# Analyzing the effects of renewable energy and climate conditions on consumer welfare

*Tarek Atalla,* Simona Bigerna,** Carlo Andrea Bollino,*** and Rolando Fuentes*****

**ABSTRACT**

This paper aims to measure the impact of the gradual adoption of Renewable Energy Sources (RES) on the welfare of consumers. To this end, we construct a theoretically founded measure of the true cost of living (TCL) and the equivalence scale (ES) for the household sector, based on a weather database of heating and cooling degree days. We estimate those values for 64 countries, which represent over two-thirds of the world population, according to World Bank statistics. We assume that the identified household in each country minimizes its expenditure on energy and other goods. We simulate alternate scenarios of renewables implementation in 2035, taking account of different RES prices, and assess the related societal implications of a gradual transition from fossil fuels to RES. The empirical results offer policymakers a basis for designing appropriate scenarios for the deployment of renewables, with the aim of fostering consumer welfare even in the context of international negotiations.

**Keywords:** Renewable Energy Sources, Complete demand system, Energy consumption, Cost of living, Equivalence scale

https://doi.org/10.5547/01956574.38.SI1.tata

## 1. INTRODUCTION

The cost of Renewable Energy Sources (RES) is increasingly becoming an issue with relevance and impact for policymakers. In accordance with this recent surge of interest, the research community has been investing more time in analyzing the external benefits of RES implementation from an environmental perspective (IEA, 2016).

The cost of RES is usually measured by the monetary expenditure associated with the supply side—both capital and operational costs—that enables assessments of the levelized cost of electricity (LCOE), with a variety of discounting factors. Microeconomic principles dictate that additional costs of RES constitute a further burden on a household budget, creating potential substitution and welfare effects with other consumption goods. This is because any household has to reallocate its limited budget in an optimal way considering the higher price of the new energy source, as defined by the conditions of the deployment of RES. This price rise can take multiple forms, such as a premium on the specific energy price, or an excise or income surcharge, as has been recommended by the European Union, set out in the 2030 Climate and Energy Policy Frame-

* Corresponding author. King Abdullah Petroleum Studies and Research Center (KAPSARC), Saudi Arabia. E-mail: tarek.atallah@outlook.com.

** University of Perugia, Italy.

*** University of Perugia, Italy and King Abdullah Petroleum Studies and Research Center (KAPSARC), Saudi Arabia.

**** King Abdullah Petroleum Studies and Research Center (KAPSARC), Saudi Arabia.

*The Energy Journal*, Vol. 38, SI1. Copyright © 2017 by the IAEE. All rights reserved.

work (European Council, 2014). This provides an opportunity for an exercise that undertakes a theoretically based, comprehensive analysis of the welfare effect costs associated with the spread of renewables.

As such, the purpose of this paper is to quantify, empirically, the impact of the deployment of renewable energy and the effect of weather conditions related to RES on the welfare of consumers. The rationale for linking diffusion of renewable technology to weather conditions is similar to that applied in the case of other technological disruptions that impact a consumer's welfare at different levels based on their heterogeneous conditions[1]. We perform this by constructing an empirical measure of the true cost of living (TCL) and the equivalence scale (ES) for the residential sector for 64 countries, which represent over two-thirds of the world population, according to the indicators published by the World Bank (2014). The TCL is a measure of the cost of living changes that result from price movements, assuming that the reference welfare level remains constant over time. This allows for analysis of how consumers adjust their demand to maintain the same level of welfare following a price change. In this respect, it provides a microeconomic foundation for measuring changes in consumers' welfare (Triplett, 2001). In parallel, the ES is a measure comparing welfare across consumers with segregating characteristics. In other words, the ES shows the relative welfare differential due to structural characteristics, all else being equal (Pollak and Wales, 1979). We use ES to analyze how more severe weather conditions may imply higher final household expenditure for some countries, even if prices for other goods remain similar.

In order to calculate ES and TCL, we estimate a demand system for the representative household in each country, following the original methodology for estimating TCL and ES that was introduced by Deaton and Muellbauer (1980) and applied by Fry and Pashardes (1989) and Deaton and Muellbauer (1986) for the case of emerging countries.

The theoretical model that supports these calculation is a cost minimization for the representative household in each country[2], which allocates expenditure between energy and another composite good, including both climate and capital stock effects, for the period 1978–2012.

We also calculate alternative scenarios for RES development in 2035, including different prices for different forms of renewable energy, and measure the welfare impact of gradual transition from fossil fuels to RES.

The paper is organized as follows: Section 2 explains the model specification. Section 3 presents the data and the estimation. Section 4 discusses the results and the scenarios for renewables development worldwide. Section 5 concludes and summarizes the main policy implications.

## 2. THEORY AND MODEL SPECIFICATION

As stated above, our aim is to calculate the true cost of living (TCL) and the equivalence scale (ES) for a number of countries. To do this we require a cost function for each country, which in its general form is given by

$$C_i = C(p_{e,i}, p_{y,i}, K_i, U_i, \Phi_i) \quad (1)$$

1. The classic example is innovation in long life milk benefiting households, or not, depending on whether they have children or not. The case of milk consumption impacting different households was presented by Pollak and Wales (1981). Harsher weather conditions would directly increase the share of 'energy' in the consumer's budget.

2. Notice that our analysis is focused on analyzing households' welfare and not the entire social welfare function.

Copyright © 2017 by the IAEE. All rights reserved.

where the country index varies as i = 1, . . . , n. The cost function depends in each country's price of energy and of the composite good $[p_{e,i}, p_{y,i}]$, total utility $U_i$, the capital stock $K_i$ and climate conditions $\Phi_i$, which are all country specific[3].

With such a cost function, it is now possible to construct the two measures of the cost to assess the impact of price and weather on consumers' welfare, respectively.

The first measure, ES, is obtained by keeping prices and capital stock and utility constant at a reference level $p_e^*$, $p_y^*$, $K^*$, $U^*$. The effect of a difference in climatic conditions between country $i = 1$ and country $i = 2$ is the ES, using the ratio:

$$ES_{1,2} = C_1(p_e^*, p_y^*, K^*, U^*, \Phi_1)/C_2(p_e^*, p_y^*, K^*, U^*, \Phi_2) \quad (2)$$

Equation (2) measures the change in total cost resulting from that change in climate conditions (from $\Phi_1$ to $\Phi_2$) which is necessary to attain the same level of welfare (utility), given the same level of prices. In other words, the ES measures the cost differential due to climate between any two countries, all else being equal.

