The regressions between ES and the predictors.

5.4.1.1 The PCA perspective.

This first discussion is centred on how the PCA analyses yielded components from the multivariate predictors. In general, these results showed that the region with less affluent households (Zoquitlán), summarised multiple elements in greater number of components. This phenomenon held despite the fact that the PCA components were able to explain an equivalent percentage of variance from the summarised elements. Thus, it suggested that as income increases, a change in the household's perception of these variables may take place, and hence, the pair-wise relationship among such elements is captured by the PCAs. In support of such hypothesis, a detailed discussion is elaborated hereafter, using each of the reduced predictors.

Table 18 Energy services analysed by blocks using a hierarchical regression model by region



Hierarchical Regression	Zoquitlán						Cuauhtémoc		
	Primary ES			Secondary ES			ES		
	β	p		β	p		β	p	
Step 1 (Demographics)									
Age							0.53	.018	*
Fam type				-0.48	.029	*			
Maternity	0.29	.065							
Affluence							0.30	.152	
R^2	0.09	.065		0.23	.029	*	0.28	.046	*
Step 2 (Demographics + Characteristics)									
Age							0.47	.030	*
Fam type				-0.57	.006	**			
Maternity	0.07	.647							
Affluence							0.36	.085	
Household age	0.43	.004	**						
Household occupancy				-0.46	.021	*			
Wall material	0.42	.010							
Floor material							0.31	.129	
DR^2	0.26	.002	**	0.20	.021	*	0.09	.122	
R^2	0.35	.001	**	0.43	.006	**	0.37	.038	*
Step 3 (Demographics+Characteristics+Equipment)									
Age							0.45	.053	
Fam type				-0.48	.026	*			
Maternity	0.15	.352							
Affluence							0.33	.210	
Household age	0.29	.084							
Household occupancy				-0.47	.018	*			
Wall material	0.30	.088							
Floor material							0.31	.144	
Secondary appliances	0.25	.150					0.05	.826	
Appliance technology				0.22	.278				
DR^2	0.04	.150		0.04	.278		0.00	.826	
R^2	0.39	.001	**	0.47	.011	*	0.37	.084	
Step 4 (Demographics+Characteristics+Equipment+Energy)									
Age							0.28	.254	
Fam type				-0.64	.013	*			
Maternity	0.18	.262							
Affluence							0.38	.133	
Household age	0.16	.371							
Household occupancy				-0.52	.062				
Wall material	0.15	.429							
Floor material							0.30	.140	
Secondary appliances	0.23	.184					0.18	.459	
Appliance technology				0.32	.196				
Modern energy	0.25	.163							
Petrol				0.14	.635		0.39	.112	
Traditional energy	-0.22	.172							
DR^2	0.05	.273		0.05	.214		0.09	.112	
R^2	0.43	0.00	**	0.40	0.02	*	0.46	0.06	
Total var. (controlling demographics)	35%			29%			19%		
Sample size (n)	38			18			22		

*Notes: * $p < 0.05$, ** $p < 0.01$*

For "household appliances", if the components defined in section 5.3.3.3 indeed emulate their hypothesised hierarchical categories ("basic", "secondary" and "superior"), then "secondary" and "superior" appliances in Zoquitlán became more "essential" from the user's perspective in Cuauhtémoc, probably due to the fact that greater income brings about easier access to these appliances.

For ES, something similar can be observed. The grouping of ES in two components in Zoquitlán ("primary ES" and "secondary ES") suggests that when income is limited some ES are prioritised and perceived as more essential for basic needs (temperature regulation, food preservation and communications), while others seem to be less relevant (illumination, transport and entertainment).

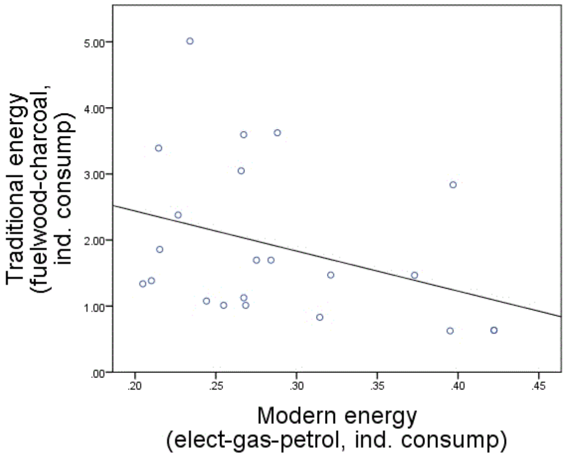


Figure 25 Modern and traditional energy use in Zoquitlán

For "energy", on the other hand, the components had relatively equal results from the PCAs in both regions, but differences were noticeable in the energy types used. This had some connection with the well-known energy ladder theory (Hosier and Dowd, 1987) and the "ES ladder" hypothesis (Sovacool, 2011a) as "traditional" and "modern energy" were used among the lower incomes, but only "modern energy" in the most affluent ones. Shifts from "traditional" to "modern energy", therefore, appeared valid as income increased (figure 25), but only when looked through the summarised ES, because the "energy ladder" concept within Mexican communities has also been reported invalid for some cases, where simultaneous use of several types of energy exist (Masera, 2000). Given such findings and our results, it may be that such preference is limited to certain ES (cooking or temperature regulation), which might change when analysed integrated with other ES. As section 5.3.3.4 has noted, ES in general improve as shifts from “traditional” to “modern energy” take place in the rural area under study. Thus, a simultaneous use of fuels does exist but energy shifts associate, in general, to better ES.

Lastly, “household technology” also aggregated multiple elements in a rather similar way suggesting a more horizontal preference for this concept. Although the analysed data only used 57 (Cuauhtémoc) and 63 (Zoquitlán) percent of the available appliances, the PCA solutions yielded a single-component for both, different only in terms of the total variance explained (92.3% for Zoquitlán and 56.6% for Cuauhtémoc). Regarding this difference, it was initially suggested that by considering another component in the PCA in Cuauhtémoc, equivalent variance would be explained and some elements would be hierarchically segregated. However, the second eigenvalue from these results was small and confirmed as not significant. Hence, all pointed to suggest that the consistent association between the elements reflects a flatter preference for acquiring technology, despite the notable differences in the average age of the equipment used among regions (see table 22 in appendix A).

In summary, these comparisons suggest that, in general, the less and the more affluent households perceive ES and other related elements differently, and such view is reflected in results from a Principal Component Analysis. As income increases in low income areas, the multiple components associated to “basic”, “secondary” or “superior” needs, evolve for the most part into fewer ones more “essential”, being better technology the only exception.

5.4.1.2 The ES predictors’ perspective.

The second part of this discussion focus on two aspects observed using the associations between ES and its predictors. Namely, that as income rise, the ES gains attained from material improvements have decreasing returns to scale (DRS), and, that despite “equipment” and “energy” might show strong predictive power from any direct regression with ES, these will be considerably reduced when controlling for other structural factors (“demographics” and “household characteristics”).

First, although it has been hypothesised that ES, in general, and particularly the most basic are largely determined by “energy” and “household equipment” (Sovacool, 2011a; Modi et al., 2006), the findings on “primary ES” from sections 5.3.3 and 5.3.4 suggests that both are controlled by more fundamental aspects. In particular, section 5.3.4 supports this, because the variance explained by “demographics” and “household characteristics” changed little from predictors-based to block-based regressions, but dropped 82 and 90 percent for “equipment” and “energy” respectively. Throughout the analysis, however, there was one consistent aspect: DRS in the ES gains in all the predictors, with the largest gains coming from the “essential” improvements. Namely, large leaps from switching walls made out of metal sheets and/or wood to adobe ones, switching soil floors to concrete ones, or the increase in the amount of appliances and energy used.

“Secondary ES”, on the other hand, seem to be less predictable by material aspects and detached to the “essential” improvements, even among lower incomes. Sections 5.3.3 and 5.3.4 support this, as “appliance technology” and “petrol”, despite being strongly associated to ES gains, could not predict “secondary ES” well when controlling for “demographics” and “household characteristics” (4 - 5 % of explained variance).

Lastly, once income has increased, the gains on ES become fully dependent on comparative wealth (section 5.3.3.1) and the use of commodities associated to particular energy types (section 5.3.3.4), but these gains seem to reach saturation points and become substantially narrower, i.e. “affluence” and “energy” (particularly “petrol”) had a predominant role to predict “ES” even after controlling for other factors (section 5.3.4). “Household equipment” also seemed relevant, but gains were determined by improvements easily associated with comfort rather than the satisfaction of basic needs (e.g. switches from concrete to wooden floors). And all the predictive power from these blocks explained comparatively narrower variation of scores on “ES” (mean scores above 4 in the 5 point scale used).

All this suggests that, similarly to the relationship between well-being and energy use, material improvements and ES satisfaction have DRS, and stronger associations among the lower incomes. However, greater energy use and household equipment are not fully equivalent to the gains, because depending on the type of ES (“primary ES” and “secondary ES”), “household characteristics” or “demographics” may be more relevant compared to those parameters. Conversely, among higher incomes, ES become more homogeneously arranged and the ES gains, if any, are narrower. These gains seemed less associated to basic material improvements, and as theory suggests (Sovacool, 2011a), probably better explained by alternative aspects, such as comfort or conspicuous consumption. The conclusion here is first, that energy used for ES do not serve totally as a surrogate of ES satisfaction, and second, that linkages between ES and direct or indirect (appliances) energy consumption have strong differences as income rise, added to the fact that when controlling for non-energy related factors, ES gains are not well explained by both parameters.

From the aforementioned, several questions arise as to what extent will material improvements targeted through commodities and energy use mean higher levels of human satisfaction (represented by ES). In addition, given the results from chapter IV on the relationships between ES and LS, both results my influence the design of alternative development paths.

5.5 Sustainable development in Mexico using energy services

Based on the findings of chapters IV and V, it might be plausible to consider that at lower-incomes, material gains reflect on well-being through certain energy services (ES). As income increase, the range of ES becomes wider, and probably dissociates once a higher income is reached. Sustainability policy should therefore consider first, that ES as the energy-well-being linkage is highly determined by income level. The policy focus by income level to enhance human well-being and reduce energy consumption is detailed below.

5.5.0.3 Low income households. Policy should note that ES in general (in components) did not link strongly to well-being in this income group, only specific ES were found strongly linked. A focus is needed on the aspects that enhance well-being through ES, while there is a possibility of targeting well-being from outside ES at households.

What aspects are therefore important inside households among the less affluent? Improving the most essential ES seems to create more favourable living conditions for this income group. According to chapter V, the highest ES gains would mainly come from focusing on simple material aspects on household conditions (e.g. wall and floor materials). Thus, programmes to promote basic improvements on household infrastructure might serve well to increase ES levels. Household equipment acquisition follows in importance. Promoting access to “modern” energy would also yield positive ES gains (albeit rather secondary compared to the two other characteristics). And finally, technology transfer, which although might serve to reduce large environmental impacts, did not seem to translate into higher scores on all ES. All these measures would have an indirect effect on well-being through ES, being temperature regulation the one receiving the highest benefits from improving technology or household conditions.

On the other hand, where should policy focus on to enhance well-being from outside the household? Better transport. The fact that only temperature regulation and transport associated strongly to well-being could demarcate policy in this direction. As suggested by the results, targeting public transport would increase well-being levels directly being mostly important among lower-incomes. Previous literature has also shown that energy consumed for transport is the only end-use having impacts on well-being levels (Poortinga et al., 2004). Thus, our policy suggestion seems consistent with results from previous literature.

In sum, in terms of welfare maximisation, temperature regulation through the improvement of basic household conditions and transport through better public services would become the most relevant targets in this income group.

5.5.0.4 Middle Income households. Policy targeting ES without any particular consideration would yield middle incomes receiving the largest benefits. This is because ES in general (as measured by components) correlated positively and strongly to well-being levels (see chapter IV). However, policy should also note that some specific ES were more relevant for well-being above others. Thus, more effective measures should target the most important ES for this income group (temperature regulation, transport and entertainment). The recommendation for low-income households previously detailed was to target the essential ES through basic household conditions. But for more wealthy households, targeting commodities and better technology seems more relevant. Nevertheless, it should be noted that as income increase, these gains have decreasing returns.

Hence, a dim line between promoting "sustainable" consumption and stimulating it into consumerism exists. This is a compelling reason to consider other alternative strategies to simply promoting more efficient end-uses of energy inside households in the name of higher well-being levels.

All these alternative strategies could centre on technological elements outside homes, e.g. material efficiency from other sectors, but more actively, on social aspects enhancing well-being. The fact that entertainment was strongly associated to well-being in this group suggests that as income increase, indoor activities progressively relate to higher well-being levels. Hence, it is not entirely clear if promoting more efficient consumption would ultimately yield positive or negative impacts. On the other hand, ES cannot be explained by better technology after certain improvement in material levels, and gains from better technology might come at the expense of creating a rebound effect. The case of Mexico with this respect is still rather unknown, but some recent studies (Davis et al., 2012) confirm the ample evidence of this phenomenon among developed (Sorrell, 2009) and developing countries (Ouyang et al., 2010; Roy, 2000). Thus, simply targeting more efficient household equipment could result in a failed strategy, and instead, they should combine the ES path with alternative means to increase well-being levels.

Among the social aspects enhancing well-being, one essential strategy not often considered would be the redefinition of its crucial aspects. As the national-scale analysis based on holistic measures suggest, better work-life balance or family life are two effective measures to be stimulated. Policy should aim to design a more sustainable middle-class role model, in which the value of leisure time is recovered. This certainly should be carefully designed, and promoted along with alternative activities to consumption. As mentioned earlier in this chapter, community participation, recreational, artistic or sport activities are among the many other measures that might come in hand. This means also creating the necessary infrastructure for such activities, as well as incentives for employers and other agents involved in their promotion.

In sum, policy would yield strong effects in this income group by means of targeting better commodities and technology for ES at households (particularly temperature regulation, transport and entertainment). However, alternative strategies should consider other elements outside homes and specially social aspects enhancing LS for more sustainable lifestyles.

5.5.0.5 High Income households. For higher-income households, policy should target methods to avoid extravagant consumption (including energy and commodities used). No gains on ES were observed from the increase on these parameters. ES gains were controlled by demographic aspects, affluence (in particular), excessive household equipment and energy consumption, suggesting that the target of income use may be entirely outside the domain of ES needs. The pursuit of these gains might be related to social signalling or conspicuous consumption, correlating even less with real measures of satisfaction (Graham, 2009). Hence, policy should prevent these lifestyles to become role models, with alternative ones among the middle class. The high income households should also be drawn into these new role models favouring work-life balance, family life or other aspects discussed above.

Yet, it is recognised that designing policy for this income group is difficult. Extravagant energy consumption (private jets, yachts, sports cars, increased travel, etc.) satisfy needs that have already crossed the threshold of better ES (or any other belonging). In many cases, life motivations centre on the wealth creation process itself. Thus, the only way to reduce consumption in this group is centring on alternative aspirations. The stimulation of charity or promoting experiences or activities outside the domain of consumption may come in hand. Revealing more clearly how higher quality goods compare to normal goods in terms of ecological benefits could become a ground for "alternative social signalling" itself. Some analysts agree with such ideas (Cliff, 2004). Additionally, it has often be thought that among developing countries higher income households are not the most pressing group for sustainability policy, yet it might be that considering its directional nature, this group would become the most crucial, as it usually sets the aspirations of middle and lower incomes.

5.5.1 Energy services as an instrument for local policy. In the context under study (Mexico), policy has not considered any of the previous ideas as crucial dimensions of well-being or development. Instead, it has focused almost exclusively on economic aspects (Federal, 2012). Mexican energy policy, on the other hand, has only concentrated on energy provision efficiency and prices (Energía, 2012), overlooking the connection to well-being or life satisfaction attained by energy consumption.

A redefinition of sustainable policy considering the previous recommendations should be aimed. Policy actions prescribed based on these suggestions, segmented by income, and through localised programs. For the less affluent simple changes on household conditions, energy provision in localities and transport would provide satisfactory results. In turn, better commodities and technology should be targeted among middle incomes. Lastly, a redefinition of the crucial aspects for well-being and development among middle, but above all, among higher incomes.

5.5.2 Energy services as an instrument for regional or international policy.

In a more international context, although the previous analysis might apply to multiple settings, they should be considered carefully. The connection between ES and well-being might slightly differ among cultures (e.g. religious views, values, etc.), which is a fertile ground for further research to create more generalised perspectives. General economic conditions might also influence policy. Some developing countries, for example, might find that the relationship between ES and material predictors are well in the range of the middle-high income group here studied. Thus, the redefinition of the crucial aspects for well-being and development would be the most meaningful aspect to design sustainable development policies. Extreme climates might also make the discussed premises deceptive, as appliances like heaters and air conditioners would have intrinsic importance not given for the analysed context. Rural and urban values might also make outcomes different, given that in some countries there is a marked contrast in values. In short, more contexts should be considered in further research to be able to generalise the findings.