The second measure, TCL, is constructed keeping $U_i$, $K_i$, and $\Phi_i$ constant for every country and allowing the prices to change. The effect of price changes from the price level 0 to the price level 1 is the TCL change. This enables us to compute the ratio for every country $i$ for two price levels, 1 and 0:

$$TCL_i^{1,0} = C_i^1(p_{e,i}^1, p_{y,i}^1, K_i, U_i, \Phi_i)/C_i^0(p_{e,i}^0, p_{y,i}^0, K_i, U_i, \Phi_i) \quad (3)$$

Equation (3) measures the change in total cost necessary to attain the same level of welfare (utility), given the same level of climatic condition, resulting from price change in every country $i$ from $(p_{e,i}^0, p_{y.i}^0)$ to $(p_{e,i}^1, p_{y,i}^1)$.

In order to be able to make the calculations in equations (2) and (3) the cost function given in Equation (1) needs to be parametrized. We therefore define the parametric cost function for each country assuming a specific flexible non-linear functional form, given by the generalized almost ideal (GAI) demand system (Bollino 1987), which is a generalization of the almost ideal (AI) system of Deaton and Muellbauer (1980), with country index $i$ and time index $t$:

$$ln\ C_{it}(p_{e,it}, p_{y,it}, U_{it}) = ln(P_{it}) + U_{it}\ G_{it}(p) \quad (4)$$

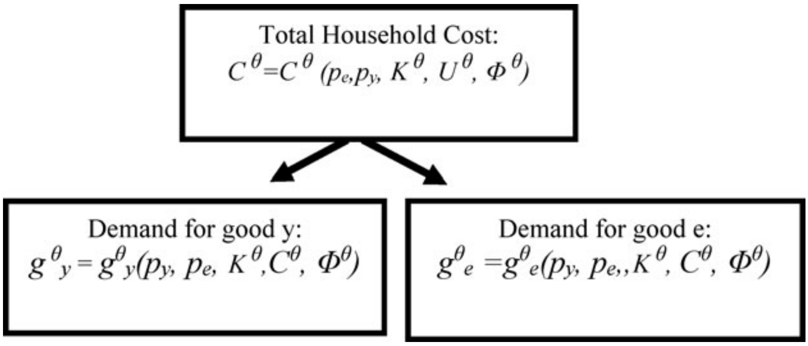
where $ln(P_{it}) = \sum_j \alpha_j ln(p_{j,it}) + \sum\sum \beta_{jk} ln(p_{j,it})\ ln(p_{k,it})\ lnG_{it}(p) = \sum_j \gamma_j ln(p_{j,it})$.

We estimate empirically equation (4) making use of the duality theory, by applying the Roy's identity to the indirect utility function, to recover the system of Marshallian demand functions; Figure 1 illustrates the relationship between the general specification of the cost function and the two demand equations. This is similar to the initial part of the first stage of the analysis in Atalla

3. We include in equation (1) the specific variables conditioning the demand for energy (Browning and Meghir, 1991), which are capital stock and climatic conditions. The stock uses energy to generate various services according to the embodied technology. Omitting the capital stock from the model would risk biasing the empirical results (Neary, 1980; Deaton and Muellbauer, 1981) and obscuring the effect of energy services (Hunt and Ryan, 2015; Schaffrin and Reiblin, 2015). Climatic conditions by their nature are exogenous to consumer choices. As remarked by an anonymous referee, in this case the parameters associated with the variables that measure capital stock and climate conditions could also be capturing differences in the cost of heating fuels and electricity across countries. This is the almost unavoidable consequence of using empirical aggregation of heterogenous elementary goods which cannot be perfect aggregates, as in Gorman (1959).

Copyright © 2017 by the IAEE. All rights reserved.

**Figure 1: Demand system for each country**




et al. (2016), which uses the same database but develops a two-stage model for 117 major economies of the world.

The relevant features of the GAI demand system are that consumer preferences can be aggregated and exhibit committed quantities, i.e. intercept parameters not depending on prices and expenditure. A committed quantity is a fixed pre-allocated consumption for each good, expenditure on which reduces the free income allocation. For a recent application of committed quantities to the energy demand, see Rowland et al. (2017). In the econometric estimation, the main advantage of committed quantities is to relieve the constraint to Engel curves to pass through the origins. We use committed quantities to introduce the climate effect in a simple way into the demand system, because theoretical properties are maintained but heterogeneity of behavior is allowed.

The demand function of GAI is parametrized as follows[4]:

$$g_{k,it} = f_k + \frac{C_{it}*}{p_{k,it}} \times \left[ \alpha_k + \Sigma_s \beta_{ks} \times ln(p_{s,it}) + \gamma_k \times ln\left(\frac{C_{it}*}{P_{it}*}\right) + \zeta_k \times K_{it} \right] \tag{5}$$

$$C_{it}* = C_{it} - \left(\sum\nolimits_s f_s p_{s,it}\right) \tag{6}$$

$$P_{it}* = \sum\nolimits_s w_s \ln(p_{s,it}) \tag{7}$$

where $g_k$ is the quantity, $k = \{y, e\}$, and $f_k$ are committed quantity parameters (depending on the country specific climate condition), $\alpha_k$ are constants, $\beta_{ks}$ are price coefficients, $\gamma_k$ are total expenditure coefficients and $\zeta_k$ are capital stock coefficients, $C_{it}*$ is the supernumerary expenditure, $P_{it}*$ is a price aggregator (Stone index) and $w_s$ are budget shares, where s ranges over the number of goods.

Equations (5)–(7) define the demand functions for composite good and energy. In order to include the climatic effect into the demand system we consider two separate measures of heating degree days (HDD) and cooling degree days (CDD) taken from Kalnay et al. (1996) and Atalla et

4. As stated above, we use duality to invert the parametric cost function (4) into an indirect utility function and then apply Roy's identity to derive the parametric functional form of the demand functions, equations (5)-(7). In these functions, every variable is indexed by *it*, which represents the data organization by a time series of countries. For instance, the quantity consumed of each good, denoted by $g_{k,it}$ for $k = \{y, e\}$, should be understood to be the quantity consumed in a certain country *i* in a certain time *t*.

Copyright © 2017 by the IAEE. All rights reserved.

al. (2015) and we assume a linear translating function, for each good k: $f_k = (\Sigma_k f_{ki} + f_{kh}\ HDD_j + f_{kc}\ CDD_j)$, for i = 1, n-1 countries, so that in the quantity expenditure space, the translating procedure shifts the Engel curve, as a function of climate variables, while preserving the theoretical structure of the demand system (Bollino et al. 2000). With theoretical restrictions, there are 16 structural parameters (of which, 12 are free) to be estimated in the system of equations (5–7) plus the number of committed parameters equal to double the number of countries minus one.

The attractive feature of this model is that the estimated parameters of the cost function in equation (4) are obtained from equations (5) to (7). This allows us to perform country by country comparisons of the welfare effects of price changes and of consumption effects related to different climatic conditions.

The next section therefore details the data used for the estimation of the demand system—and hence indirectly the cost function—and discusses the results of the estimation.

## 3. DATA AND ESTIMATION

### 3.1 Data

The dataset required to estimate the demand system detailed above in order to construct the cost function to measure the TCL and ES and to construct the alternative scenarios for RES development in 2035 has been constructed with information on energy consumption, total expenditure, prices and other variables for the period 1978–2012.

The data is originally available for 117 countries used for the estimation and is the same as that used in Atalla et al. (2016). Data availability is different for different countries; specifically, we have different time series for different countries; hence, it is an unbalanced panel. The weather impact is taken from a specific database, based on location appropriate HDD and CDD, in (Atalla et al., 2015). The household consumption expenditure in real terms and consumption deflators are computed, according to the National Income Accounts' (NIA) international guidelines and using the World Bank's Development Indicator database (World Bank, 2014) and the IEA's energy balances (2014), as reported in Atalla et al. (2016).

We computed the consumption of the composite good *y,* subtracting energy consumption expenditure $p_e\ e$ from total consumption *C* in nominal terms, constructing the appropriate deflators $p_e$ and $p_y$, and using these deflators to respect the identity: $C = p_e\ e + p_y\ y$.

The inclusion of capital stock and climatic conditions in the estimation of energy demand has been discussed in literature. For example, the single equation approach to investigating the energy demand can be found in Beaver and Huntington (1992), Steinbucks and Neuhoff (2014). In addition, other research addressed the issue of residential electric power demand in a household production model (Willett and Naghshpour, 1987; Flaig, 1990), the impact of energy efficiency and the impact of weather on short-term and long-term residential demand (Atalla and Hunt, 2016; Bašta and Heòlman, 2013; Auffhammer and Mansur, 2014).

In this paper we assume that energy is used for a variety of needs requiring capital equipment (e.g. residential appliances, space conditioning, etc.), which is predetermined to the goods allocation choice and the translating technique, (Pollak 1991, Bollino et al., 2000), and accommodates heterogeneous behavior of agents for the interaction between climate and energy prices.

### 3.2 Parameter Estimation

The econometric estimation of the GAI model specified in Equations (5) – (7) is satisfactory, based on a non-linear seemingly unrelated regression (SUR), with 2007 observations for 117

Copyright © 2017 by the IAEE. All rights reserved.

countries, in the period 1978–2012. See Table 1 for details. The significance is high for all structural coefficients. The climate coefficients are significant for both the CDD and the HDD variable ($f_{y*c}$, $f_{y*h}$, $f_{e*c}$, and $f_{e*h}$ in Table 1). The preferred model GAI is a statistical generalization, based on reported LR test values, with related degrees of freedom, of several restricted models, as reported in Table 1. In detail, we have tested the GAI model against several restrictions: restriction R1 is setting to zero the committed quantities; R2 assumes no effect of the capital stock; R3 assumes no effect the weather variables; R4 assumes zero cross price effect, meaning that the simultaneous demand estimation is unnecessary; R5 assumes that demand behavior is not determined jointly by prices and income. In particular, the preferred model GAI, which is a specific parametrization of a rank-three model[5] according to Gorman (1981), is a generalization of the original AI model, justifying the introduction of the committed quantities, as shown by the rejection of restriction R1. The poorer performance of AI is confirmed by other rank three generalizations of the AI model in the literature, such as QUAIDS (Banks et al. 1997) and EASI (Lewbel and Pendakur, 2009). The other tested restrictions are all rejected, namely, the restriction R2 of no effect of K stock; the restriction R3 of no effect of climate variables; the restriction R4 of zero cross price effects, justifying the complete demand approach; the restriction R5 of zero price and income effects, thus confirming the importance of price and income as determinants of the demand functions.

**Table 1: Estimated coefficients of GAI model**

| *Parameter* | *Value* | *standard.error* | *t-stat* | *p-value* |
|---|---|---|---|---|
| $\beta_{yy}$ | .035 | .537E-07 | 645680. | [.000] |
| $\beta_{ye}$ | −.032 | .756E-07 | 427980. | [.000] |
| $\gamma_y$ | .039 | .732E-07 | 529384. | [.000] |
| $\zeta_y$ | .264E-03 | .609E-09 | 433286. | [.000] |
| $\alpha_e$ | .334 | .857E-06 | 389749. | [.000] |
| $\beta_{ee}$ | .029 | .162E-06 | 179361. | [.000] |
| $\gamma_e$ | .024 | .628E-07 | 382921. | [.000] |
| $\zeta_e$ | .166E-03 | .409E-09 | 406977. | [.000] |
| $f_{y*c}$ | 2.117 | .629E-03 | 3361.79 | [.000] |
| $f_{y*h}$ | −4.95 | .218E-03 | −22633.8 | [.000] |
| $f_{e*c}$ | 1.27 | .699E-05 | 181844. | [.000] |
| $f_{e*h}$ | .179 | .153E-05 | 116386. | [.000] |

**Restrictions and tests of model estimation**

| ***Model restriction*** | ***Restr*** | ***Brief description of the restriction and LR test = −2(logL$_0$-logL$_1$)*** |
|---|---|---|
| GAI vs AI | R1 | No committed quantities<br>LR = (49033 − 48964)∗2 = 138, df = 2 |
| GAI K vs GAI | R2 | No effect of K stock<br>LR = (48964 − 48396)∗2 = 1136, df = 2 |
| GAI K W vs GAI | R3 | No effect of K stock and climate translating<br>LR = (48396 − 40471)∗2 = 15850, df = 230 |
| GAI zero cross effects | R4 | Restriction on cross price coefficient<br>LR = (40929 − 40471)∗2 = 916, df = 1 |
| GAI exogenous demand | R5 | No price and income effects on demand<br>LR = (53987 − 40471)∗2 = 27032, df = 11 |

5. The important result of Gorman (1981) is that non linearity of the Engel curves can be at maximum expressed by three independent terms in income, to ensure that the demand functions are integrable into a utility function. In this context, the rank three models are the most general parametric models that are theoretically admissible.