5.6 Conclusion

This assessment of human well-being and energy use through energy services focused on material predictors using Mexican household-level data of two regions is summarised as follows.

First, in households of the less affluent location (Zoquitlán) more than one component summarised predictors with multiple variables (similarly to energy services in the previous chapter), suggesting a hierarchical classification.

Second, energy services gains from material improvements were only significant in the most essential energy services (temperature, food preservation, and communications) of the less affluent region (Zoquitlán). In the same location, less essential energy services (illumination, transport and entertainment) yielded modest gains. In the middle income region (Cuauhtémoc) gains became even smaller.

Third, using the data from both regions energy services observed decreasing returns to scale from material improvements, reaching saturation levels in higher income similarly to broader well-being metrics. Thus, once a level attained, energy services and material aspects also decouple.

Fourth, the improvement of essential energy services (temperature, food preservation, and communications) in the less affluent region (Zoquitlán) seemed strongly associated to material improvements, i.e. simple household conditions (e.g. wall and floor materials). More and better home equipment, as well as increases in energy use were relegated to a second place. Appliance technology, although positive to reduce environmental impacts, only seemed relevant to less-essential energy services (illumination, transport and entertainment). And finally, for households in the higher-income region, all the predictors (better material conditions, higher levels of energy consumption or larger number of commodities) yielded only minimal gains in energy services (measured through the component "general ES").

Considering the results from both regions, higher human well-being levels analysed through energy services point to suggest that the most critical issues are improving simple material aspects on household conditions among lower incomes, more efficient end-uses of energy among middle incomes and a redefinition of a sound lifestyle focusing on other aspects such as work-life balance, family life, etc. among higher incomes.

5.7 References

CFE [Comisión Federal de Electricidad]. Conoce tu recibo. Retrieved March 2013 from http://www.cfe.gob.mx/casa/Paginas/Casa.aspx

Clift, R. (2004). Metrics for supply chain sustainability. In Technological Choices for Sustainability (pp. 239-253). Springer Berlin Heidelberg.

Cravioto, J., Yamasue, E., Okumura, H. and Ishihara, K.N. (2014). Energy service satisfaction in two Mexican communities: A study on demographic, household, equipment and energy related predictors. Energy Policy, 73, 110-126.

Davis, L., Alan, F. and Paul, G. (2012). The economics of household energy efficiency: Evidence from Mexico's cash for coolers program. Unpublished manuscript.

De la Cruz, H. (2011). Sube gas LP, gasolina y diesel. El Mundo de Tehuacán, Feb 11, 2011.

Energía, Secretaria de (2012) Estrategía nacional de energía 2013-2027. México.

Federal, Administración Pública (2012). Plan nacional de desarrollo 2013-2018. México.

Field, A. (2009). Discovering statistics using SPSS. New York: Sage publications.

Graham, C. (2009). Happiness around the world: The paradox of happy peasants and miserable millionaires. Oxford University Press.

Haas, R., Nakicenovic, N., Ajanovic, A., Faber, T., Kranzl, L., Müller, A. and Resch, G. (2008). Towards sustainability of energy systems: A primer on how to apply the concept of energy services to identify necessary trends and policies. Energy Policy, 36(11), 4012-4021.

Hosier, R.H. and Dowd, J. (1987). Household fuel choice in Zimbabwe: An empirical test of the energy ladder hypothesis. Resources and Energy, 9(4), 347-361.

Jonsson, D.K., Gustafsson, S., Wangel, J., Höjer, M., Lundqvist, P. and Svane, Ö. (2011). Energy at your service: Highlighting energy usage systems in the context of energy efficiency analysis. Energy Efficiency, (4), 355-369.

Kahane, A. (1991). New perspectives for energy efficiency and system optimization. Energy Policy, 19(3), 199-201.

Masera, O.R., Saatkamp, B.D. and Kammen, D.M. (2000). From linear fuel switching to multiple cooking strategies: A critique and alternative to the energy ladder model. World Development, 28(12), 2083-2103.

Mazur, A. and Rosa, E.A. (1974). Energy and life-style. Science, 186, 607-610.

Mazur, A. (2011). Does increasing energy or electricity consumption improve quality of life in industrial nations? Energy Policy, 39(5), 2568-2572.

Modi, V., McDade, S., Lallement, D. and Saghir, J. (2006). Energy services for the millennium development goals. New York: Energy Sector Management Assistance Programme, United Nations Development Programme. UN Millennium Project and The World Bank.

Norgard, J.S. (2000). Models of energy saving systems: the battlefield of environmental planning. International Journal of Global Energy Issues, 13, 1-3.

Ouyang, J., Enshen, L. and Kazunori, H. (2010). Rebound effect in Chinese household energy efficiency and solution for mitigating it. Energy, 35(12), 5269-5276.

Pasternak, A. (2000). Global energy futures and human development: A framework for analysis (rep. no. UCRL-ID-140773: 1–25). Lawrence Livermore National Laboratory, California (USA).

PEMEX [Petróleos Mexicanos] (2014). Indicadores petroleros - informe mensual sobre producción y comercio de hidrocarburos. Vol 26(1), México.

Poortinga, W., Steg, L. and Vlek, C. (2004). Values, environmental concern, and environmental behavior: A study into household energy use. Environment and Behavior, 36(1), 70-93.

Quiroz-Carranza, J., and Roger O. (2010). Uso y manejo de leña combustible en viviendas de seis localidades de Yucatán, México. Madera y bosques, 16(2), 47-67.

Reister, D. and Devine, W. (1981). Total costs of energy services. Energy, 6(4), 305-315.

Rosas, J., Sheinbaum, C. and Morillon, D. (2010). The structure of household energy consumption and related CO_2 emissions by income group in Mexico. Energy for Sustainable Development, 14(2), 127-133.

Roy, J. (2000). The rebound effect: some empirical evidence from India. Energy Policy, 28(6), 433-438.

Sorrell, S., John, D. and Matt, S. (2009). Empirical estimates of the direct rebound effect: A review. Energy Policy 37(4), 1356-1371.

Sovacool, B.K. (2011a). Conceptualizing urban household energy use: Climbing the "energy services ladder". Energy Policy, 39(3), 1659-1668.

Sovacool, B.K. (2011b). Security of energy services and uses within urban households. Current Opinion in Environmental Sustainability, 3(4), 218-224.

Steinberger, J.K. and Roberts, J.T. (2010). From constraint to sufficiency: The decoupling of energy and carbon from human needs, 1975-2005. Ecological Economics, 70(2), 425-433.

Wirl, F. (1995). Impact of regulation on demand side conservation programs. Journal of Regulatory Economics, 7(1), 43-62.

VI. Conclusions

This thesis has explored the connection between human well-being and energy consumption using two scales of analysis contextualised in Mexico. First, through a novel application of Data Envelopment Analysis (DEA), three comparative-performance indices of well-being in relation to energy use and environmental stress were built to evaluate holistic performance in a country-level analysis. In the light of previous theory, crucial elements for paths towards general sustainable performance and the case study were determined. Second, through a novel measurement of energy services (ES) in Mexican households, an assessement on how exactly energy use contributes to higher levels of well-being in the case study was carried out.

Through the country-level analysis, it was found that higher efficiencies of DEA-based human development and well-being efficiency indices associated with certain geographic (tropical climate, specific regions), cultural (certain religious and language groups), demographic (younger populations, reduced affluence levels) and lifestyle (better work-life balance) elements. Higher DEA-based production efficiency was only associated similarly with lifestyle (stronly associated to higher work-life balance) and to a lesser extent with geographic (mixed climates, specific regions) and demographic (older populations, increased affluence levels) elements.

All this demarcated the following considerations for a more sustainable performance in Mexico. First, that increasing economic activity or energy consumption would yield lower levels of efficiency, as Mexico seemed already above the threshold of unefficient performance (61.9% -production-; 16.6% -development-; 14.3% -well-being-). To attain a more sustainable performance, a refocus towards an alternative path would be needed. In such path, the following aspects should be considered: Given the results on the influence of cultural elements, a local perspective seems crucial, because cultural traits regionally shared may explain the barriers for achieving more efficient performance. Internal geographic differences should also be noted, as based on the results by climate in the holistically-observed DEA efficiencies, regions in the north, south and coasts might need more technology improvements to decrease the energy used and environmental impact of economic activities and practices related to higher well-being levels (e.g. cooling and heating of space). However, results point to suggest that the most important of the analysed elements is lifestyle. Increasing leisure time or improving work-life balance and promoting alternatives to consumption (e.g. community participation, recreational and artistic activities or sports) seemed to yield the highest gains, but it would require the creation of necessary capacity for such activities and incentives to the agents involved (productive units and population).

At the same time, through the household-level analysis by income group, it was clear first, that households allow to visualise how energy contributes to higher levels of human well-being through energy services (communications, entertainment, food preservation, illumination, temperature regulation and transport). Regarding this, transport and temperature regulation seem the most important ES to enhance well-being levels, followed by entertainment, being more relevant at middle incomes, and finally illumination communications and food preservation at last. Second, that although ES gains showed a general decrease in returns to scale from material increase, further improvements are needed by income group as summarised below.

Among lower incomes, targeting basic household infrastructure focused on simple but effective reconditioning of wall and floor materials would be the most effective. Promoting access to “modern” energy (electricity and gas) would come in second place, and improving appliance technology, despite it might serve to reduce large environmental impacts, would come third, as it reflected less on ES (and ultimately well-being). These measures would increase well-being levels mostly through better temperature regulation (the most important ES for well-being in this group). Additionally, improving public transport services could also yield similar results because transport had the same importance as temperature regulation in this income group.

Among middle incomes, further ES associated to well-being (entertainment, besides transport and temperature regulation), suggesting that as income increase, energy consumption for indoor activities progressively relate to well-being levels. To enhance these ES, commodities and better technology seemed more relevant than household conditions, but the linkages to material gains reduced, particularly at higher income levels.

In sum, the connection between human well-being and energy use is determined by a set of geographic, demographic, material and lifestyle considerations that should set future strategies to enhance well-being in Mexico as seen through energy use. Among these, policy should be designed considering region, climate, income-level and lifestyle practices. A more sustainable middle-class role model is also crucial, redefining aspirations for well-being. Two possible stimuli could be activities associated to promoting leisure time such as better work-life balance or family life, but these should come with alternative activities to consuming.

The findings of this thesis may set a pathway to build more comprehensive analyses on crucial aspects to creating sustainable development paths based on the connection between human well-being and energy use. It is also an starting point to bring welfare, energy and environmental policy together in a more holistic perspective. Future research should consider the recommendations detailed in the following and final chapter (VII).

VII. Further research

The previous studies are the first approximation to a more comprehensive understanding of linkages between energy use and well-being. Future work could focus on a macro or a micro-scale, or combine aspects from both scales in more sophisticated analyses. The following paragraphs present a series of recommendations for this thesis' analyses with the aim to advance the understanding of the energy-well-being link and to find tractable methods serving policy design.

7.1 Energy and well-being in a macro-scale and sustainable development (the Goldemberg corner)

Future macro-scale works approaching the link through a holistic multi-dimensional comparative index could consider the following suggestions. First, as efficiency scores may change in time it is advisable to utilise time series analyses. DEA has the capabilities to make such models. When data availability might becomes an issue, surveying data might be necessary for more comprehensive studies.

Second, larger data sets would allow the use of multivariate regression models to search for predictors able to explain with more detail holistic efficiency in the Goldemberg corner (chapter III). These approach would test predictors or blocks of predictors controlling for geography, demographics and socio-cultural elements through hierarchical regressions.

Third, several technical improvements are also feasible inside the formulations. For example, energy consumption (TPES per capita) as one of the inputs is assumed to have a causal effect with the outputs (GDP per capita, HDI and subjective well-being), whereas CO_2 emissions, an undesirable output, was also treated as an input for simplicity in the formulation (see section 3.2.4). This consideration can be the subject of further comparisons by building the equivalent undesirable-output model without treating it as an input. Other improvements akin would include a comparison of results with a BCC DEA model, breaking the assumption of the constant returns to scale (in the output) in search for any considerable differences.

More complex relations using several predictors besides energy consumption and environmental stress could also be the subject of further studies. Such approach would only be limited by the amount of information available to explain efficiency scores, because the fewer countries considered, the less accurate the outcomes.

Finally, the use of such holistic indices might also help create sustainability targets. Such an approach seems feasible by using a dummy country in the analysis. Given a set of indicators, this fictitious country would represent an exemplary sustainable performance. Hence, all other peers would be evaluated compared to it, and the analysis of slacks would explicitly determine improvement targets for each country. Naturally, the approach could help to set environmental or economic targets in international binding agreements, using either cross-country or time series data.

7.2 Energy and well-being in a micro-scale and energy services as a linkage

In a more localised scale, the analysis of energy services at household showed a novel approach to link both ends. However, several improvements are advised to create more robust and comprehensive analyses.

First, further research should consider more ES and multiple contexts. Replicating this research in other locations with variations on rural/urban contexts, cultural background, climates and higher stratifications of income level is also desirable. Time series analyses would also add robustness to the analyses, both in relation to well-being measures (chap. IV), as well as with material predictors (chap. V). More accurate information would serve for better sustainability policy design in local contexts, particularly on measures to improve end-uses of energy in households through technology transfer programs, etc.

Furthermore, energy services might also be analysed through the holistic efficiency approaches of chapter III, provided that larger data sets become available (or surveyed). This would offer a fertile ground for more approaches integrating both methodological aspects discussed in this thesis, centred on questions such as: what factors can describe the most efficient households?, etc.

Finally, as energy and well-being have other connections not only through consumption inside households, the links between material conditions (and energy indirectly) and well-being could be brought into similar analyses. More sophisticated approaches, such as path analysis or structural equation modelling might be useful to study these interactions. This would complement the findings on energy services as one energy-well-being linkage, building a more comprehensive description of the energy-well-being link.

Table 19 Descriptive statistics of material predictors of energy services

Quantitative Variables

Block/Concept	Element	Units	Cuauhtémoc				Zoquitlán			
			Mean	Std dev.	Min	Max	Mean	Std dev.	Min	Max
Demographics	Age	-	36.5	14.6	17	77	37.7	16.5	12	72
	(Affluence related)									
	Number of clothes	[sets]	43.3	21.6	14	84	11.4	7.2	7	28
		[times per year]	13.1	13.5	1	52	3.3	2.5	1	8
	Clothes purchasing rate									
Household characteristics	Household age	[years]	14.5	10.1	1.5	50	28.3	18.7	1.5	50
	(Occupancy related)									
	Household size	[members]	4.2	1.2	2	7	5.6	2.7	1	15
	Number of rooms	-	7.1	3.6	2	20	3.2	1.1	1	6
Equipment[1]	Household appliances	-	-	-	-	-	-	-	-	-
	Household technology	-	-	-	-	-	-	-	-	-
Energy	Electricity	[kWh/month]	1860.8	1559.4	113.45	8103.7	84.6	43.8	0	215.95
	Gas	[kg/month]	106.9	95.7	14.68	391.45	15.7	19.5	0	78.1
	Fuelwood	[g/month]	0	0	0	0	715.5	601.9	83	2771
	Charcoal	[g/month]	114.9	875.4	0	6667	3150.0	7213.1	0	20000
	Petrol	[l/month]	203.3	230.5	0	850	1.6	9.5	0	57

Nominal Variables

Block	Element	Groups	Percentages	
			Cuauhtémoc	Zoquitlán
Demographics	Gender	Male	50.9	32.5
		Female	49.1	67.5
	Family type	Living alone	8.6	10
		Nuclear family	91.4	90
	Maternity	Have	41.4	65
		Don't have	58.6	35
	Job status	Have	58.6	72.5
		Don't have	39.7	27.5
	(Affluence related)			
	Mobile phone	Have	96.6	97.5
		Don't have	1.7	2.5
	Car	Have	93.1	12.5
		Don't have	6.9	87.5
Household characteristics	Type	Single house in land	50.9	82.1
		Sharing land or construction	26.3	17.9
		Apartment	22.8	0
	Wall material	Metal sheet or wood	0	5
		Adobe	0	55
		Brick or concrete	100	40
	Ceiling material	Cardboard, metal sheet or wood	0	22.5
		Brick, concrete or mixed	100	77.5
	Floor material	Soil	3.4	20
		Concrete	12.1	70
		Mosaic, wood or mixed	84.5	10

Notes:

(1) The variables under the Equipment block are PCA factors with zero as mean value, the descriptives of the condensed elements are omitted in this table but discussed in sections 3.2.1 and 3.2.2

Table 20 PCA factor loadings on number of household appliances (direct oblimin rotation)

Cuauhtémoc			
		Factor	
		1	2
Basic Appliances	Stove (gas)	.720	-.148
	Washing machine	.665	
	Microwave oven	.553	
	Heater (other)	.546	
	Refrigerator	.533	.257
	Gas tank	.206	
Secondary Appliances	DVD	-.111	.721
	TV		.689
	Computer		.656
	Fan (electric)	-.219	.597
	Phone		.571
	Printer	.109	.553
	Radio	-.259	.532
	Toaster (electric)		.516
	Heater (electric)	.161	.475
	Boiler		.473
	Heating system	-.187	.460
	Extractor (electric)	-.218	.458
	Car	.105	.421
	Videoplayer	-.152	.362
	Bulbs per room	-.439	.359
	Videogames		.315
Not Clear	Iron	.624	.473
	Air conditioner	.326	.405
	Oven	.359	.398
	Teapot (electric)	.223	.289
	Blender (electric)	.402	.279
	Stove (electric)	-.380	.243
	Water pump	-.383	.155
Not relevant	Hairdryer	-.124	.149
	Heater (gas)		
	Motorcycle		
	Eigenvalue	1.5	1.1
	Explained variance	16.6	27.5
	Total exp. var.		44.1
	Cronbach's Alpha	0.668	
	Kaiser-Meyer-Olkin	0.303	

Zoquitlán				
		Factor		
		1	2	3
Basic Appliances	Iron	.602	-.319	
	Boiler	.643	.109	-.560
	Stove (gas)	.617	.133	
	Refrigerator	.691	.260	-.312
	Microwave oven	.518		
	Blender (electric)	.667	-.351	
	Phone	.656		
Secondary Appliances	Washing machine	.214	.752	
	Extractor (electric)	-.179	.674	
	Videoplayer	.135	.817	
Superior Appliances	Bulbs per room		.162	.642
	Gas tank	-.126		.273
	Printer	.228	-.266	.565
	Car	.121	-.358	.655
Not Clear	TV	.664	.250	.452
	DVD	.478	.151	.545
	Computer	.490	.212	.479
	Radio	-.197	.263	.143
Not relevant	Heater (other)		-.177	-.615
	Oven	-.102	-.107	
	Eigenvalue	1.4	1.2	1.1
	Explained variance	20.3	14.1	11.8
	Total exp. var.			46.2
	Cronbach's Alpha	0.668		
	Kaiser-Meyer-Olkin	0.376		

Notes:
Eigenvalues are significant to the 95% C.I. from a parallel analysis
(-0.1,0.1) Factor loadings are omitted from the scale; [-0.2,-0.1] and [0.1,0.2] factor loadings in grey

Table 21 PCA factor loadings on number of household appliances. Reduced scale (direct oblimin rotation).

Cuauhtémoc			Zoquitlán		
	Factor			Factor	
	1	2		1	2
Stove (gas)	.735	-.344	Boiler	.640	.157
Microwave oven	.732		Stove (gas)	.710	
Washing machine	.724		Refrigerator	.497	.370
Oven	.657	.231	Microwave oven	.789	-.205
Iron	.556	.269	Phone	.733	
Refrigerator	.399	.140			
			Iron	-.101	.886
Fan (electric)	-.105	.729	Blender (electric)		.830
TV	.218	.721	TV	.255	.441
DVD	.242	.672			
Computer	.176	.639	Eigenvalue	1.8	1.0
Radio	-.342	.534	Explained variance	42.4	13.7
Phone		.497	Total exp. var.		56
Extractor (electric)		.465			
Bulbs per room	-.245	.450	Cronbach's Alpha	0.796	
Car		.450	Kaiser-Meyer-Olkin	0.759	
Heating system	.140	.321			
Eigenvalue	1.5	1.1			
Explained variance	23.6	39.6			
Total exp. var.		63.2			
Cronbach's Alpha	0.703				
Kaiser-Meyer-Olkin	0.701				

Notes:

Eigenvalues are significant to the 95% C.I. from a parallel analysis

(-0.1,0.1) Factor loadings are omitted from the scale; [-0.2,-0.1] and [0.1,0.2] factor loadings in grey

Table 22 Descriptive statistics of household appliance age

	Cuauhtémoc		Zoquitlán	
Appliance's age	mean [yrs]	std. dev.	mean [yrs]	std. dev.
Iron	2.6	2.5	6.1	7.3
Refrigerator	5.7	4.9	9.5	6.3
Microwave oven	5.6	4.5	2.1	1.1
TV	3.6	2.7	10.6	10.9
DVD	3.7	2.5	3.9	1.8
Radio	5.3	4.6	8.4	12.0
Computer	2.7	1.7	3.0	.
Phone	7.5	7.1	5.2	3.7
Car	3.0	2.3	1.9	1.2
Boiler	6.4	5.6	10.7	8.1
Stove (gas)	7.5	6.6	10.3	7.7
Blender (electric)	3.2	3.6	6.1	6.2
Average	4.7		6.5	

Table 23 PCA factor loadings on household technology (appliance age). Direct oblimin rotation.

Cuauhtémoc		Zoquitlán	
	Factor 1		Factor 1
Iron	.552	Boiler	.967
Refrigerator	.830	Stove (gas)	.915
Microwave oven	.799	Iron	.953
TV	.825	Blender (electric)	.986
DVD	.907	TV	.981
Radio	.778		
Computer	.644	Eigenvalue	4.6
Phone	.790	Explained variance	92.3
Car	.558		
		Cronbach's Alpha	0.939
Eigenvalue	5.1	Kaiser-Meyer-Olkin	0.802
Explained variance	56.6		
Cronbach's Alpha	0.878		
Kaiser-Meyer-Olkin	0.812		

Notes:

Eigenvalues are significant to the 95% C.I. from a parallel analysis

Table 24 PCA factor loadings on energy use (direct oblimin rotation)

Cuauhtémoc		Zoquitlán			
Modern energy		Modern energy		Traditional energy	
	Factor 1		Factor 1		Factor 1
Electricity per member [kWh/month]	.847	Electricity per member [kWh/month]	.835	Fuelwood individual [g/month]	.794
Gas per member [kg/month]	.847	Gas per member [kg/month]	.835	Charcoal individual [g/month]	.794
Eigenvalue	1.4	Eigenvalue	1.4	Eigenvalue	1.3
Explained variance	71.8	Explained variance	69.7	Explained variance	63.0
Cronbach's Alpha	0.608	Cronbach's Alpha	0.566	Cronbach's Alpha	0.413
Kaiser-Meyer-Olkin	0.500	Kaiser-Meyer-Olkin	0.500	Kaiser-Meyer-Olkin	0.500

Notes:

Eigenvalues are significant to the 95% C.I. from a parallel analysis

Table 25 PCA factor loadings on affluence related elements. Total sample (direct oblimin rotation).

Affluence	
	Factor 1
Household occupancy	.742
Mobile phone	.931
Car	.869
Clothes	.853
Eigenvalue	2.9
Explained variance	72.5
Cronbach's Alpha	0.871
Kaiser-Meyer-Olkin	0.788

Notes:

Eigenvalue significant to the 95% C.I. from a parallel analysis

Survey questionnaire

Individual information

(part 1)

1. Gender: 0) Female 1) Male

2. Age: __________

Members in the household

3. How many people live in your house? _____

4. Who of the following lives in your house?

☐ My father ☐ My mother ☐ My partner ☐ My son/daughter How many?_____ ☐ Other persons How many?_____

5. Are you employed? 0) No 1) Yes

Personal assets

6. How often do you purchase clothes for your individual use?

0) Once a year 1) 6 months - 1 year 2) 3 – 6 months 3) 1 - 3 months 4) 1 week – 1 month 5) Every week

7. Approximately, how many sets of clothes do you own (for how many days)?

_______________________ days / weeks

8. Do you own a mobile phone? 0) No 1) Yes

Life satisfaction

9. Taking into account everything, how satisfied or dissatisfied you are currently with your life as a whole (1 - 5)?

1	2	3	4	5
Dissatisfied				Satisfied

Energy use and services in households

(part 2)

10. In general, how would you consider these features in your house? (mark with an X):

Energy service:	Inadequate	Barely sufficient	Normal	Good	Very good
Illumination					
Temperature regulation					
Easiness to preserve my food					
Communications					
Transport					
Entertainment					

Characteristics of your household

11. My household is:	1. A single house in a lot. 2. A house sharing the lot with another. 3. A house sharing the construction and the lot. 4. A duplex house. 5. An apartment. 6. A room built on top of a roof. 7. A space not built for use as a household.
12. My household was built:	0. Less than 3 years ago. 1. From 3 to 6 years ago. 2. From 7 to 10 years ago. 3. From 11 to 20 years ago. 4. From 21 to 30 years ago. 5. From 31 to 50 years ago. 6. More than 50 years ago. -1. I don't know.

13. No. of rooms in your household (without hallways and bathrooms) _________

14. No. of dormitories in your household _________

15. Where would you obtain the following and how much would you usually pay for it:

	Average monthly payment (pesos)	Supply method
Electricity		a) No supply available. b) Public service. c) Own generation. d) Mixed: public service & own generation.
Gas		a) No supply available. b) Natural gas [piped gas supply]. c) Liquefied petroleum gas [supply from LP gas tankers].
Charcoal		a) Supplier. b) No supply available.
Fuelwood		a) Own collection. b) Supplier. c) No supply available.
Petrol		a) Supplier. b) No supply available.

16. Type of illumination of your household and number of light-bulbs. Please write the total number of light bulbs used in your house:

☐a) Incandescent ________

☐b) Fluorescent (CFL) ________

☐c) Halogen filament ________

☐d) Oil lamp, candles ________

☐e) LED ________

☐f) Fluorescent (CFL) ________

17. My house walls are made of:	0. Asbestos/steel sheet. 1. Wood. 2. Adobe. 3. Bricks, concrete, stone. 4. Mixed (sheet, wood). 5. Mixed (adobe, concrete).

18. My house ceilings are made of:	a) Waste material. b) Cardboard sheet. c) Steel sheet. d) Asbestos sheet. e) Palm or straw. f) Wood or shingle. g) Tiles. h) Prefabricated concrete slabs.

19. My floor is made of:	a) Soil. b) Concrete. c) Plastic or vinyl tiles. d) Mosaics. e) Wood or parquet.

20. From the following objects which ones do you own in your house and approximately how long ago did you purchased each of them?

Household equipment	Total number owned	How long ago were they purchased? (months / years)
Air conditioner		
Blender		
Boiler		
Car		
Computer		
DVD		
Extractor		
Fan (electric)		
Gas tank		
Hairdryer		
Heater (electric)		
Heater (gas)		
Heater (other)		
Heating system		
Iron		
Microwave oven		
Motorcycle		
Oven		
Phone		
Printer		
Radio		
Refrigerator		
Stove (electric)		
Stove (gas)		
Teapot (electric)		
Toaster (electric)		
TV		
Videogames		
Video player		
Washing machine		
Water pump		

Table 26 Previous sustainability indices used in chapter 3

	DEA Indices			Other Indices	
	Ramanathan (2002)	Cravioto et al. (2011)			
Countries	GDP Efficiency [%]	GDP Efficiency [%]	HDI Efficiency [%]	Happy Planet Index	Ecological footprint [gha/capita]
Argentina	39	59.4	6.4	54.06	2.71
Australia	44	30.2	1.7	41.98	6.68
Brazil	25	65.2	13.7	52.93	2.93
Bulgaria	58	22.9	3.9	34.15	3.56
Canada	36	27.6	1.7	43.56	6.43
Chile	49	42.1	6.2	53.88	3.24
China	24	34.7	6.4	44.66	2.13
Costa Rica	-	100.0	17.7	64.04	2.52
France	16	67.1	5.0	46.52	4.91
Germany	-	46.0	3.0	47.20	4.57
Ghana	17	100.0	41.7	40.30	1.74
Greece	46	45.7	3.3	40.53	4.92
India	1	70.9	21.8	50.87	0.87
Indonesia	3	71.5	25.4	55.48	1.13
Iran	43	36.1	6.6	41.69	2.66
Israel	26	45.8	3.1	55.20	3.96
Italy	23	56.5	3.9	46.35	4.52
Jamaica	-	15.2	5.9	58.53	1.72
Japan	15	45.2	3.0	47.51	4.17
Korea	47	33.9	2.8	43.78	4.62
Malaysia	53	32.0	4.4	40.49	3.90
Mexico	55	58.6	8.2	52.89	3.30
Morocco	37	76.8	17.8	47.89	1.32
New Zealand	19	41.5	3.4	51.56	4.31
Nigeria	7	84.8	72.5	33.62	1.44
Norway	1	73.6	3.8	51.43	4.77
Philippines	34	95.1	27.9	52.35	0.98
Poland	64	41.0	4.7	42.58	3.94
Russia	-	19.2	2.5	34.52	4.40
Saudi Arabia	-	22.1	2.3	45.97	3.99
South Africa	61	24.0	2.9	28.19	2.59
Spain	28	49.1	3.8	44.06	4.74
Sweden	1	92.1	5.8	46.17	5.71
Tanzania	1	88.6	100.0	30.74	1.19
Thailand	44	42.8	7.1	53.46	2.41
Turkey	5	54.0	7.1	47.62	2.55
United Kingdom	32	56.0	3.4	47.93	4.71
United States	33	31.8	1.5	37.34	7.19
Uzbekistan	-	13.6	8.4	46.00	1.82
Venezuela	52	24.1	5.3	56.87	3.02

Table 27 Chapter 3 data on geographical and demographic predictors

Country	Geographical		Demographic		
	Climate	Region	Poverty index	Population [million]	Median age [years]
Argentina	Temperate/Subartic	America (South)	2.9	40.41	30.8
Australia	Arid	Oceania	0.0	22.27	37.1
Brazil	Tropical	America (South)	6.8	194.95	29.9
Bulgaria	Temperate	Europe (East)	3.9	7.49	42.8
Canada	Temperate/Subartic	America (North)	0.0	34.02	40.0
Chile	Temperate/Subartic	America (South)	1.9	17.11	32.8
China	Diverse	Asia (East)	18.6	1,341.34	35.1
Costa Rica	Tropical	America (Central/Caribbean)	3.1	4.66	29.3
France	Temperate	Europe (West)	0.0	62.79	40.4
Germany	Temperate	Europe (West)	0.0	82.30	45.1
Ghana	Tropical	Africa (central)	51.8	24.39	20.5
Greece	Temperate	Europe (East)	0.0	11.36	42.5
India	Diverse	Asia (South/Southeast)	59.2	1,224.61	26.1
Indonesia	Tropical	Asia (South/Southeast)	43.3	239.87	27.5
Iran	Arid	Asia (West/Center)	8.0	73.97	28.0
Israel	Temperate	Asia (West/Center)	0.0	7.42	30.1
Italy	Temperate	Europe (West)	0.0	60.55	44.0
Jamaica	Tropical	America (Central/Caribbean)	5.9	2.74	27.5
Japan	Temperate	Asia (East)	0.0	126.54	45.5
Korea	Temperate	Asia (East)	0.0	48.18	38.9
Malaysia	Tropical	Asia (South/Southeast)	2.3	28.40	27.0
Mexico	Diverse	America (North)	4.1	113.42	26.6
Morocco	Temperate	Africa (north)	14.2	31.95	26.7
New Zealand	Temperate	Oceania	0.0	4.37	36.9
Nigeria	Diverse	Africa (central)	82.2	158.42	17.8
Norway	Temperate/Subartic	Europe (North)	0.0	4.88	38.9
Philippines	Tropical	Asia (South/Southeast)	41.7	93.26	22.7
Poland	Temperate	Europe (East)	0.1	38.28	38.6
Russia	Diverse	Europe (East)	0.3	142.96	38.2
Saudi Arabia	Arid	Asia (West/Center)	0.0	27.45	27.0
South Africa	Arid	Africa (south)	26.2	50.13	25.7
Spain	Temperate	Europe (West)	0.0	46.08	41.0
Sweden	Temperate/Subartic	Europe (North)	0.0	9.38	40.9
Tanzania	Tropical	Africa (central)	73.0	44.84	17.5
Thailand	Tropical	Asia (South/Southeast)	3.5	69.12	36.4
Turkey	Temperate	Europe (East)	2.6	72.75	29.0
United Kingdom	Temperate	Europe (West)	0.0	62.04	40.1
United States	Diverse	America (North)	0.0	310.38	37.3
Uzbekistan	Arid	Asia (West/Center)	16.0	27.44	24.9
Venezuela	Tropical	America (South)	12.9	28.98	26.7