Copyright © 2017 by the IAEE. All rights reserved.

In summary, the demand system estimate provides statistically acceptable parameters that can now be used to calculate the cost functions for individual countries (i.e. in equation (4) above) in order to calculate the ES and TCL measures shown in Equations (2) and (3) above. This is done in the next section.

## 4. RESULTS OF ES AND TCL ESTIMATION

### 4.1 Input data for empirical calculations

The data set is compiled of several sets of renewable cost estimates published by leading organizations, which were then transformed into estimates of LCOE. This is a summary measure that represents the per kilowatt hour cost of building and operating a power plant over an assumed financial life after discounting all capital, fuel, operating costs and other costs (EIA, 2016).

The cost estimates were represented as trajectory forecasts of levelized costs up to 2035. The LCOE trajectory of RES is expected to be downward, but at different rates. For example, the LCOE of wind might drop 14% over the period 2010–2020, in places with load factors of 30%, while the LCOE of photovoltaics is expected to fall by 20%, but in half the time (SENER, 2012a, SENER, 2012b). These figures are indicative of the relative levels of maturity of these technologies.

In terms of actual deployment, our scenario for setting prices for 2035 accounts for the physical limitations on RES penetration resulting from the availability of sun and wind. The penetration rate is calculated up to the year 2035 using a Gompertz curve that includes asymptotic growth factors dependent on solar and wind availability. The minimum value for efficient solar energy implementation has been assumed to be 900 $kWh/m^2$ for long-term direct solar irradiation, with ideal conditions at 1300 $kWh/m^2$. As for wind energy, the ideal wind speed would be 7.5 m/s while the turbine would still be functional at a speed of 5 m/s. Worldwide solar and wind maps have been collected for the target countries from SOLARGIS (2016) and VAISALA (2016) for an average interval of 10 years. The country specific growth factors vary proportionally according to how close the value is to the ideal.

We build a variable indexing the price of renewable energy sources as a weighted average of solar and wind power. For each country, we use a recent estimation of LCOE (Elshurafa and Albardi, 2016) and the quantity of solar and wind produced in the most recent year:

$$P\_RES = P\_solar \times [Share]\_Solar + P\_wind \times [Share]\_wind \tag{8}$$

where P_solar and P_wind are the price indices of solar and wind, respectively, and [Share]_Solar and [Share]_wind are the quantity shares of the two RES. We then use the shares of RES in total energy consumption and the current price of energy pe in our database to construct the price of fossil fuels, satisfying the identity:

$$p\_e = P\_RES \times [Share]\_RES + P\_fossil \times (1 - [Share]\_RES) \tag{9}$$

where p_e is the price of energy, P_RES is the price of RES and P_fossil is the price of fossil fuel sources. In this way we make use of specific information relative to RES and fossil fuels and render it coherent with our data.

Obviously, this implies that households are interested in the aggregate price of energy and not in the specific share of RES from which they derive energy. This is in accordance with Hunt

Copyright © 2017 by the IAEE. All rights reserved.

and Ryan's (2015) approach of considering that households derive utility from the services rendered by energy.

### 4.2 Equivalence scale calculations

We generated the empirical estimation of the ES for the year 2012 for the subset of countries reported in Table 2. Note that the simulation of equation (2) involves simulating the cost, for a representative household of each country, that is necessary to achieve the same level of welfare as for a chosen reference country, at the same level of prices but at different climate conditions, according to the estimated model. The choice of the reference country was based on the closest OECD economy to the median, with a population distribution not age skewed. This allowed for comparisons not only with a country with typically mild temperatures but which also had advanced economic development. Using these criteria, the reference country selected was France.

The ES was computed at three different levels of prices, given the convexity and the non linearity of the estimated cost function[6]. Specifically, we took the average world price across countries in 2012 and chose a low level price, similar to that for Gulf Cooperation Council countries, and a high level price, similar to that for the high taxation, developed North European countries. The results reflect a range of variation in the equivalence scale.

We found that one group of countries has values 1.5 times that of France, which means that all else being equal, i.e. with same level of welfare and prices, these need to spend 50% more because of the adverse climate conditions. In Europe, Italy, Spain, Portugal and Greece all show values above unity. This suggests that these Mediterranean countries have to spend more than France, mainly because of their hotter summer climates. By contrast, Sweden, Finland and Switzerland have values that are also above unity, probably due to their colder winters. In other words, there are two groups of European countries, both with higher values than France, for opposite reasons, namely, hot countries that have to spend more in the summer and cold ones in the winter.

Other countries show a ratio below unity, with values around 0.5 or 0.2, which means that they can spend less than France to attain the same welfare level, because they have more favorable climate conditions. Germany shows a ratio of 0.9 and China 0.8, so both have a situation very similar to France. Italy has a value of 1.8, while Saudi Arabia is close to 1.5. In addition, Canada, the U.K. and the U.S. reflect values between 0.4 and 0.5.

The simulated values for per capita total expenditure and energy expenditure for each country relative to that of France in the various scenarios, at the three levels of energy price—low, medium and high—are reported in Table 3.

Note that with the same energy prices across the world there are significant country disparities, with different levels of welfare. We report in the right hand section of Table 3 the cost per capita of energy for each country relative to that of France. For example, China's energy spend is 0.37 compared with France, while U.S. expenditure is 1.46 times greater.

The simulated values with the same energy price level worldwide show that country disparities compared with France tend to reduce for some countries—Australia, U.K., U.S. and Norway, among others—as price shifts higher. This is true of developed economies, which likely have a stronger similarity to France, but some emerging countries with dynamic growth, such as India,

6. Given the non linearity of the model, computation of eq. (4) was not possible for all countries in the dataset. For some countries the three price levels used for the computation of the ES were yielding non-admissible numerical results, like log of negative numbers. We report results for a subset of 64 countries in Table 2.