Table 28 Chapter 3 data on cultural predictors

Country	Cultural				
	Language group	Language familiy	Religious diversity	Religion classification	work life balance [hrs]
Argentina	Italic	Indo-European	3.0	Christian	-
Australia	Germanic	Indo-European	5.6	Mixed	14.41
Brazil	Italic	Indo-European	2.3	Christian	14.97
Bulgaria	Slavic	Indo-European	3.5	Christian	-
Canada	Germanic	Indo-European	5.3	Mixed	14.25
Chile	Italic	Indo-European	2.2	Christian	14.41
China	Chinese	Sino-Tibetan	7.3	Mixed	-
Costa Rica	Italic	Indo-European	1.9	Christian	-
France	Italic	Indo-European	5.9	Mixed	15.33
Germany	Germanic	Indo-European	5.3	Mixed	15.31
Ghana	Niger-congo	Niger-Kordofanian	4.7	Mixed	-
Greece	Greek	Indo-European	2.5	Christian	14.91
India	Indo-Iranian	Indo-European	4.0	Hindu	-
Indonesia	Austronesian	Austronesian	2.6	Muslim	-
Iran	Indo-Iranian	Indo-European	0.1	Muslim	-
Israel	Semitic	Afro-Asiatic	4.5	Jewish	14.48
Italy	Italic	Indo-European	3.3	Christian	14.98
Jamaica	Germanic	Indo-European	4.3	Christian	-
Japan	Altaic	Altaic	6.2	Mixed	14.93
Korea	Altaic	Altaic	7.4	Mixed	14.63
Malaysia	Austronesian	Austronesian	6.3	Mixed	-
Mexico	Italic	Indo-European	1.1	Christian	13.89
Morocco	Semitic	Afro-Asiatic	0.0	Muslim	-
New Zealand	Germanic	Indo-European	6.2	Mixed	14.87
Nigeria	Chadic	Afro-Asiatic	5.9	Mixed	-
Norway	Germanic	Indo-European	3.1	Christian	15.56
Philippines	Austronesian	Austronesian	1.6	Christian	-
Poland	Slavic	Indo-European	1.2	Christian	14.20
Russia	Slavic	Indo-European	4.9	Mixed	14.97
Saudi Arabia	Semitic	Afro-Asiatic	1.5	Muslim	-
South Africa	Niger-congo	Niger-Kordofanian	3.6	Christian	-
Spain	Italic	Indo-European	3.9	Christian	16.06
Sweden	Germanic	Indo-European	5.4	Mixed	15.11
Tanzania	Niger-congo	Niger-Kordofanian	5.7	Mixed	-
Thailand	Daic	Daic	1.5	Buddhist	-
Turkey	Turkic	Altaic	0.4	Muslim	13.42
United Kingdom	Germanic	Indo-European	5.1	Mixed	14.83
United States	Germanic	Indo-European	4.1	Christian	14.27
Uzbekistan	Turkic	Altaic	0.7	Muslim	-
Venezuela	Italic	Indo-European	2.2	Christian	-

Table 29 Chapter 3 data for DEA formulations

		Inputs		Outputs		
Countries	DMU	TPES cap [toe p cap]	CO$_2$ cap [tCO$_2$ p cap]	GDP cap PPP [US$ p cap]	HDI	SWB
Argentina	1	1.907	4.403	15,296.58	0.808	6.5
Australia	2	5.559	17.026	42,596.29	0.933	7.2
Brazil	3	1.392	2.086	15,239.25	0.744	6.9
Bulgaria	4	2.513	6.084	16,097.83	0.777	4.2
Canada	5	7.259	15.077	42,338.64	0.902	7.4
Chile	6	2.140	4.441	21,370.10	0.822	6.6
China	7	2.153	6.307	11,214.77	0.719	5.1
Costa Rica	8	1.016	1.469	13,833.11	0.763	7.3
France	9	3.846	4.749	37,473.63	0.884	6.6
Germany	10	3.877	9.262	43,600.11	0.911	6.7
Ghana	11	0.336	0.500	3,724.93	0.573	5.1
Greece	12	2.405	6.978	25,980.09	0.853	5.1
India	13	0.595	1.409	4,948.33	0.586	4.6
Indonesia	14	0.854	1.678	9,449.35	0.684	5.4
Iran	15	2.883	6.780	16,846.03	0.749	4.6
Israel	16	3.068	9.452	31,993.62	0.888	7.1
Italy	17	2.709	6.160	35,931.10	0.872	5.8
Jamaica	18	1.038	2.587	8,556.15	0.715	5.4
Japan	19	3.543	9.542	35,718.98	0.890	6
Korea	20	5.269	11.504	32,222.59	0.891	6
Malaysia	21	2.724	6.596	23,114.03	0.773	5.9
Mexico	22	1.545	3.553	16,260.76	0.756	7.3
Morocco	23	0.571	1.562	6,976.69	0.617	5
New Zealand	24	4.375	7.077	32,602.04	0.910	7.2
Nigeria	25	0.797	0.376	5,404.84	0.504	5.5
Norway	26	5.910	7.081	65,399.84	0.944	7.7
Philippines	27	0.448	0.837	6,150.24	0.660	5
Poland	28	2.567	7.798	23,598.56	0.834	5.9
Russia	29	5.174	10.830	23,519.70	0.778	5.6
Saudi Arabia	30	6.792	15.708	49,706.65	0.836	6.5
South Africa	31	2.681	7.791	12,596.68	0.658	5.1
Spain	32	2.683	5.568	32,235.60	0.869	6.3
Sweden	33	5.269	4.133	44,433.73	0.898	7.6
Tanzania	34	0.462	0.174	2,288.21	0.488	4
Thailand	35	1.879	3.558	14,859.23	0.722	6.3
Turkey	36	1.578	4.085	18,635.97	0.759	5.3
United Kingdom	37	3.028	7.245	37,569.32	0.892	6.9
United States	38	6.812	16.019	51,456.66	0.914	7
Uzbekistan	39	1.626	3.614	4,788.99	0.661	6
Venezuela	40	2.447	5.652	18,019.60	0.764	7.1

Table 30 Chapter 3 DEA envelopment models' coefficients (weights)

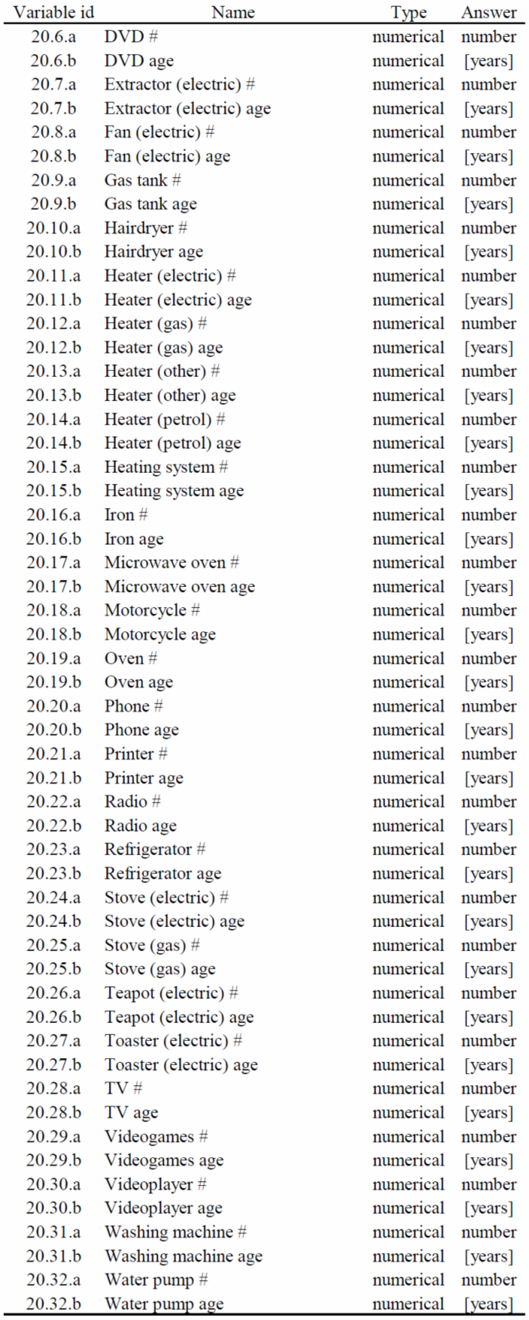
Country	DMU	Production DEA Coefficients		Development DEA Coefficients		Well-being DEA Coefficients	
		λ_{12}	λ_{35}	λ_{12}	λ_{35}	λ_{12}	λ_{35}
Argentina	1	1.2745	0	1.4101	0	1.2745	0
Australia	2	1.4118	0	1.6271	0	1.4118	0
Brazil	3	1.3529	0	1.2973	0	1.3529	0
Bulgaria	4	0.8235	0	1.3562	0	0.8235	0
Canada	5	1.451	0	1.5733	0	1.451	0
Chile	6	1.2941	0	1.4333	0	1.2941	0
China	7	1	0	1.2545	0	1	0
Costa Rica	8	1.3988	0.0415	1.2975	0.0385	1.3988	0.0415
France	9	1.1066	0.2391	1.3029	0.2816	1.1066	0.2391
Germany	10	1.3137	0	1.5901	0	1.3137	0
Ghana	11	1	0	1	0	1	0
Greece	12	1	0	1.4875	0	1	0
India	13	0.902	0	1.0219	0	0.902	0
Indonesia	14	1.0588	0	1.1937	0	1.0588	0
Iran	15	0.902	0	1.3073	0	0.902	0
Israel	16	1.3922	0	1.5488	0	1.3922	0
Italy	17	1.1373	0	1.5209	0	1.1373	0
Jamaica	18	1.0588	0	1.248	0	1.0588	0
Japan	19	1.1765	0	1.5528	0	1.1765	0
Korea	20	1.1765	0	1.5538	0	1.1765	0
Malaysia	21	1.1569	0	1.3484	0	1.1569	0
Mexico	22	1.4314	0	1.3186	0	1.4314	0
Morocco	23	0.9804	0	1.0759	0	0.9804	0
New Zealand	24	1.4118	0	1.5876	0	1.4118	0
Nigeria	25	0.1526	1.1805	0.1157	0.8953	0.1526	1.1805
Norway	26	1.2557	0.3239	1.3495	0.3481	1.2557	0.3239
Philippines	27	0.9804	0	1.1506	0	0.9804	0
Poland	28	1.1569	0	1.4554	0	1.1569	0
Russia	29	1.098	0	1.3578	0	1.098	0
Saudi Arabia	30	1.2745	0	1.4576	0	1.2745	0
South Africa	31	1	0	1.1475	0	1	0
Spain	32	1.2353	0	1.5159	0	1.2353	0
Sweden	33	0.7505	0.9431	0.7564	0.9505	0.7505	0.9431
Tanzania	34	0	1	0	1	0	1
Thailand	35	1.2353	0	1.2595	0	1.2353	0
Turkey	36	1.0392	0	1.3235	0	1.0392	0
United Kingdom	37	1.3529	0	1.5557	0	1.3529	0
United States	38	1.3725	0	1.5941	0	1.3725	0
Uzbekistan	39	1.1765	0	1.1532	0	1.1765	0
Venezuela	40	1.3922	0	1.3323	0	1.3922	0

Note: λ_1 *to* λ_{11}, λ_{13} *to* λ_{34} *and* λ_{36} *to* λ_{40} *take zero as value*

Table 31 Chapter 4 and 5 energy services survey variable list (1/2)

Variable id	Name	Type	Answer	Label
No	Questionnaire number	numerical	-	
0	Region	nominal	0/1	[0 - Zoquitlán, 1 - Cuauhtémoc]
1	Gender	nominal	0/1	[0 - Female, 1 - Male]
2	Age	numerical	[years]	
3	Household members	numerical	number	
4.a	Members - Father	nominal	0/1	[0 - No, 1 - Yes]
4.b	Members - Mother	nominal	0/1	[0 - No, 1 - Yes]
4.c	Members - Spouse	nominal	0/1	[0 - No, 1 - Yes]
4.d	Members - Child	numerical	number	
4.e	Others	numerical	number	
fam	Family type	nominal	0-3	[0 - Living alone, 1 - 3 With family]
mat	Maternity	nominal	0/1	[0 - No children, 1 - With children]
5	Job status	nominal	0/1	[0 - Unemployed, 1 - Employed]
6	Clothing frequency of purchase	ordinal	0-5	*See questionnaire (Appendix B)
7	Clothing quantity owned	numerical	[weeks]	
8	Mobile	nominal	0/1	[0 - No, 1 - Yes]
9	Life satisfaction (self-rated)	ordinal	1-5	
10.a	Ilumination	ordinal	1-5	
10.b	Temperature regulation	ordinal	1-5	
10.c	Food preservation	ordinal	1-5	
10.d	Communications	ordinal	1-5	
10.e	Transport	ordinal	1-5	
10.f	Entertainment	ordinal	1-5	
11	Household type	nominal	1-7	*See questionnaire (Appendix B)
12	Household age	ordinal	-1-7	*See questionnaire (Appendix B)
13	Rooms	numerical	number	
14	Dormitories	numerical	number	
15.a	Electricity consumption	nominal	[Pesos]	
15.b	Electricity supply method	nominal	0/1/2/3	*See questionnaire (Appendix B) [0=a; 1=b; 2=c; 3=d]
15.c	Gas consumption	nominal	[Pesos]	
15.d	Gas supply method	nominal	0/1/2	*See questionnaire (Appendix B) [0=a; 1=b; 2=c]
15.e	Charcoal consumption	nominal	[Pesos]	
15.f	Coal supply method	nominal	0/1	*See questionnaire (Appendix B) [0=a; 1=b]
15.g	Wood consumption	nominal	[Pesos]	
15.h	Wood supply method	nominal	0/1/2/3	*See questionnaire (Appendix B) [0=a; 1=b; 2=c]
15.i	Petrol consumption	nominal	[Pesos]	
15.j	Petrol supply method	nominal	0/1	*See questionnaire (Appendix B) [0=a; 1=b]
16.a	Lightbulbs filament #	numerical	number	
16.b	Lightbulbs fluorescent #	numerical	number	
16.c	Lightbulbs halogen #	numerical	number	
16.d	Oil lamps #	numerical	number	
16.e	Lightbulbs neon #	numerical	number	
16.f	Lightbulbs LED #	numerical	number	
17	Wall material	nominal	0-5	*See questionnaire (Appendix B)
18	Ceiling material	nominal	0-5	*See questionnaire (Appendix B)
19	Floor material	nominal	0-5	*See questionnaire (Appendix B)
20.1.a	Air conditioner #	numerical	number	
20.1.b	Air conditioner age	numerical	[years]	
20.2.a	Blender (electric) #	numerical	number	
20.2.b	Blender (electric) age	numerical	[years]	
20.3.a	Boiler #	numerical	number	
20.3.b	Boiler age	numerical	[years]	
20.4.a	Car #	numerical	number	
20.4.b	Car age	numerical	[years]	
20.5.a	Computer #	numerical	number	
20.5.b	Computer age	numerical	[years]	

Table 32 Chapter 4 and 5 energy services survey variable list (2/2)



Variable id	Name	Type	Answer
20.6.a	DVD #	numerical	number
20.6.b	DVD age	numerical	[years]
20.7.a	Extractor (electric) #	numerical	number
20.7.b	Extractor (electric) age	numerical	[years]
20.8.a	Fan (electric) #	numerical	number
20.8.b	Fan (electric) age	numerical	[years]
20.9.a	Gas tank #	numerical	number
20.9.b	Gas tank age	numerical	[years]
20.10.a	Hairdryer #	numerical	number
20.10.b	Hairdryer age	numerical	[years]
20.11.a	Heater (electric) #	numerical	number
20.11.b	Heater (electric) age	numerical	[years]
20.12.a	Heater (gas) #	numerical	number
20.12.b	Heater (gas) age	numerical	[years]
20.13.a	Heater (other) #	numerical	number
20.13.b	Heater (other) age	numerical	[years]
20.14.a	Heater (petrol) #	numerical	number
20.14.b	Heater (petrol) age	numerical	[years]
20.15.a	Heating system #	numerical	number
20.15.b	Heating system age	numerical	[years]
20.16.a	Iron #	numerical	number
20.16.b	Iron age	numerical	[years]
20.17.a	Microwave oven #	numerical	number
20.17.b	Microwave oven age	numerical	[years]
20.18.a	Motorcycle #	numerical	number
20.18.b	Motorcycle age	numerical	[years]
20.19.a	Oven #	numerical	number
20.19.b	Oven age	numerical	[years]
20.20.a	Phone #	numerical	number
20.20.b	Phone age	numerical	[years]
20.21.a	Printer #	numerical	number
20.21.b	Printer age	numerical	[years]
20.22.a	Radio #	numerical	number
20.22.b	Radio age	numerical	[years]
20.23.a	Refrigerator #	numerical	number
20.23.b	Refrigerator age	numerical	[years]
20.24.a	Stove (electric) #	numerical	number
20.24.b	Stove (electric) age	numerical	[years]
20.25.a	Stove (gas) #	numerical	number
20.25.b	Stove (gas) age	numerical	[years]
20.26.a	Teapot (electric) #	numerical	number
20.26.b	Teapot (electric) age	numerical	[years]
20.27.a	Toaster (electric) #	numerical	number
20.27.b	Toaster (electric) age	numerical	[years]
20.28.a	TV #	numerical	number
20.28.b	TV age	numerical	[years]
20.29.a	Videogames #	numerical	number
20.29.b	Videogames age	numerical	[years]
20.30.a	Videoplayer #	numerical	number
20.30.b	Videoplayer age	numerical	[years]
20.31.a	Washing machine #	numerical	number
20.31.b	Washing machine age	numerical	[years]
20.32.a	Water pump #	numerical	number
20.32.b	Water pump age	numerical	[years]