Copyright © 2017 by the IAEE. All rights reserved.

**Table 2: Equivalence scale for climate conditions – countries - year 2012 (*)
Reference country: France**

| | Country | Low price equivalence scale | Medium price equivalence scale | High price equivalence scale |
|---|---|---|---|---|
| 1 | *Albania* | 0.62 | 0.56 | 0.46 |
| 2 | *Angola* | 0.32 | 0.27 | 0.20 |
| 3 | *Australia* | 0.96 | 0.97 | 0.98 |
| 4 | *Austria* | 1.43 | 1.44 | 1.45 |
| 5 | *Bahrain* | 0.36 | 0.33 | 0.29 |
| 6 | *Belgium* | 1.08 | 1.08 | 1.08 |
| 7 | *Bolivia* | 1.08 | 1.10 | 1.12 |
| 8 | *Brazil* | 1.06 | 1.07 | 1.08 |
| 9 | *Cameroon* | 2.03 | 1.95 | 1.82 |
| 10 | *Canada* | 0.37 | 0.24 | 0.04 |
| 11 | *Chile* | 0.55 | 0.54 | 0.53 |
| 12 | *China* | 0.83 | 0.78 | 0.69 |
| 13 | *Colombia* | 0.20 | 0.19 | 0.17 |
| 14 | *Cote d'Ivoire* | 1.53 | 1.47 | 1.37 |
| 15 | *Czech Rep.* | 0.71 | 0.68 | 0.61 |
| 16 | *Ecuador* | 0.49 | 0.49 | 0.48 |
| 17 | *Finland* | 1.43 | 1.43 | 1.44 |
| 18 | *France* | 1.00 | 1.00 | 1.00 |
| 19 | *Gabon* | 4.01 | 4.06 | 4.14 |
| 20 | *Georgia* | 1.32 | 1.32 | 1.32 |
| 21 | *Germany* | 0.92 | 0.91 | 0.90 |
| 22 | *Ghana* | 0.94 | 0.91 | 0.86 |
| 23 | *Greece* | 1.16 | 1.17 | 1.18 |
| 24 | *Guatemala* | 1.41 | 1.40 | 1.37 |
| 25 | *Hungary* | 0.64 | 0.59 | 0.52 |
| 26 | *India* | 1.17 | 1.14 | 1.10 |
| 27 | *Indonesia* | 0.87 | 0.83 | 0.77 |
| 28 | *Ireland* | 1.17 | 1.18 | 1.19 |
| 29 | *Italy* | 1.78 | 1.80 | 1.82 |
| 30 | *Japan* | 3.26 | 3.29 | 3.34 |
| 31 | *Jordan* | 0.26 | 0.22 | 0.17 |
| 32 | *Kenya* | 0.39 | 0.25 | 0.04 |
| 33 | *Lebanon* | 0.27 | 0.25 | 0.21 |
| 34 | *Malaysia* | 0.73 | 0.73 | 0.71 |
| 35 | *Mexico* | 0.44 | 0.44 | 0.44 |
| 36 | *Moldova* | 0.49 | 0.30 | |
| 37 | *Morocco* | 1.40 | 1.41 | 1.42 |
| 38 | *Mozambique* | 0.34 | 0.05 | |
| 39 | *Netherlands* | 0.57 | 0.56 | 0.54 |
| 40 | *New Zealand* | 0.44 | 0.44 | 0.44 |
| 41 | *Niger* | 0.47 | 0.47 | 0.47 |
| 42 | *Nigeria* | 0.38 | 0.20 | |
| 43 | *Norway* | 0.89 | 0.89 | 0.90 |
| 44 | *Oman* | 0.67 | 0.67 | 0.66 |
| 45 | *Paraguay* | 0.45 | 0.34 | 0.15 |
| 46 | *Peru* | 0.11 | 0.10 | 0.10 |
| 47 | *Poland* | 0.52 | 0.49 | 0.44 |
| 48 | *Portugal* | 1.21 | 1.22 | 1.24 |
| 49 | *Serbia* | 0.29 | 0.17 | |
| 50 | *Slovakia* | 1.24 | 1.23 | 1.21 |
| 51 | *South Africa* | 1.28 | 1.28 | 1.28 |
| 52 | *South Korea* | 1.44 | 1.44 | 1.45 |

*(continued)*

Copyright © 2017 by the IAEE. All rights reserved.

**Table 2: Equivalence scale for climate conditions – countries - year 2012 (*)**
**Reference country: France** *(continued)*

| | Country | Low price equivalence scale | Medium price equivalence scale | High price equivalence scale |
|---|---|---|---|---|
| 53 | *Spain* | 1.69 | 1.71 | 1.74 |
| 54 | *Sudan* | 0.92 | 0.91 | 0.88 |
| 55 | *Sweden* | 1.21 | 1.21 | 1.21 |
| 56 | *Switzerland* | 1.13 | 1.14 | 1.15 |
| 57 | *Thailand* | 1.42 | 1.42 | 1.41 |
| 58 | *Tunisia* | 0.13 | 0.08 | 0.00 |
| 59 | *Turkey* | 1.06 | 1.07 | 1.07 |
| 60 | *Ukraine* | 0.39 | 0.33 | 0.24 |
| 61 | *United Arab Emirates* | 0.35 | 0.30 | 0.21 |
| 62 | *United Kingdom* | 0.85 | 0.85 | 0.86 |
| 63 | *United States* | 0.50 | 0.50 | 0.48 |
| 64 | *Vietnam* | 0.32 | 0.28 | 0.22 |
| | Average | 0.89 | 0.92 | 0.91 |
| | standard deviation | 0.70 | 0.67 | 0.73 |

**Notes*:
Total cost ratio = ratio of country total cost to cost of France
Equivalence scale = cost ratio to cost of France
Some countries have a shorter average than the stated period. None has less than three years.

are also included. As such, higher world prices imply that countries with an ES greater than 1 show a reduction of the ES and countries with an ES lower than 1 show an increase in ES, resulting from the increasing prevalence of the substitution effect.

For another group of countries—China, Columbia, Lebanon, Poland and UAE, among others—higher prices bring about an increase in relative disparity. These are mainly emerging economies, plus some eastern European countries.

The relationship between estimated ES and GDP per capita (Figure 2) shows a negligible correlation coefficient of 0.29, reflecting that the climatic impact on welfare is largely independent of the level of development achieved by a country, which is represented by its GDP per capita.

In addition, the ES of the climatic variables is seen as increasing, suggesting that an increase in degree days, all else being equal, produces an increase in energy demand. We highlight the fact that this result was obtained assuming the same level of welfare across countries. It implies that a representative household in a country with extreme weather conditions must allocate a greater share of its spending to energy to achieve the reference comfort level. The values of CDD are higher than those of HDD, reflecting the differential in energy efficiency between cooling and heating systems. Consequently, the effect of extreme hot weather, which implies cooling needs, is greater than that of extreme cold weather. We also find that the ES of cooling is inversely correlated to GDP per capita, suggesting that cooling efficiency is greater in higher income countries.

### 4.3 True Cost of Living calculations

The TCL reflects the time variation of the cost borne by the representative household to purchase the consumption bundle, given a reference level of welfare, because of goods price infla-

Copyright © 2017 by the IAEE. All rights reserved.

**Table 3: Relative Per Capita total expenditure and energy expenditure - climate variation - 2012**
**Reference country: France**

| | Country | Total expenditure ratio | Low price total exp ratio | Medium price total exp ratio | High price total exp ratio | Energy expenditure ratio | Low price energy exp ratio | Medium price energy exp ratio | High price energy exp ratio |
|---|---|---|---|---|---|---|---|---|---|
| 1 | *Albania* | 0.142 | 0.203 | 0.183 | 0.163 | 0.203 | 0.875 | 0.570 | 0.590 |
| 2 | *Angola* | 0.130 | 0.163 | 0.150 | 0.140 | 0.377 | 0.484 | 0.340 | 0.360 |
| 3 | *Australia* | 1.304 | 1.257 | 1.252 | 1.269 | 0.815 | 0.818 | 0.774 | 0.677 |
| 4 | *Austria* | 1.095 | 1.204 | 1.134 | 1.095 | 1.126 | 2.307 | 1.538 | 1.328 |
| 5 | *Bahrain* | 0.396 | 0.445 | 0.445 | 0.396 | 0.840 | 1.137 | 0.742 | 0.742 |
| 6 | *Belgium* | 0.992 | 1.081 | 1.027 | 1.003 | 1.122 | 1.941 | 1.360 | 1.271 |
| 7 | *Bolivia* | 0.065 | 0.078 | 0.065 | 0.065 | 0.188 | 0.169 | 0.071 | 0.045 |
| 8 | *Brazil* | 0.270 | 0.273 | 0.265 | 0.265 | 0.181 | 0.317 | 0.233 | 0.202 |
| 9 | *Cameroon* | 0.042 | 0.085 | 0.069 | 0.056 | 0.238 | 0.497 | 0.310 | 0.304 |
| 10 | *Canada* | 1.140 | 1.926 | 1.731 | 1.495 | 1.645 | 9.575 | 7.254 | 7.947 |
| 11 | *Chile* | 0.398 | 0.421 | 0.402 | 0.402 | 0.424 | 0.655 | 0.440 | 0.428 |
| 12 | *China* | 0.077 | 0.120 | 0.098 | 0.087 | 0.367 | 0.558 | 0.319 | 0.306 |
| 13 | *Colombia* | 0.178 | 0.180 | 0.174 | 0.177 | 0.145 | 0.205 | 0.145 | 0.151 |
| 14 | *Cote d'Ivoire* | 0.042 | 0.071 | 0.058 | 0.049 | 0.247 | 0.354 | 0.221 | 0.214 |
| 15 | *Czech Rep.* | 0.324 | 0.424 | 0.387 | 0.355 | 0.860 | 1.365 | 0.935 | 0.954 |
| 16 | *Ecuador* | 0.174 | 0.183 | 0.170 | 0.174 | 0.161 | 0.277 | 0.165 | 0.156 |
| 17 | *Finland* | 1.105 | 1.251 | 1.154 | 1.105 | 1.324 | 2.769 | 1.724 | 1.482 |
| 18 | *France* | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 19 | *Gabon* | 0.171 | 0.341 | 0.213 | 0.171 | 0.725 | 2.047 | 0.853 | 0.597 |
| 20 | *Georgia* | 0.102 | 0.131 | 0.117 | 0.102 | 0.248 | 0.467 | 0.233 | 0.190 |
| 21 | *Germany* | 1.026 | 1.054 | 1.049 | 1.040 | 1.083 | 1.335 | 1.267 | 1.309 |
| 22 | *Ghana* | 0.068 | 0.089 | 0.081 | 0.073 | 0.178 | 0.309 | 0.197 | 0.194 |
| 23 | *Greece* | 0.631 | 0.683 | 0.643 | 0.631 | 0.602 | 1.204 | 0.759 | 0.649 |
| 24 | *Guatemala* | 0.137 | 0.182 | 0.160 | 0.146 | 0.443 | 0.634 | 0.386 | 0.355 |
| 25 | *Hungary* | 0.322 | 0.427 | 0.387 | 0.354 | 0.807 | 1.470 | 1.017 | 1.050 |
| 26 | *India* | 0.050 | 0.068 | 0.060 | 0.055 | 0.168 | 0.248 | 0.156 | 0.151 |
| 27 | *Indonesia* | 0.093 | 0.119 | 0.110 | 0.102 | 0.253 | 0.380 | 0.271 | 0.280 |
| 28 | *Ireland* | 0.929 | 1.015 | 0.944 | 0.915 | 0.844 | 2.016 | 1.172 | 0.972 |
| 29 | *Italy* | 0.885 | 0.876 | 0.886 | 0.878 | 0.775 | 0.752 | 0.895 | 0.805 |
| 30 | *Japan* | 0.892 | 0.913 | 0.953 | 0.910 | 0.876 | 0.988 | 1.506 | 1.369 |
| 31 | *Jordan* | 0.180 | 0.212 | 0.191 | 0.191 | 0.254 | 0.508 | 0.349 | 0.371 |
| 32 | *Kenya* | 0.038 | 0.069 | 0.060 | 0.052 | 0.255 | 0.373 | 0.269 | 0.289 |
| 33 | *Lebanon* | 0.369 | 0.415 | 0.384 | 0.384 | 0.277 | 0.860 | 0.584 | 0.599 |
| 34 | *Malaysia* | 0.195 | 0.215 | 0.202 | 0.197 | 0.315 | 0.422 | 0.274 | 0.261 |
| 35 | *Mexico* | 0.378 | 0.365 | 0.360 | 0.369 | 0.204 | 0.253 | 0.199 | 0.192 |
| 36 | *Moldova* | 0.074 | 0.184 | 0.147 | 0.129 | 0.276 | 1.158 | 0.809 | 0.883 |
| 37 | *Morocco* | 0.075 | 0.089 | 0.079 | 0.075 | 0.118 | 0.239 | 0.128 | 0.103 |
| 38 | *Mozambique* | 0.025 | 0.066 | 0.055 | 0.041 | 0.243 | 0.465 | 0.339 | 0.366 |
| 39 | *Netherlands* | 0.949 | 0.996 | 0.960 | 0.956 | 1.133 | 1.497 | 1.117 | 1.129 |
| 40 | *New Zealand* | 0.921 | 0.921 | 0.891 | 0.906 | 0.594 | 0.936 | 0.564 | 0.505 |
| 41 | *Niger* | 0.012 | 0.012 | 0.012 | 0.012 | 0.061 | 0.020 | 0.012 | 0.008 |
| 42 | *Nigeria* | 0.080 | 0.161 | 0.141 | 0.116 | 0.551 | 0.957 | 0.711 | 0.775 |
| 43 | *Norway* | 1.968 | 2.021 | 1.942 | 1.942 | 1.321 | 2.589 | 1.744 | 1.532 |
| 44 | *Oman* | 0.460 | 0.506 | 0.460 | 0.460 | 0.644 | 0.989 | 0.552 | 0.483 |
| 45 | *Paraguay* | 0.080 | 0.139 | 0.120 | 0.100 | 0.239 | 0.717 | 0.498 | 0.528 |
| 46 | *Peru* | 0.156 | 0.149 | 0.147 | 0.151 | 0.158 | 0.082 | 0.056 | 0.056 |
| 47 | *Poland* | 0.142 | 0.166 | 0.157 | 0.150 | 0.280 | 0.411 | 0.301 | 0.316 |
| 48 | *Portugal* | 0.564 | 0.601 | 0.564 | 0.552 | 0.428 | 1.023 | 0.601 | 0.483 |
| 49 | *Serbia* | 0.252 | 0.442 | 0.388 | 0.334 | 0.496 | 2.245 | 1.623 | 1.758 |
| 50 | *Slovakia* | 0.388 | 0.485 | 0.424 | 0.400 | 0.667 | 1.539 | 0.909 | 0.836 |
| 51 | *South Africa* | 0.287 | 0.317 | 0.299 | 0.290 | 0.415 | 0.611 | 0.423 | 0.387 |
| 52 | *South Korea* | 0.592 | 0.626 | 0.609 | 0.597 | 0.839 | 0.960 | 0.787 | 0.732 |
| 53 | *Spain* | 0.696 | 0.703 | 0.694 | 0.687 | 0.560 | 0.762 | 0.704 | 0.601 |
| 54 | *Sudan* | 0.083 | 0.099 | 0.091 | 0.086 | 0.164 | 0.275 | 0.176 | 0.169 |
| 55 | *Sweden* | 1.101 | 1.205 | 1.143 | 1.108 | 1.295 | 2.292 | 1.593 | 1.461 |
| 56 | *Switzerland* | 1.604 | 1.646 | 1.588 | 1.580 | 1.183 | 2.125 | 1.505 | 1.290 |
| 57 | *Thailand* | 0.098 | 0.118 | 0.106 | 0.101 | 0.208 | 0.318 | 0.199 | 0.180 |
| 58 | *Tunisia* | 0.153 | 0.184 | 0.172 | 0.166 | 0.251 | 0.533 | 0.386 | 0.417 |