Table 33 Chapter 4 and 5 energy services survey data (1/14)

Variable id No	0	1	2	3	4.a	4.b	4.c	4.d	4.e	fam	mat	5	6	7	8	9
1	0	0	49	2	-	-	1	-	-	2	0	1	1	1	0	3
2	0	0	22	11	1	1	-	8	-	1	1	1	3	1	0	3
3	0	0	28	6	1	1	-	3	-	1	1	1	-	-	0	4
4	0	0	28	4	-	1	-	2	-	1	1	0	1	1	0	4
5	0	0	36	5	-	-	1	3	-	2	1	1	1	1	0	4
6	0	1	28	6	1	1	-	-	3	2	0	1	1	4	1	4
7	0	1	19	15	1	1	-	-	12	2	0	1	3	-	0	3
8	0	0	38	6	1	1	-	-	3	2	0	0	1	-	0	3
9	0	0	12	6	1	1	-	-	3	2	0	1	-	-	0	4
10	0	1	15	10	1	1	-	-	7	2	0	0	3	-	0	3
11	0	0	33	10	-	-	-	-	-	0	0	1	1	1	0	5
12	0	0	23	7	1	1	-	2	2	1	1	1	1	-	0	3
13	0	0	17	6	-	1	-	3	1	1	1	1	3	1	0	4
14	0	0	39	4	-	-	1	2	-	2	1	1	1	2	0	4
15	0	0	35	4	-	-	-	2	1	1	1	0	1	2	0	5
16	0	1	49	1	-	-	-	-	-	0	0	1	1	1	0	4
17	0	0	22	3	-	1	-	1	-	1	1	1	3	4	0	4
18	0	0	29	4	-	1	-	1	1	1	1	1	3	2	0	3
19	0	0	60	2	-	-	-	1	-	1	1	1	1	4	0	3
20	0	1	38	3	-	-	-	2	-	1	1	1	1	1	0	4
21	0	0	71	4	-	-	1	2	-	2	1	0	1	1	0	5
22	0	0	37	3	1	-	-	1	-	1	1	0	1	1	0	4
23	0	0	64	4	-	-	1	2	1	2	1	0	1	4	0	4
24	0	0	37	5	1	1	-	-	2	2	0	1	1	2	0	3
25	0	0	72	8	1	1	1	2	2	2	1	1	0	1	0	3
26	0	0	33	7	-	-	1	3	2	2	1	0	1	1	0	4
27	0	1	40	7	-	-	1	3	2	2	1	1	1	1	0	3
28	0	0	67	4	-	1	-	2	-	1	1	1	-	-	0	4
29	0	0	32	6	1	1	-	1	2	1	1	1	1	1	0	4
30	0	1	28	7	1	1	-	3	1	1	1	1	1	-	0	4
31	0	0	50	4	-	-	-	-	-	0	0	1	1	1	0	4
32	0	0	20	7	1	1	-	-	4	2	0	0	2	-	0	4
33	0	1	16	5	1	1	-	2	-	1	1	1	3	-	0	3
34	0	1	63	5	1	-	-	1	2	1	1	1	1	1	0	4
35	0	1	33	5	-	-	-	-	-	0	0	0	2	2	0	3
36	0	1	72	8	1	1	-	-	5	2	0	1	3	1	0	3
37	0	0	35	5	1	1	-	2	-	1	1	1	0	1	0	-
38	0	1	42	5	1	1	-	2	-	1	1	1	2	2	0	3
39	0	0	40	3	1	1	-	-	-	2	0	0	1	2	0	3
40	0	1	35	5	-	-	1	3	-	2	1	1	1	1	0	3

Table 34 Chapter 4 and 5 energy services survey data (2/14)

Variable id																				
No	10.a	10.b	10.c	10.d	10.e	10.f	11	12	13	14	15.a	15.b	15.c	15.d	15.e	15.f	15.g	15.h	15.i	15.j
1	4	1	3	4	1	1	1	1	3	1	200	1	103	2	-	-	250	2	-	-
2	4	4	4	4	4	3	1	4	3	3	80	1	-	-	-	-	500	3	-	-
3	3	1	1	1	3	3	1	2	3	2	200	1	220	2	-	-	-	-	-	-
4	4	3	3	1	1	1	4	1	2	1	150	1	60	2	-	-	100	3	-	-
5	4	4	4	3	3	3	1	1	2	2	35	1	210	2	-	-	-	1	-	-
6	4	1	3	2	3	1	1	4	6	3	90	1	210	2	-	-	200	2	-	-
7	3	1	1	1	1	1	1	6	2	2	120	1	-	-	-	-	-	1	-	-
8	4	1	4	4	4	4	1	2	3	2	140	1	120	2	-	-	1000	3	-	-
9	3	-	-	1	4	4	1	2	3	2	80	-	-	-	-	-	-	3	-	-
10	3	3	2	3	3	4	1	4	3	3	125	1	-	-	-	-	-	1	-	-
11	4	3	4	4	4	3	1	6	4	2	300	1	200	2	-	-	150	3	400	1
12	1	1	1	1	1	1	1	2	1	1	-	0	-	0	-	0	300	3	-	-
13	2	3	1	2	2	2	7	6	4	2	50	1	-	0	-	0	-	3	-	-
14	4	1	1	3	3	1	3	0	3	2	200	1	105	2	9	1	-	-	-	-
15	4	3	1	4	3	3	3	6	4	2	100	1	108	2	-	-	250	3	-	-
16	4	3	3	3	3	1	1	5	2	1	105	1	17	2	-	-	50	2	-	-
17	2	5	4	3	2	2	1	4	5	4	200	1	-	-	-	-	-	1	-	-
18	4	3	3	3	1	1	1	4	5	3	130	1	-	2	120	1	240	2	-	-
19	4	3	3	3	4	4	1	6	3	3	135	1	220	2	150	1	150	2	-	-
20	1	1	3	3	4	3	1	3	3	2	50	1	105	2	-	-	110	2	-	-
21	3	4	3	3	1	1	1	6	4	3	300	1	200	2	-	-	200	2	-	-
22	4	4	4	4	4	1	3	6	2	1	140	1	-	0	-	-	-	1	-	-
23	5	3	3	3	3	2	3	5	3	2	130	1	68	2	-	-	125	2	-	-
24	5	3	3	3	3	2	3	5	3	2	130	1	68	2	-	-	125	2	-	-
25	1	4	3	3	2	2	1	6	4	2	125	1	300	2	-	-	30	3	-	-
26	1	4	3	3	2	2	1	6	4	2	125	1	300	2	-	-	30	3	-	-
27	1	4	3	3	2	2	1	6	4	2	125	1	300	2	-	-	30	3	-	-
28	4	4	4	4	4	4	1	6	5	2	350	1	820	2	120	1	-	0	-	-
29	1	3	1	1	4	1	1	-1	2	2	80	1	-	-	150	1	500	2	-	-
30	3	1	4	3	4	3	1	0	2	2	100	-	-	-	-	-	500	3	-	-
31	3	3	4	1	3	1	1	2	1	1	150	1	200	-	-	-	-	1	-	-
32	4	3	4	1	4	4	1	4	3	3	150	1	73	2	-	-	200	3	-	-
33	2	2	2	2	2	2	1	6	4	2	250	1	210	2	-	-	-	1	-	-
34	1	3	4	4	3	1	1	5	5	2	80	1	500	2	-	-	-	-	-	-
35	4	5	5	4	3	4	1	1	4	4	150	1	210	2	-	-	-	-	-	-
36	3	3	3	3	3	3	1	4	3	3	140	1	203	2	-	-	500	3	-	-
37	5	4	4	1	4	5	1	2	2	2	150	-	-	-	-	-	500	3	-	-
38	3	1	4	3	3	1	1	3	2	1	75	1	110	2	150	1	250	2	-	-
39	4	1	4	1	4	1	1	3	2	1	120	1	-	-	150	1	300	3	-	-
40	2	3	3	2	3	2	3	6	3	2	125	-	100	-	-	-	125	2	-	-

Table 35 Chapter 4 and 5 energy services survey data (3/14)

Variable id																	
No	16.a	16.b	16.c	16.d	16.e	16.f	17	18	19	20.1.a	20.1.b	20.2.a	20.2.b	20.3.a	20.3.b	20.4.a	20.4.b
1	3	4	0	0	0	0	2	4	0	-	-	-	-	-	-	-	-
2	6	0	0	0	0	0	2	3	0	-	-	-	-	-	-	-	-
3	9	0	0	0	0	0	3	1	1	-	-	-	-	-	-	-	-
4	0	5	0	0	0	0	3	4	1	-	-	-	-	-	-	-	-
5	0	5	0	0	0	0	3	4	1	-	-	-	-	-	-	-	-
6	0	10	0	0	0	0	4	3	1	-	-	-	-	-	-	-	-
7	5	0	0	0	0	0	2	3	1	-	-	-	-	-	-	-	-
8	7	0	0	0	0	0	2	1	1	-	-	-	-	-	-	-	-
9	7	0	0	0	0	0	2	1	1	-	-	-	-	-	-	-	-
10	5	0	0	0	0	0	2	3	1	-	-	-	-	-	-	-	-
11	8	0	0	0	0	0	2	3	0	-	-	-	-	-	-	-	-
12	0	0	0	1	0	0	2	0	1	-	-	-	-	-	-	-	-
13	0	5	0	0	0	0	2	3	1	-	-	-	-	-	-	-	-
14	0	10	0	0	0	0	5	5	1	-	-	-	-	-	-	-	-
15	6	0	0	0	0	0	2	3	1	-	-	-	-	-	-	-	-
16	4	0	0	0	0	0	2	3	1	-	-	-	-	-	-	-	-
17	7	0	0	0	0	0	3	4	3	-	-	-	-	-	-	-	-
18	0	6	0	0	0	0	3	4	1	-	-	-	-	-	-	-	-
19	3	3	0	0	0	0	2	3	7	-	-	-	-	-	-	-	-
20	4	0	0	0	0	0	3	4	1	-	-	-	-	-	-	-	-
21	5	0	0	0	0	0	2	2	1	-	-	-	-	-	-	-	-
22	4	0	0	0	0	0	2	3	0	-	-	-	-	-	-	-	-
23	4	0	0	0	0	0	2	3	1	-	-	-	-	-	-	-	-
24	4	0	0	0	0	0	2	3	1	-	-	-	-	-	-	-	-
25	2	0	0	0	2	0	3	3	1	-	-	-	-	-	-	-	-
26	2	0	0	0	2	0	3	3	1	-	-	-	-	-	-	-	-
27	4	0	0	0	0	0	3	3	1	-	-	-	-	-	-	-	-
28	8	0	0	0	0	0	3	4	1	-	-	-	-	-	-	-	-
29	3	0	0	0	0	0	2	3	1	-	-	-	-	-	-	-	-
30	5	0	0	0	0	0	2	1	1	-	-	-	-	-	-	-	-
31	3	0	0	0	0	0	2	1	0	-	-	-	-	-	-	-	-
32	2	4	0	0	0	0	2	3	5	-	-	-	-	-	-	-	-
33	8	0	0	0	0	0	2	3	1	-	-	-	-	-	-	-	-
34	0	10	0	0	0	0	3	4	3	-	-	-	-	-	-	-	-
35	0	0	0	0	7	0	3	4	1	-	-	-	-	-	-	-	-
36	0	6	0	0	0	0	5	3	3	-	-	-	-	-	-	-	-
37	0	3	0	0	0	0	5	1	0	-	-	-	-	-	-	-	-
38	3	3	0	0	0	0	3	3	5	-	-	-	-	-	-	-	-
39	0	2	0	0	0	0	1	1	1	-	-	-	-	-	-	-	-
40	4	0	0	0	0	0	2	3	1	-	-	-	-	-	-	-	-

Table 36 Chapter 4 and 5 energy services survey data (4/14)

Variable id No	20.5.a	20.5.b	20.6.a	20.6.b	20.7.a	20.7.b	20.8.a	20.8.b	20.9.a	20.9.b	20.10.a	20.10.b	20.11.a	20.11.b
1	-	-	-	-	-	-	1	20	-	-	-	-	-	-
2	-	-	-	-	-	-	1	4	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	1	3	-	-	-	-	-	-
5	-	-	-	-	-	-	1	8	-	-	-	-	-	-
6	-	-	-	-	-	-	1	3	-	-	-	-	-	-
7	-	-	-	-	-	-	2	3	-	-	-	-	-	-
8	-	-	-	-	-	-	1	2	-	-	-	-	-	-
9	-	-	-	-	-	-	1	3	-	-	-	-	-	-
10	-	-	-	-	-	-	1	3	-	-	-	-	-	-
11	-	-	-	-	-	-	1	5	-	-	-	-	-	-
12	1	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	1	4	-	-	-	-	-	-
14	-	-	-	-	-	-	1	1	1	1	-	-	-	-
15	-	-	-	-	-	-	1	3	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	1	3.5	-	-	-	-	-	-
18	-	-	-	-	-	-	1	0.3	1	3	-	-	-	-
19	-	-	-	-	-	-	1	10	-	-	-	-	1	5
20	-	-	-	-	-	-	1	3	-	-	-	-	-	-
21	-	-	-	-	-	-	1	10	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	1	3	1	2	-	-	-	-
24	-	-	-	-	-	-	1	3	1	2	-	-	-	-
25	1	-	-	-	-	-	1	25	-	-	-	-	-	-
26	1	-	-	-	-	-	1	25	-	-	-	-	-	-
27	1	-	-	-	-	-	1	25	-	-	-	-	-	-
28	-	-	-	-	-	-	1	1	1	2	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	-	-	-	-	-	-	1	5	-	-	-	-	-	-
33	-	-	-	-	-	-	1	2	1	4	-	-	-	-
34	-	-	-	-	-	-	1	3	-	-	-	-	-	-
35	-	-	-	-	-	-	1	2	-	-	-	-	-	-
36	-	-	-	-	-	-	1	1	-	-	-	-	-	-
37	-	-	-	-	-	-	-	-	-	-	-	-	-	-
38	-	-	-	-	-	-	1	1	-	-	-	-	-	-
39	-	-	-	-	-	-	1	-	-	-	-	-	-	-
40	1	-	-	-	-	-	1	3	1	1	-	-	-	-

Table 37 Chapter 4 and 5 energy services survey data (5/14)

Variable id															
No	**20.12.a**	**20.12.b**	**20.13.a**	**20.13.b**	**20.14.a**	**20.14.b**	**20.15.a**	**20.15.b**	**20.16.a**	**20.16.b**	**20.17.a**	**20.17.b**	**20.18.a**	**20.18.b**	**20.19.a**
1	1	11	1	10	-	-	-	-	1	11	-	-	1	10	-
2	1	4	-	-	-	-	1	3	-	-	-	-	-	-	-
3	-	-	-	-	-	-	1	3	1	6	-	-	1	6	-
4	1	2	-	-	-	-	-	-	1	4	-	-	-	-	-
5	1	6	1	3	-	-	1	3	1	5	-	-	1	8	-
6	1	5	1	3	-	-	1	8	1	5	-	-	1	10	-
7	1	3	-	-	-	-	1	8	1	4	-	-	-	-	-
8	-	-	-	-	-	-	1	2	-	-	-	-	1	4	-
9	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-
10	1	3	-	-	-	-	1	3	-	-	-	-	-	-	-
11	1	8	-	-	-	-	1	8	-	-	-	-	1	3	-
12	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
13	1	3	-	-	-	-	1	3	-	-	-	-	-	-	-
14	1	1	1	4	1	2	-	-	-	-	-	-	1	1	-
15	1	-	1	2	-	-	1	60	-	-	-	-	1	20	-
16	1	4	-	-	-	-	1	4	-	-	-	-	1	12	-
17	1	4	1	7	-	-	1	2	1	8	-	-	1	7	-
18	1	10	1	8	-	-	1	8	1	8	-	-	1	20	-
19	1	0.5	-	-	-	-	1	5	-	-	-	-	1	5	-
20	1	2	-	-	-	-	1	10	-	-	-	-	1	10	-
21	1	20	1	3	-	-	-	-	1	20	-	-	1	20	-
22	1	2	1	6	-	-	-	-	-	-	-	-	-	-	-
23	1	2	1	4	-	-	1	3	1	15	-	-	1	3	-
24	1	2	1	4	-	-	1	3	1	15	-	-	1	3	-
25	1	20	-	-	-	-	-	-	1	20	-	-	1	25	-
26	1	20	-	-	-	-	-	-	1	20	-	-	1	25	-
27	1	20	-	-	-	-	-	-	1	20	-	-	1	25	-
28	1	2	1	-	-	-	1	-	1	8	-	-	1	10	-
29	-	-	-	-	-	-	1	6	-	-	-	-	-	-	-
30	-	-	-	-	-	-	1	3	-	-	-	-	-	-	-
31	-	-	-	-	-	-	1	12	-	-	-	-	1	6	-
32	1	5	-	-	-	-	1	3	1	6	-	-	1	5	-
33	1	1	-	-	-	-	1	4	1	4	-	-	1	5	-
34	1	2	1	15	-	-	1	30	1	2	-	-	1	2	-
35	1	2	-	-	-	-	-	-	1	2	-	-	1	2	-
36	1	2	-	-	-	-	-	-	1	6	-	-	1	20	-
37	1	10	-	-	-	-	1	6	-	-	-	-	-	-	-
38	1	-	1	1	-	-	1	5	-	-	-	-	1	10	-
39	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40	1	5	1	3	-	-	1	13	1	10	-	-	1	10	-

Table 38 Chapter 4 and 5 energy services survey data (6/14)

Variable id														
No	20.19.b	20.20.a	20.20.b	20.21.a	20.21.b	20.22.a	20.22.b	20.23.a	20.23.b	20.24.a	20.24.b	20.25.a	20.25.b	20.26.a
1	-	-	-	2	12	-	-	-	-	-	-	-	-	-
2	-	-	-	1	15	-	-	-	-	-	-	-	-	-
3	-	-	-	1	3	-	-	-	-	1	3	1	10	-
4	-	-	-	1	4	-	-	-	-	-	-	-	-	-
5	-	-	-	1	8	-	-	-	-	-	-	-	-	-
6	-	-	-	2	15	-	-	-	-	-	-	-	-	-
7	-	-	-	1	10	-	-	-	-	-	-	-	-	-
8	-	-	-	1	5	-	-	-	-	-	-	-	-	-
9	-	-	-	1	-	-	-	-	-	-	-	-	-	-
10	-	-	-	1	3	-	-	-	-	-	-	1	2	-
11	-	-	-	1	5	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	1	2	-	-	-	-	-	-	-	-	-
14	-	-	-	2	3	-	-	-	-	-	-	-	-	-
15	-	-	-	1	6	-	-	1	5	-	-	-	-	-
16	-	-	-	1	4	-	-	-	-	-	-	-	-	-
17	-	-	-	4	5	-	-	1	10	1	8	1	6	-
18	-	-	-	2	5	-	-	-	-	1	12	-	-	-
19	-	-	-	1	10	-	-	-	-	-	-	-	-	-
20	-	-	-	1	10	-	-	-	-	-	-	-	-	-
21	-	-	-	1	30	-	-	1	20	-	-	-	-	-
22	-	-	-	1	8	-	-	-	-	-	-	-	-	-
23	-	-	-	1	10	-	-	1	3	-	-	-	-	-
24	-	-	-	1	10	-	-	1	3	-	-	-	-	-
25	-	-	-	1	40	-	-	1	20	-	-	-	-	-
26	-	-	-	1	40	-	-	1	20	-	-	-	-	-
27	-	-	-	1	40	-	-	1	20	-	-	-	-	-
28	-	-	-	1	-	-	-	1	25	-	-	1	4	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	1	3	-	-	-	-	1	3	-	-	-
31	-	-	-	1	20	-	-	-	-	-	-	-	-	-
32	-	-	-	1	16	-	-	-	-	-	-	-	-	-
33	-	-	-	1	3	-	-	1	1	-	-	-	-	-
34	-	-	-	1	3	-	-	1	4	1	6	1	20	-
35	-	-	-	1	2	-	-	1	4	-	-	-	-	-
36	-	-	-	1	3	-	-	1	5	1	4	1	8	-
37	-	-	-	1	4	-	-	-	-	-	-	-	-	-
38	-	-	-	1	5	-	-	1	10	-	-	-	-	-
39	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40	-	-	-	1	10	-	-	1	10	-	-	-	-	-

Table 39 Chapter 4 and 5 energy services survey data (7/14)

Variable id No	20.26.b	20.27.a	20.27.b	20.28.a	20.28.b	20.29.a	20.29.b	20.30.a	20.30.b	20.31.a	20.31.b	20.32.a	20.32.b
1	-	-	-	-	-	1	0.3	-	-	-	-	-	-
2	-	-	-	-	-	1	7	-	-	-	-	-	-
3	-	-	-	-	-	1	3	1	3	-	-	-	-
4	-	1	2	-	-	1	4	-	-	-	-	1	5
5	-	-	-	-	-	1	4	-	-	-	-	-	-
6	-	1	3	1	3	1	4	-	-	-	-	-	-
7	-	-	-	-	-	1	3	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	1	3	-	-	-	-	-	-
11	-	1	1	-	-	1	8	-	-	-	-	1	10
12	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	1	3	2	-	1	3	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	4	-	2	2	-	-	-	-	-	-
18	-	-	-	-	-	1	4	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-	1	0.3	-	-	1	5	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	1	5	-	-	-	-	-	-
24	-	-	-	-	-	1	5	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	1	15
32	-	-	-	-	-	-	-	-	-	-	-	-	-
33	-	-	-	-	-	1	4	-	-	-	-	-	-
34	-	-	-	-	-	-	-	-	-	-	-	1	12
35	-	-	-	-	-	1	2	-	-	-	-	-	-
36	-	-	-	-	-	-	-	-	-	-	-	-	-
37	-	-	-	-	-	-	-	-	-	-	-	-	-
38	-	-	-	-	-	-	-	-	-	-	-	-	-
39	-	-	-	-	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 40 Chapter 4 and 5 energy services survey data (8/14)

Variable id																
No	**0**	**1**	**2**	**3**	**4.a**	**4.b**	**4.c**	**4.d**	**4.e**	**fam**	**mat**	**5**	**6**	**7**	**8**	**9**
41	1	0	20	3	1	1	-	-	-	2	0	0	4	-	1	3
42	1	1	21	3	-	-	-	-	-	0	0	0	4	-	1	5
43	1	1	20	5	1	1	-	-	2	2	0	0	2	-	1	4
44	1	0	25	5	1	1	-	-	2	2	0	1	3	8	1	4
45	1	0	32	5	-	-	1	3	-	2	1	0	3	8	1	4
46	1	0	30	5	1	1	1	1	-	2	1	0	4	12	1	4
47	1	0	36	5	-	-	1	3	-	2	1	1	2	-	1	4
48	1	0	33	6	1	1	-	-	3	2	0	1	3	-	1	5
49	1	0	30	3	-	-	1	1	-	2	1	1	3	-	1	5
50	1	1	30	2	-	1	-	-	-	3	0	1	3	-	1	5
51	1	0	28	5	1	1	-	-	2	2	0	1	4	-	1	4
52	1	0	29	7	1	1	1	2	1	2	1	1	3	-	1	5
53	1	1	72	5	-	-	1	1	2	2	1	0	2	-	1	4
54	1	1	65	4	-	1	-	2	-	1	1	1	3	-	1	4
55	1	1	37	5	-	-	-	-	4	0	0	1	4	8	1	4
56	1	1	53	5	-	-	1	3	-	2	1	1	3	-	1	-
57	1	1	22	5	1	1	-	-	2	2	0	1	3	-	1	4
58	1	1	28	5	1	1	-	-	2	2	0	1	4	-	0	4
59	1	1	45	4	-	-	1	2	-	2	1	1	3	-	1	4
60	1	1	49	5	-	1	1	2	-	2	1	1	3	8	1	5
61	1	-	-	4	-	-	-	-	3	0	0	0	2	-	1	4
62	1	0	20	4	1	1	-	-	1	2	0	0	4	-	1	5
63	1	0	45	5	-	-	1	3	-	2	1	0	2	4	1	4
64	1	0	60	2	-	1	-	-	-	3	0	0	3	-	1	4
65	1	1	56	6	-	1	1	3	-	2	1	1	3	-	1	5
66	1	1	37	2	1	-	-	-	-	3	0	1	2	6	1	3
67	1	1	26	6	1	1	-	-	3	2	0	0	3	-	1	4
68	1	0	18	4	1	1	-	-	1	2	0	0	2	2	1	3
69	1	1	33	4	1	1	-	-	1	2	0	1	2	4	1	3
70	1	1	17	4	1	1	-	-	1	2	0	0	4	-	1	2
71	1	1	19	4	1	1	-	-	1	2	0	-	2	-	1	5
72	1	0	19	4	1	1	-	-	1	2	0	0	4	12	1	5
73	1	1	41	3	-	-	1	1	-	2	1	1	3	4	1	5
74	1	1	31	6	-	1	-	-	4	3	0	1	3	4	-	5
75	1	0	35	2	-	-	-	1	-	1	1	1	2	4	1	5
76	1	0	66	2	-	-	1	-	-	3	0	0	2	4	1	5
77	1	0	47	5	-	-	1	3	-	2	1	1	3	8	1	3
78	1	0	77	5	-	-	-	1	3	2	1	0	3	-	1	3
79	1	1	24	4	1	1	-	-	1	2	0	0	4	-	1	5
80	1	1	41	4	-	-	-	-	3	0	0	1	2	4	1	4
81	1	1	29	4	-	1	-	-	2	3	0	1	5	12	1	4
82	1	0	24	5	1	1	-	-	2	2	0	0	5	-	1	1
83	1	0	30	4	1	1	-	-	1	2	0	0	2	-	1	3
84	1	0	29	4	1	1	1	-	-	2	0	1	4	-	1	5
85	1	1	24	4	1	1	-	-	1	2	0	1	2	-	1	4
86	1	0	57	3	-	1	1	-	-	2	0	0	3	-	1	4
87	1	1	39	4	-	-	1	2	-	2	1	1	2	-	1	5
88	1	1	43	4	-	-	1	2	-	2	1	1	3	-	1	5
89	1	0	25	5	1	1	-	-	2	2	0	1	2	6	1	3
90	1	1	27	2	-	-	-	1	-	1	1	1	3	-	1	5
91	1	0	51	4	-	1	1	1	-	2	1	1	4	8	1	3
92	1	0	53	5	-	-	1	3	-	2	1	0	4	-	1	5
93	1	0	40	4	-	-	-	-	3	0	0	1	3	4	1	4
94	1	0	43	2	-	-	-	1	-	1	1	1	0	2	1	5
95	1	1	58	3	-	-	1	1	-	2	1	0	2	-	1	5
96	1	0	36	4	-	-	1	2	-	2	1	1	3	-	1	3
97	1	1	25	5	1	1	-	-	2	2	0	0	2	4	1	4
98	1	1	29	6	-	1	-	-	4	3	0	1	2	-	1	3

Table 41 Chapter 4 and 5 energy services survey data (9/14)

Variable id																				
No	**10.a**	**10.b**	**10.c**	**10.d**	**10.e**	**10.f**	**11**	**12**	**13**	**14**	**15.a**	**15.b**	**15.c**	**15.d**	**15.e**	**15.f**	**15.g**	**15.h**	**15.i**	**15.j**
41	5	5	5	5	5	3	1	3	10	7	300	1	2000	2	-	-	-	-	-	-
42	5	5	5	5	5	5	3	2	4	4	3000	1	1000	2	-	-	-	-	-	-
43	2	2	3	3	3	3	1	4	10	6	200	1	500	2	-	-	-	-	-	-
44	4	3	4	3	4	4	1	2	9	5	1500	1	500	2	-	-	-	-	-	-
45	4	3	4	3	4	4	1	2	8	3	1500	1	700	2	-	-	-	-	-	-
46	5	4	5	4	4	4	-	0	7	5	1500	1	450	2	-	-	-	-	-	-
47	5	3	4	4	4	4	4	4	8	4	1500	1	2000	2	-	-	-	-	-	-
48	4	4	4	4	4	4	1	3	7	4	1000	1	1250	2	-	-	-	-	500	1
49	4	4	4	4	4	4	2	2	9	3	2000	1	2000	2	-	-	-	-	700	1
50	5	3	4	5	4	5	1	6	4	5	750	1	500	1	-	-	-	-	-	-
51	5	5	5	5	5	5	2	2	3	3	2000	1	1000	2	-	-	-	-	3000	1
52	4	2	4	5	5	5	1	0	8	4	200	1	600	2	-	-	-	-	1600	1
53	5	4	5	5	5	5	2	2	8	4	2000	1	1500	1	-	-	-	-	1000	1
54	4	4	4	4	4	4	1	3	20	6	5000	3	4000	2	-	-	-	-	2400	1
55	5	4	4	4	4	4	4	4	5	2	600	1	500	1	-	-	-	-	2000	-
56	4	3	4	4	4	4	5	1	4	2	1000	1	500	1	-	-	-	-	1000	1
57	3	3	4	5	5	5	3	4	6	4	200	1	500	2	-	-	-	-	1500	1
58	4	4	4	4	4	4	1	3	8	5	1200	1	700	2	-	-	-	-	6000	1
59	5	5	5	5	5	5	1	1	8	3	70	1	3000	2	-	-	-	-	2000	1
60	5	5	5	5	5	5	5	-1	5	4	2500	1	700	1	-	-	-	-	2000	1
61	5	5	5	5	5	5	5	4	2	2	2000	1	3500	1	-	-	-	-	-	-
62	5	5	5	5	5	5	5	4	2	2	2000	1	3500	1	-	-	-	-	-	-
63	5	5	5	5	5	5	1	2	8	4	-	1	700	1	-	-	-	-	300	1
64	5	5	5	5	5	5	1	4	12	7	400	1	700	2	-	-	-	-	1500	1
65	5	5	5	5	5	5	5	0	7	6	1300	1	1500	2	-	-	-	-	6000	-
66	5	3	5	5	5	4	5	1	3	2	650	1	450	2	-	-	-	-	-	-
67	4	4	5	4	3	3	4	3	6	6	275	1	4000	2	80	-	-	-	-	-
68	4	2	4	4	4	4	2	5	5	3	140	1	400	2	-	-	-	-	1200	1
69	4	1	4	3	4	1	1	3	9	4	300	1	400	2	-	-	-	-	700	1
70	2	2	2	2	2	2	5	2	8	4	2000	2	800	1	-	-	-	-	-	-
71	5	5	5	5	5	5	3	-	4	3	-	1	-	2	-	-	-	-	-	-
72	5	5	5	5	5	5	1	2	10	3	-	1	600	1	-	-	-	-	400	1
73	5	5	5	5	4	4	1	-1	6	3	500	1	900	2	-	-	-	-	800	1
74	4	3	4	4	4	4	3	0	16	8	-	1	-	2	-	-	-	-	-	-
75	4	3	4	3	4	5	5	1	3	2	200	1	150	1	-	-	-	-	800	-
76	5	5	5	5	5	5	5	1	4	2	450	1	350	1	-	-	-	-	1200	1
77	5	5	5	5	5	5	4	4	4	3	2000	1	2000	2	-	-	-	-	-	-
78	3	2	1	1	1	2	4	2	5	4	500	1	1500	1	-	-	-	-	800	1
79	4	3	4	5	5	5	1	4	3	3	500	1	1000	1	-	-	-	-	3000	1
80	5	4	5	5	5	5	1	4	12	6	875	1	350	2	-	-	-	-	-	1
81	5	4	5	5	5	5	5	3	7	3	-	1	-	2	-	-	-	-	-	1
82	5	5	5	5	5	5	1	3	13	4	2000	1	800	1	-	-	-	-	6000	1
83	3	2	3	2	2	2	3	3	7	3	-	1	-	1	-	-	-	-	-	1
84	4	3	4	4	5	4	1	3	4	3	500	2	200	1	-	-	-	-	-	-
85	5	4	5	5	5	5	1	3	6	4	-	1	-	2	-	-	-	-	2250	1
86	4	4	5	5	5	5	5	1	6	3	300	1	800	2	-	-	-	-	500	1
87	4	4	4	4	4	4	1	4	4	3	1500	1	800	2	-	-	-	-	-	1
88	5	4	5	5	5	4	1	3	7	4	500	1	300	2	-	-	-	-	1200	1
89	5	4	5	5	2	4	1	-1	7	4	-	1	-	2	-	0	-	-	-	-
90	5	5	5	5	5	5	5	0	2	2	700	1	300	1	-	-	-	-	3000	1
91	4	3	5	5	4	5	1	4	6	4	500	1	800	2	-	-	-	-	-	-
92	5	5	5	5	5	5	1	3	14	4	1200	1	1500	2	-	-	-	-	-	-
93	5	3	5	5	5	5	1	2	5	3	3000	-	900	-	-	-	-	-	1200	-
94	4	4	5	5	5	5	1	3	8	4	800	1	500	2	-	-	-	-	-	-
95	5	5	5	5	5	5	1	2	10	4	-	1	-	1	-	-	-	-	-	-
96	2	2	5	5	5	5	5	2	5	3	-	-	-	-	-	-	-	-	-	-
97	5	3	5	5	5	5	1	4	13	4	1200	1	500	2	-	-	-	-	-	-
98	5	5	5	5	5	5	2	-1	8	6	800	2	500	1	-	-	-	-	-	1