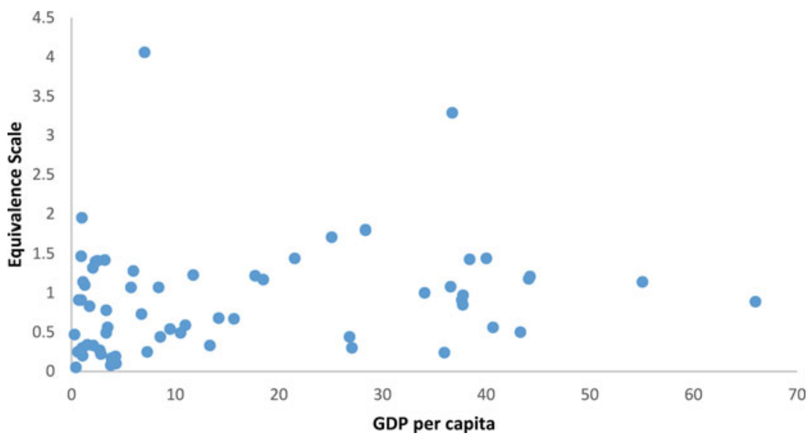
*(continued)*

Copyright © 2017 by the IAEE. All rights reserved.

**Table 3: Relative Per Capita total expenditure and energy expenditure - climate variation - 2012**
**Reference country: France** *(continued)*

| | Country | Total expenditure ratio | Low price total exp ratio | Medium price total exp ratio | High price total exp ratio | Energy expenditure ratio | Low price energy exp ratio | Medium price energy exp ratio | High price energy exp ratio |
|---|---|---|---|---|---|---|---|---|---|
| 59 | *Turkey* | 0.433 | 0.439 | 0.429 | 0.428 | 0.408 | 0.511 | 0.411 | 0.377 |
| 60 | *Ukraine* | 0.176 | 0.228 | 0.212 | 0.198 | 0.456 | 0.737 | 0.542 | 0.582 |
| 61 | *UAE* | 0.132 | 0.171 | 0.159 | 0.148 | 0.089 | 0.555 | 0.410 | 0.441 |
| 62 | *UK* | 1.337 | 1.290 | 1.304 | 1.321 | 0.883 | 0.842 | 0.987 | 0.996 |
| 63 | *USA* | 1.574 | 1.581 | 1.562 | 1.573 | 1.456 | 1.730 | 1.485 | 1.554 |
| 64 | *Vietnam* | 0.069 | 0.083 | 0.077 | 0.074 | 0.217 | 0.220 | 0.159 | 0.168 |

**Figure 2: ES and GDP per capita**




tion. In Table 4 we show the annual growth rate for the actual total cost and price level and for the TCL, computed according to the model's estimation for the period 2000–2012[7]. In practice, while the TCL takes into account the utility, maximizing response to price changes, the statistical price index typically uses fixed weightings, or other methods used by national statistical offices. Consequently, differences between the price index and the TCL quantify the bias, which can be overestimation or underestimation, of the true societal impact of the price changes. Note that there are some appreciable differences. A positive correlation between the overestimation and GDP per capita is shown in Figure 3.