Table 42 Chapter 4 and 5 energy services survey data (10/14)

Variable id																	
No	**16.a**	**16.b**	**16.c**	**16.d**	**16.e**	**16.f**	**17**	**18**	**19**	**20.1.a**	**20.1.b**	**20.2.a**	**20.2.b**	**20.3.a**	**20.3.b**	**20.4.a**	**20.4.b**
41	0	35	0	0	0	0	3	4	3	-	-	-	-	-	-	-	-
42	-	-	-	-	-	-	3	4	4	1	2	1	5	1	5	-	-
43	12	0	0	0	0	0	3	4	1	-	-	-	-	-	-	-	-
44	10	4	0	0	0	0	3	4	3	-	-	1	4	-	-	-	-
45	12	0	0	0	0	0	3	4	3	-	-	1	1	1	4	-	-
46	0	16	0	0	0	0	3	4	3	-	-	1	4	5	3	-	-
47	29	0	0	0	0	0	3	4	3	-	-	-	-	1	10	-	-
48	2	35	2	0	0	0	3	4	3	-	-	1	10	-	-	1	13
49	22	2	15	0	0	0	3	4	8	-	-	1	7	-	-	-	-
50	16	2	0	0	0	0	3	4	3	-	-	1	2	3	5	-	-
51	0	12	0	0	0	0	3	4	3	-	-	1	3	3	10	-	-
52	0	20	0	0	0	0	3	4	3	-	-	1	-	2	-	-	-
53	10	15	0	0	0	0	3	4	3	-	-	1	1	1	2	-	-
54	150	0	0	0	0	0	3	5	8	-	-	1	-	10	-	-	-
55	7	2	0	0	0	0	3	4	3	-	-	1	-	1	-	-	-
56	6	0	0	0	0	0	3	4	1	-	-	-	-	-	-	-	-
57	10	10	0	0	0	0	3	4	3	-	-	1	10	-	-	1	20
58	70	0	0	0	0	0	3	4	3	1	-	1	-	-	-	1	-
59	60	0	0	0	0	0	3	4	3	-	-	-	-	1	3	-	-
60	25	0	0	0	0	0	3	4	4	1	3	-	-	1	4	-	-
61	26	0	0	0	0	0	3	4	4	-	-	1	5	1	30	-	-
62	10	18	0	0	0	0	3	4	4	-	-	1	5	-	-	-	-
63	50	0	0	0	0	0	3	4	7	-	-	1	5	-	-	-	-
64	-	-	-	-	-	-	3	4	3	-	-	-	-	2	1	-	-
65	0	68	0	0	0	0	3	4	8	-	-	1	0.1	-	-	-	-
66	-	-	-	-	-	-	3	4	8	-	-	1	5	-	-	-	-
67	-	-	-	-	-	-	3	4	3	-	-	-	-	1	15	-	-
68	12	0	0	0	0	0	3	4	3	-	-	1	-	1	-	-	-
69	28	0	0	0	0	0	3	4	2	-	-	1	-	1	-	-	-
70	15	0	0	0	0	0	3	4	4	-	-	1	2	-	-	1	2
71	0	7	0	0	0	0	3	4	2	-	-	1	-	-	-	-	-
72	3	25	0	0	0	0	3	4	3	-	-	1	3	-	-	-	-
73	20	38	0	0	0	0	3	4	4	-	-	1	-	3	-	-	-
74	20	0	9	0	0	0	3	4	6	-	-	-	-	-	-	-	-
75	0	7	0	0	0	0	3	4	4	-	-	-	-	-	-	1	4
76	0	10	0	0	0	0	3	4	4	-	-	1	5	1	5	-	-
77	10	20	0	0	0	0	3	4	8	2	3	-	-	5	1	-	-
78	50	0	0	0	0	0	3	4	1	-	-	1	5	-	-	1	5
79	13	0	0	0	0	0	3	4	4	-	-	1	3	-	-	-	-
80	4	21	0	0	0	0	3	4	4	1	20	-	-	-	-	1	20
81	10	0	0	0	0	0	3	4	3	-	-	-	-	-	-	-	-
82	0	15	0	0	0	0	3	4	4	-	-	-	-	2	10	-	-
83	2	14	0	0	0	0	3	4	1	-	-	1	18	-	-	1	-
84	5	30	0	10	0	0	3	4	4	-	-	1	5	1	10	-	-
85	18	0	0	20	0	0	3	4	3	-	-	1	8	-	-	-	-
86	25	0	0	0	0	0	3	4	3	-	-	1	2	-	-	1	3
87	30	0	10	0	0	0	3	4	1	-	-	1	5	1	10	1	10
88	20	0	0	0	0	0	3	4	3	-	-	1	12	2	1	-	-
89	0	20	0	0	0	0	3	4	3	-	-	1	2	-	-	-	-
90	0	10	0	0	0	0	3	4	4	-	-	-	-	1	3	-	-
91	0	50	0	0	0	0	3	4	1	1	-	-	-	1	-	-	-
92	0	25	20	0	0	10	3	3	8	4	0.5	1	2	4	1	1	1
93	0	20	0	0	0	0	3	4	3	-	-	-	-	-	-	-	-
94	0	10	0	0	0	0	3	4	3	3	-	1	-	4	-	-	-
95	0	60	0	0	0	0	3	4	3	1	6	1	6	1	6	-	-
96	0	12	0	0	0	0	3	4	3	-	-	1	5	1	5	-	-
97	0	20	0	0	0	0	3	4	3	-	-	1	0.5	1	4	1	4
98	30	0	4	0	0	0	3	4	4	1	2	-	-	-	-	1	2

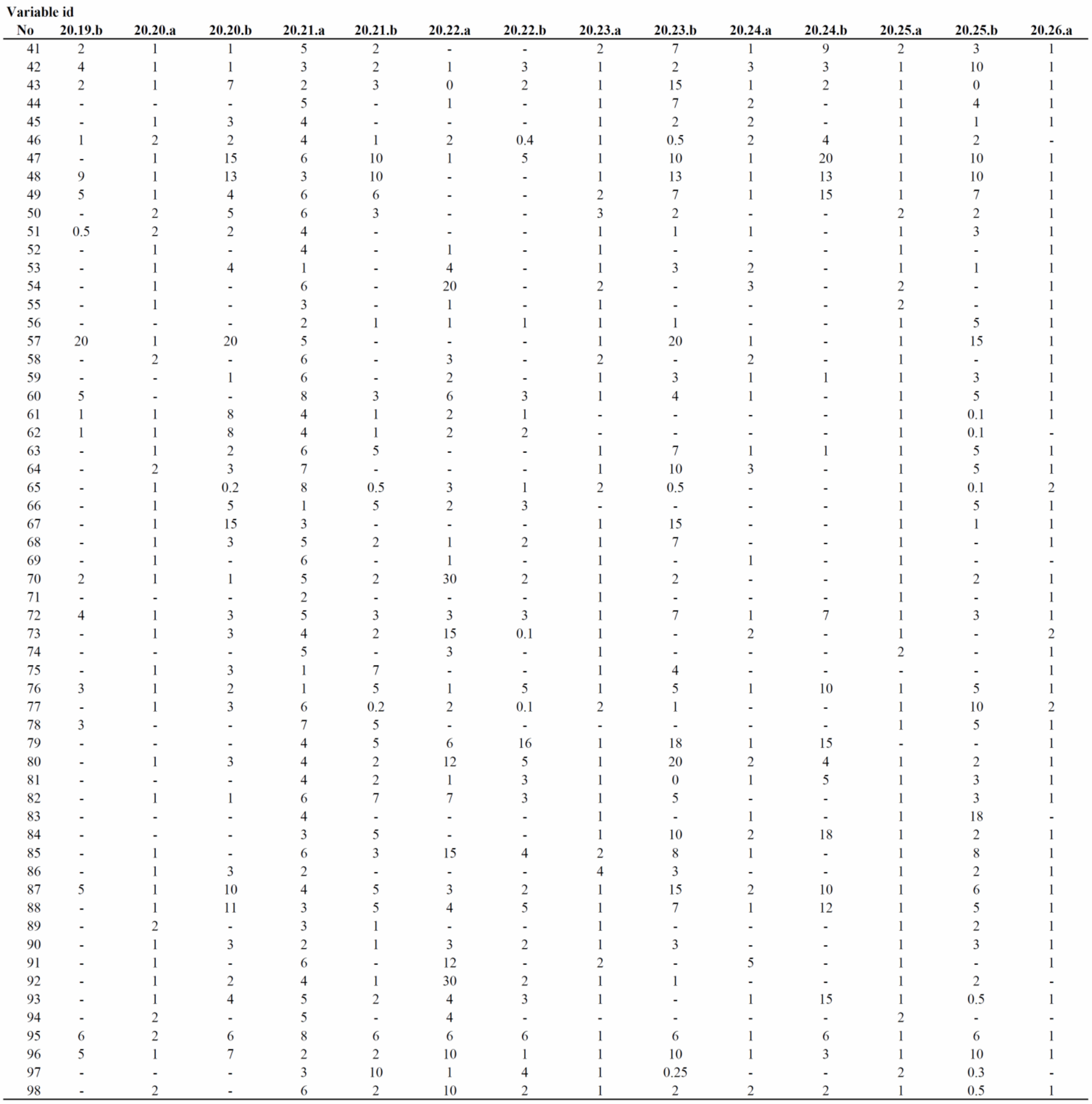
Table 43 Chapter 4 and 5 energy services survey data (11/14)

Variable id														
No	20.5.a	20.5.b	20.6.a	20.6.b	20.7.a	20.7.b	20.8.a	20.8.b	20.9.a	20.9.b	20.10.a	20.10.b	20.11.a	20.11.b
41	1	7	-	-	-	-	4	0.3	1	5	-	-	1	5
42	-	-	-	-	1	4	1	5	1	3	-	-	1	2
43	-	-	-	-	-	-	1	2	1	6	-	-	1	6
44	-	-	-	-	-	-	2	0.3	1	7	-	-	1	4
45	-	-	-	-	1	4	3	1	1	4	-	-	1	6
46	-	-	-	-	1	4	3	6	2	0.7	-	-	1	3
47	-	-	-	-	-	-	1	10	1	15	-	-	1	10
48	-	-	-	-	-	-	1	2	1	13	-	-	1	13
49	-	-	-	-	-	-	1	8	1	7	-	-	1	7
50	-	-	-	-	3	5	2	1	3	2	-	-	2	10
51	-	-	-	-	-	-	2	1	1	3	-	-	1	5
52	-	-	-	-	-	-	2	1	1	-	-	-	1	-
53	-	-	-	-	-	-	2	2	1	3	-	-	1	3
54	-	-	-	-	-	-	3	-	1	-	-	-	1	-
55	-	-	-	-	-	-	2	-	1	-	-	-	-	-
56	-	-	-	-	-	-	1	0.3	1	1	-	-	-	-
57	-	-	-	-	-	-	1	8	1	20	-	-	1	20
58	-	-	-	-	-	-	3	-	1	-	-	-	1	-
59	-	-	-	-	1	3	2	0.2	-	-	-	-	1	3
60	-	-	-	-	1	4	2	1	1	7	-	-	1	9
61	-	-	-	-	-	-	1	1	1	8	-	-	1	8
62	-	-	-	-	-	-	1	1	1	3	-	-	1	8
63	-	-	-	-	-	-	1	2	1	5	-	-	1	5
64	-	-	-	-	-	-	4	1	3	1	-	-	1	30
65	-	-	-	-	1	1	2	0.1	1	0.1	-	-	2	1
66	-	-	-	-	-	-	1	5	1	5	-	-	1	5
67	-	-	-	-	-	-	1	2	1	13	-	-	1	12
68	-	-	-	-	-	-	1	2	1	3	-	-	1	1
69	-	-	-	-	-	-	1	-	1	-	1	-	1	-
70	-	-	-	-	-	-	1	2	1	3	-	-	1	4
71	-	-	-	-	-	-	1	-	-	-	-	-	-	-
72	-	-	-	-	-	-	1	2	1	4	-	-	1	7
73	-	-	-	-	2	-	1	-	1	-	-	-	1	-
74	-	-	-	-	-	-	2	-	2	-	-	-	2	-
75	-	-	-	-	-	-	1	3	1	3	-	-	1	4
76	-	-	-	-	1	5	2	5	1	5	-	-	1	5
77	-	-	-	-	5	1	3	0.5	1	5	-	-	1	2
78	-	-	-	-	-	-	2	3	1	5	-	-	1	5
79	-	-	-	-	-	-	1	2	1	11	-	-	-	-
80	-	-	-	-	-	-	2	3	1	3	-	-	1	20
81	-	-	-	-	-	-	2	1	1	10	-	-	-	-
82	-	-	-	-	-	-	2	1	1	2	-	-	1	1
83	-	-	-	-	-	-	1	0.5	1	8	-	-	1	-
84	-	-	-	-	-	-	1	5	1	17	-	-	1	10
85	-	-	-	-	-	-	2	5	1	5	-	-	1	-
86	-	-	-	-	-	-	1	3	1	3	-	-	1	3
87	-	-	-	-	-	-	1	10	1	10	-	-	1	10
88	-	-	-	-	-	-	1	3	1	10	-	-	1	8
89	-	-	-	-	4	-	2	2	1	2	-	-	1	-
90	-	-	-	-	-	-	1	2	1	3	-	-	1	3
91	-	-	-	-	1	-	1	-	1	-	-	-	1	-
92	-	-	-	-	-	-	2	2	1	0.5	-	-	1	1
93	-	-	-	-	-	-	2	1	1	5	-	-	1	2
94	-	-	-	-	-	-	4	-	2	-	-	-	2	-
95	-	-	-	-	1	6	3	4	1	6	-	-	1	6
96	-	-	-	-	-	-	3	1	1	2	-	-	2	2
97	-	-	-	-	-	-	1	0.5	1	2	-	-	1	15
98	-	-	-	-	1	2	1	2	1	2	-	-	1	2

Table 44 Chapter 4 and 5 energy services survey data (12/14)

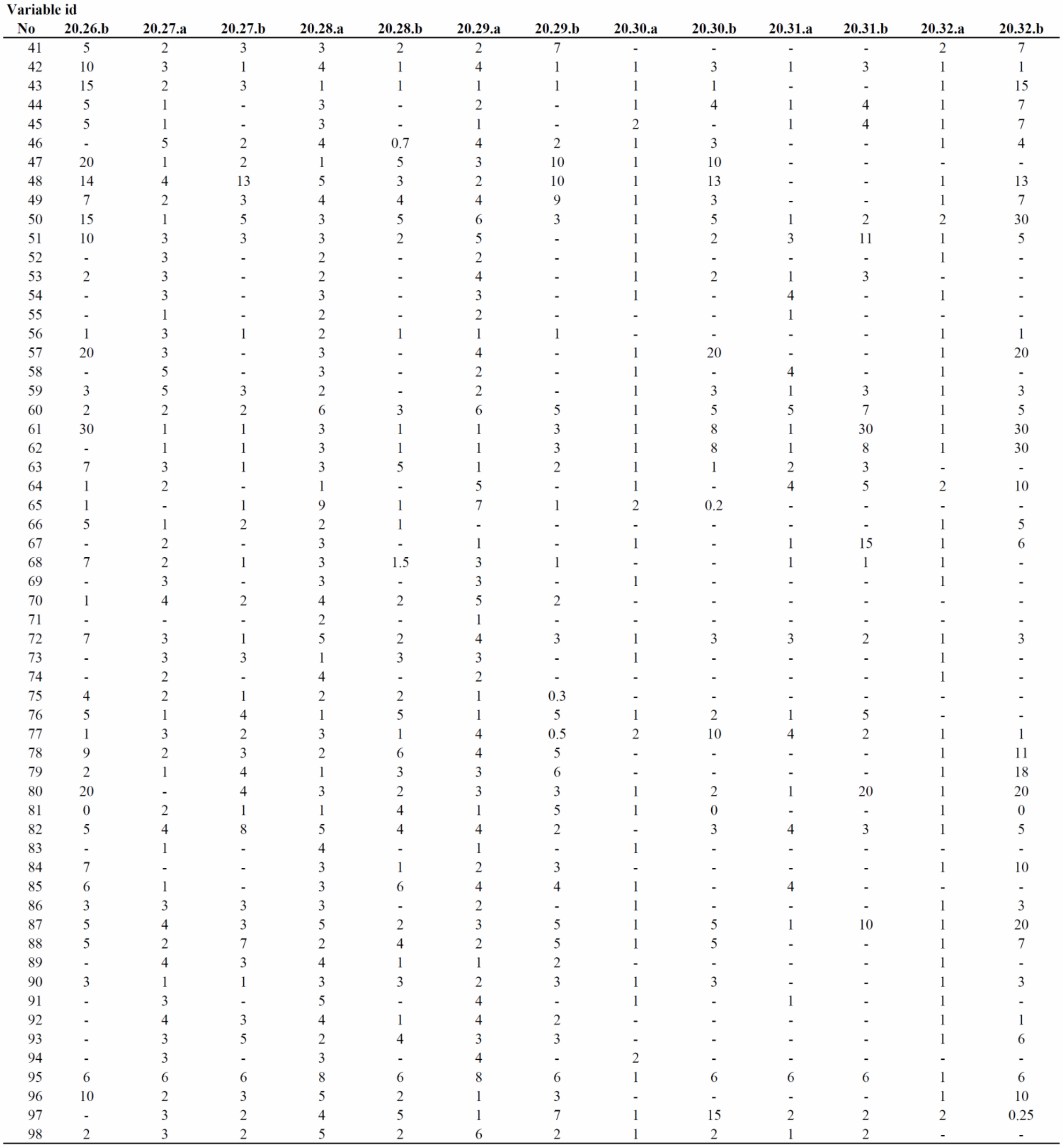
Variable id															
No	20.12.a	20.12.b	20.13.a	20.13.b	20.14.a	20.14.b	20.15.a	20.15.b	20.16.a	20.16.b	20.17.a	20.17.b	20.18.a	20.18.b	20.19.a
41	3	2	1	20	2	3	-	-	3	-	-	-	2	6	1
42	2	2	1	2	5	4	2	2	1	4	-	-	1	6	2
43	1	1	1	3	1	1	1	3	1	7	-	-	1	15	1
44	1	-	1	-	1	-	3	-	1	4	-	-	1	4	-
45	1	-	1	-	3	-	2	-	1	6	-	-	1	5	-
46	2	1	2	6	2	2	5	5	1	4	-	-	1	3	2
47	-	1	1	20	1	5	2	20	1	15	-	-	1	10	-
48	2	13	1	13	1	4	1	8	1	13	-	-	1	13	2
49	2	4	3	6	2	6	2	6	1	7	-	-	1	7	1
50	2	2	1	20	1	10	-	-	1	5	-	-	2	10	-
51	2	1	1	10	1	2	2	-	1	3	-	-	1	5	2
52	2	-	1	-	1	-	1	-	1	-	-	-	1	-	1
53	1	2	1	-	1	-	3	-	1	2	-	-	1	2	-
54	1	-	7	-	1	-	3	-	2	-	1	-	-	-	1
55	1	-	1	-	2	-	-	-	1	-	-	-	1	-	-
56	1	1	-	-	1	1	1	1	1	1	-	-	1	1	-
57	1	20	1	20	2	-	3	-	1	20	-	-	1	20	1
58	1	-	2	-	2	-	3	-	1	-	-	-	1	-	1
59	1	-	1	-	2	-	2	-	1	3	-	-	1	3	1
60	2	5	1	-	3	2	1	-	2	5	-	-	1	7	1
61	1	1	1	2	1	0.3	1	2	1	8	1	30	-	-	1
62	1	1	1	1	1	0.5	1	2	1	8	1	8	-	-	1
63	2	1	2	1	1	1	2	1	2	2	1	5	-	-	-
64	1	-	1	-	1	-	5	-	2	2	3	30	3	30	1
65	1	0.1	3	2	4	0.5	-	-	2	0.2	1	1	1	1	-
66	1	-	2	5	1	2	-	-	1	5	-	-	1	-	-
67	2	-	2	-	1	-	1	-	1	15	-	-	1	2	1
68	-	-	1	8	1	2	1	-	1	1	1	2	-	-	1
69	1	-	1	-	3	-	4	-	1	-	-	-	1	-	1
70	1	2	1	2	1	2	1	2	1	2	-	-	1	2	1
71	1	-	1	-	1	-	1	-	1	-	-	-	1	-	-
72	2	1	1	0.25	4	2	5	3	1	3	1	7	-	-	1
73	1	-	1	-	2	9	2	-	1	-	-	-	1	-	-
74	-	-	1	-	2	-	-	-	1	-	-	-	4	-	1
75	1	3	1	3	1	3	1	5	1	0.3	-	-	1	4	-
76	1	3	1	20	1	5	1	5	1	5	-	-	1	5	1
77	2	3	1	3	2	3	4	1	1	2	-	-	1	1	-
78	1	3	-	-	1	5	-	-	1	5	-	-	1	9	1
79	1	4	1	20	1	6	1	4	1	7	-	-	1	15	-
80	1	3	1	2	1	3	1	10	2	2	1	20	1	20	-
81	1	0.25	2	0	1	3	1	2	1	5	-	-	1	0	-
82	2	3	1	1	1	1	-	-	1	8	-	-	1	6	-
83	1	-	1	-	2	-	1	-	1	18	-	-	1	-	-
84	1	5	1	2	2	1	4	2	1	18	-	-	1	10	-
85	2	2	2	-	1	5	3	6	1	9	-	-	1	-	1
86	1	-	1	-	1	-	1	-	1	3	1	3	-	-	1
87	1	5	1	18	1	2	2	10	1	10	-	-	1	10	1
88	2	3	2	15	1	4	1	10	1	8	-	-	1	8	-
89	1	-	1	-	1	1	-	-	1	2	-	-	-	-	1
90	1	3	1	3	1	3	-	-	1	3	1	3	-	-	-
91	1	-	3	-	3	-	4	-	2	-	-	-	1	-	1
92	1	1	2	1	2	2	2	2	2	1	-	-	2	2	-
93	1	0.25	2	8	2	2	2	10	3	4	-	-	1	2	-
94	2	-	1	-	2	-	-	-	2	-	-	-	2	-	1
95	1	6	2	6	2	6	4	6	1	6	1	6	-	-	1
96	2	5	1	10	2	1	3	3	1	1	-	-	1	10	2
97	1	5	1	7	1	5	1	15	2	5	-	-	1	15	-
98	1	2	1	2	1	2	1	2	1	2	-	-	1	2	-

Table 45 Chapter 4 and 5 energy services survey data (13/14)



Variable id													
No	**20.19.b**	**20.20.a**	**20.20.b**	**20.21.a**	**20.21.b**	**20.22.a**	**20.22.b**	**20.23.a**	**20.23.b**	**20.24.a**	**20.24.b**	**20.25.a**	**20.25.b**	**20.26.a**
41	2	1	1	5	2	-	-	2	7	1	9	2	3	1
42	4	1	1	3	2	1	3	1	2	3	3	1	10	1
43	2	1	7	2	3	0	2	1	15	1	2	1	0	1
44	-	-	-	5	-	1	-	1	7	2	-	1	4	1
45	-	1	3	4	-	-	-	1	2	2	-	1	1	1
46	1	2	2	4	1	2	0.4	1	0.5	2	4	1	2	-
47	-	1	15	6	10	1	5	1	10	1	20	1	10	1
48	9	1	13	3	10	-	-	1	13	1	13	1	10	1
49	5	1	4	6	6	-	-	2	7	1	15	1	7	1
50	-	2	5	6	3	-	-	3	2	-	-	2	2	1
51	0.5	2	2	4	-	-	-	1	1	1	-	1	3	1
52	-	1	-	4	-	1	-	1	-	-	-	1	-	1
53	-	1	4	1	-	4	-	1	3	2	-	1	1	1
54	-	1	-	6	-	20	-	2	-	3	-	2	-	1
55	-	1	-	3	-	1	-	1	-	-	-	2	-	1
56	-	-	-	2	1	1	1	1	1	-	-	1	5	1
57	20	1	20	5	-	-	-	1	20	1	-	1	15	1
58	-	2	-	6	-	3	-	2	-	2	-	1	-	1
59	-	-	1	6	-	2	-	1	3	1	1	1	3	1
60	5	-	-	8	3	6	3	1	4	1	-	1	5	1
61	1	1	8	4	1	2	1	-	-	-	-	1	0.1	1
62	1	1	8	4	1	2	2	-	-	-	-	1	0.1	-
63	-	1	2	6	5	-	-	1	7	1	1	1	5	1
64	-	2	3	7	-	-	-	1	10	3	-	1	5	1
65	-	1	0.2	8	0.5	3	1	2	0.5	-	-	1	0.1	2
66	-	1	5	1	5	2	3	-	-	-	-	1	5	1
67	-	1	15	3	-	-	-	1	15	-	-	1	1	1
68	-	1	3	5	2	1	2	1	7	-	-	1	-	1
69	-	1	-	6	-	1	-	1	-	1	-	1	-	-
70	2	1	1	5	2	30	2	1	2	-	-	1	2	1
71	-	-	-	2	-	-	-	1	-	-	-	1	-	1
72	4	1	3	5	3	3	3	1	7	1	7	1	3	1
73	-	1	3	4	2	15	0.1	1	-	2	-	1	-	2
74	-	-	-	5	-	3	-	1	-	-	-	2	-	1
75	-	1	3	1	7	-	-	1	4	-	-	-	-	1
76	3	1	2	1	5	1	5	1	5	1	10	1	5	1
77	-	1	3	6	0.2	2	0.1	2	1	-	-	1	10	2
78	3	-	-	7	5	-	-	-	-	-	-	1	5	1
79	-	-	-	4	5	6	16	1	18	1	15	-	-	1
80	-	1	3	4	2	12	5	1	20	2	4	1	2	1
81	-	-	-	4	2	1	3	1	0	1	5	1	3	1
82	-	1	1	6	7	7	3	1	5	-	-	1	3	1
83	-	-	-	4	-	-	-	1	-	1	-	1	18	-
84	-	-	-	3	5	-	-	1	10	2	18	1	2	1
85	-	1	-	6	3	15	4	2	8	1	-	1	8	1
86	-	1	3	2	-	-	-	4	3	-	-	1	2	1
87	5	1	10	4	5	3	2	1	15	2	10	1	6	1
88	-	1	11	3	5	4	5	1	7	1	12	1	5	1
89	-	2	-	3	1	-	-	1	-	-	-	1	2	1
90	-	1	3	2	1	3	2	1	3	-	-	1	3	1
91	-	1	-	6	-	12	-	2	-	5	-	1	-	1
92	-	1	2	4	1	30	2	1	1	-	-	1	2	-
93	-	1	4	5	2	4	3	1	-	1	15	1	0.5	1
94	-	2	-	5	-	4	-	-	-	-	-	2	-	-
95	6	2	6	8	6	6	6	1	6	1	6	1	6	1
96	5	1	7	2	2	10	1	1	10	1	3	1	10	1
97	-	-	-	3	10	1	4	1	0.25	-	-	2	0.3	-
98	-	2	-	6	2	10	2	1	2	2	2	1	0.5	1

Table 46 Chapter 4 and 5 energy services survey data (14/14)



Variable id													
No	20.26.b	20.27.a	20.27.b	20.28.a	20.28.b	20.29.a	20.29.b	20.30.a	20.30.b	20.31.a	20.31.b	20.32.a	20.32.b
41	5	2	3	3	2	2	7	-	-	-	-	2	7
42	10	3	1	4	1	4	1	1	3	1	3	1	1
43	15	2	3	1	1	1	1	1	1	-	-	1	15
44	5	1	-	3	-	2	-	1	4	1	4	1	7
45	5	1	-	3	-	1	-	2	-	1	4	1	7
46	-	5	2	4	0.7	4	2	1	3	-	-	1	4
47	20	1	2	1	5	3	10	1	10	-	-	-	-
48	14	4	13	5	3	2	10	1	13	-	-	1	13
49	7	2	3	4	4	4	9	1	3	-	-	1	7
50	15	1	5	3	5	6	3	1	5	1	2	2	30
51	10	3	3	3	2	5	-	1	2	3	11	1	5
52	-	3	-	2	-	2	-	1	-	-	-	1	-
53	2	3	-	2	-	4	-	1	2	1	3	-	-
54	-	3	-	3	-	3	-	1	-	4	-	1	-
55	-	1	-	2	-	2	-	-	-	1	-	-	-
56	1	3	1	2	1	1	1	-	-	-	-	1	1
57	20	3	-	3	-	4	-	1	20	-	-	1	20
58	-	5	-	3	-	2	-	1	-	4	-	1	-
59	3	5	3	2	-	2	-	1	3	1	3	1	3
60	2	2	2	6	3	6	5	1	5	5	7	1	5
61	30	1	1	3	1	1	3	1	8	1	30	1	30
62	-	1	1	3	1	1	3	1	8	1	8	1	30
63	7	3	1	3	5	1	2	1	1	2	3	-	-
64	1	2	-	1	-	5	-	1	-	4	5	2	10
65	1	-	1	9	1	7	1	2	0.2	-	-	-	-
66	5	1	2	2	1	-	-	-	-	-	-	1	5
67	-	2	-	3	-	1	-	1	-	1	15	1	6
68	7	2	1	3	1.5	3	1	-	-	1	1	1	-
69	-	3	-	3	-	3	-	1	-	-	-	1	-
70	1	4	2	4	2	5	2	-	-	-	-	-	-
71	-	-	-	2	-	1	-	-	-	-	-	-	-
72	7	3	1	5	2	4	3	1	3	3	2	1	3
73	-	3	3	1	3	3	-	1	-	-	-	1	-
74	-	2	-	4	-	2	-	-	-	-	-	1	-
75	4	2	1	2	2	1	0.3	-	-	-	-	-	-
76	5	1	4	1	5	1	5	1	2	1	5	-	-
77	1	3	2	3	1	4	0.5	2	10	4	2	1	1
78	9	2	3	2	6	4	5	-	-	-	-	1	11
79	2	1	4	1	3	3	6	-	-	-	-	1	18
80	20	-	4	3	2	3	3	1	2	1	20	1	20
81	0	2	1	1	4	1	5	1	0	-	-	1	0
82	5	4	8	5	4	4	2	-	3	4	3	1	5
83	-	1	-	4	-	1	-	1	-	-	-	-	-
84	7	-	-	3	1	2	3	-	-	-	-	1	10
85	6	1	-	3	6	4	4	1	-	4	-	-	-
86	3	3	3	3	-	2	-	1	-	-	-	1	3
87	5	4	3	5	2	3	5	1	5	1	10	1	20
88	5	2	7	2	4	2	5	1	5	-	-	1	7
89	-	4	3	4	1	1	2	-	-	-	-	1	-
90	3	1	1	3	3	2	3	1	3	-	-	1	3
91	-	3	-	5	-	4	-	1	-	1	-	1	-
92	-	4	3	4	1	4	2	-	-	-	-	1	1
93	-	3	5	2	4	3	3	-	-	-	-	1	6
94	-	3	-	3	-	4	-	2	-	-	-	-	-
95	6	6	6	8	6	8	6	1	6	6	6	1	6
96	10	2	3	5	2	1	3	-	-	-	-	1	10
97	-	3	2	4	5	1	7	1	15	2	2	2	0.25
98	2	3	2	5	2	6	2	1	2	1	2	-	-

List of Publications

Journal articles

Cravioto, J., Bakr, M., Aoyagi, S., Park, S. and Utama, N.A. (2011) Community acceptance of nuclear power generation in Japan and relevant influencing factors. International Journal of Renewable Energy Research (IJRER), Vol.1, No.2, pp.56-61.

Cravioto, J., Yamasue, E., Okumura, H. and Ishihara, K.N. (2013) Road transport externalities in Mexico: Estimates and international comparisons. Transport Policy, 30, pp.63-76.

Cravioto, J., Yamasue, E., Okumura, H. and Ishihara, K.N. (2014) Energy service satisfaction in two Mexican communities: A study on demographic, household, equipment and energy related predictors. Energy Policy, 73, pp.110-126.

Proceedings (international conferences) and book chapters

Cravioto, J., Yamasue, E., Okumura, H. and Ishihara, K.N. (2010) Performance analysis between well-being, energy and environmental indicators using data envelopment analysis. In Zero-Carbon Energy Kyoto 2010, Springer Japan, pp. 49-55.

Higashikura, S., Wijaya, M.E., Cravioto, J., Ibano, K., Tamunaidu, P., Kinjo, R. and Lim, J.Y. (2012) Measures for nuclear power substitution in the electricity supply to Kyoto City. In Zero-Carbon Energy Kyoto 2011, Springer Japan, pp.85-91, 2012.

Material to be published

Cravioto, J. and Yamasue, E. Variations from the use of economic, subjective and objective well-being indices in a holistic assessment of the energy-well-being link. Joint conference of the International Society for Industrial Ecology (ISIE), 12th Socio-Economic Metabolism section conference and 5th Asia-Pacific conference, Sep 2016. Nagoya, Japan.