This implies that the overestimation is more marked for advanced economies, with some limited exceptions. For example, in the case of the U.S., the price index underestimates the TCL at 2.1% instead of 3.0% for the period 2000–2012. In the case of the U.K., the price index overestimates the TCL, in particular, as 2.4% instead of 0.4% for the years 2000–2012 but also as 1.7% instead of 1.1% in the most recent period, 2005–2012. In parallel, a pattern of overestimation in the price index also occurs in Australia, Finland, Germany, Indonesia, India and Sweden. By con-

7. For the same reasons given in footnote 6, computation of equation (4) was not possible for all countries in the dataset. We report results for a subset of 64 countries in Table 4.

Copyright © 2017 by the IAEE. All rights reserved.

**Table 4: Total cost, price level, cost of living – annual average growth rates 2000–2012 CLI : Cost of Living Index**

| | | Annual average growth rate 2000 to 2005 | | | Annual average growth rate 2005 to 2012 | | | Annual average growth rate 2000 to 2012 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Country | Cost | Deflator | TCL | Cost | Deflator | TCL | Cost | Deflator | TCL |
| 1 | *Albania* | 6.7 | 1.6 | 0.3 | 2.7 | 1.5 | 3.9 | 9.5 | 3.1 | 4.2 |
| 2 | *Algeria* | 5.4 | 2.9 | | 3.5 | 4.8 | 5.0 | 9.1 | 7.8 | |
| 3 | *Australia* | 3.2 | 1.5 | 1.6 | 4.2 | 2.4 | 1.1 | 7.4 | 3.8 | 2.8 |
| 4 | *Austria* | 1.4 | 0.7 | 0.9 | 1.6 | 1.0 | −0.8 | 3.0 | 1.7 | 0.1 |
| 5 | *Bahrain* | 4.6 | 2.7 | 7.3 | 5.3 | 2.7 | −0.8 | 10.1 | 5.4 | 6.4 |
| 6 | *Belgium* | 1.3 | 0.9 | 2.2 | 2.0 | 1.2 | 0.3 | 3.3 | 2.0 | 2.6 |
| 7 | *Bolivia* | 3.0 | 2.0 | 3.0 | 7.5 | 4.8 | 10.4 | 10.7 | 6.9 | 13.7 |
| 8 | *Brazil* | 4.8 | 3.9 | | 7.0 | 3.9 | 8.7 | 12.1 | 8.0 | |
| 9 | *Cameroon* | 2.5 | 0.8 | −3.9 | 4.2 | 1.7 | 3.7 | 6.8 | 2.5 | −0.3 |
| 10 | *Canada* | 2.4 | 1.0 | 2.9 | 2.8 | 1.3 | 3.8 | 5.3 | 2.3 | 6.8 |
| 11 | *Chile* | 4.2 | 2.4 | 2.9 | 6.3 | 2.9 | 4.8 | 10.8 | 5.3 | 7.8 |
| 12 | *China* | 4.0 | 1.3 | 1.2 | 8.3 | 2.9 | 3.4 | 12.6 | 4.2 | 4.6 |
| 13 | *Colombia* | 3.9 | 2.6 | 6.1 | 5.7 | 2.9 | 8.1 | 9.8 | 5.6 | 14.7 |
| 14 | *Cote d'Ivoire* | 2.0 | 1.3 | 12.9 | 3.6 | 1.9 | 5.6 | 5.6 | 3.2 | 19.3 |
| 15 | *Czech Rep.* | 2.4 | 1.0 | 0.1 | 1.4 | 0.6 | −0.6 | 3.8 | 1.6 | −0.5 |
| 16 | *Ecuador* | 7.4 | 5.0 | 5.5 | 6.0 | 3.6 | 8.2 | 13.8 | 8.7 | 14.2 |
| 17 | *Finland* | 1.7 | 0.4 | −0.8 | 2.3 | 1.2 | −1.8 | 4.1 | 1.6 | −2.6 |
| 18 | *France* | 1.7 | 0.8 | 1.9 | 1.6 | 1.0 | 0.3 | 3.3 | 1.8 | 2.3 |
| 19 | *Gabon* | 2.8 | 1.3 | | 6.4 | 3.9 | 11.8 | 9.5 | 5.2 | |
| 20 | *Georgia* | 3.0 | 2.5 | 8.9 | 7.7 | 3.7 | 4.6 | 10.9 | 6.3 | 14.0 |
| 21 | *Germany* | 0.6 | 0.4 | −1.9 | 1.1 | 0.6 | −3.1 | 1.7 | 1.1 | −5.0 |
| 22 | *Ghana* | 10.8 | 9.0 | | 13.1 | 13.3 | 12.0 | 25.4 | 23.4 | |
| 23 | *Greece* | 3.2 | 1.3 | 3.2 | −0.3 | 1.2 | 0.6 | 2.8 | 2.6 | 3.8 |
| 24 | *Guatemala* | 3.1 | 1.5 | 3.9 | 5.4 | 3.3 | −2.0 | 8.7 | 4.9 | 1.8 |
| 25 | *Hungary* | 4.8 | 2.7 | 2.7 | 1.3 | 2.1 | 1.5 | 6.2 | 4.9 | 4.3 |
| 26 | *India* | 4.1 | 1.7 | 0.5 | 9.0 | 4.2 | 4.0 | 13.4 | 6.0 | 4.5 |
| 27 | *Indonesia* | 5.6 | 3.9 | 2.9 | 8.8 | 5.9 | 8.0 | 14.9 | 10.0 | 11.1 |
| 28 | *Ireland* | 3.4 | 1.6 | 1.6 | 0.2 | −0.2 | −4.6 | 3.7 | 1.5 | −3.1 |
| 29 | *Italy* | 1.4 | 1.1 | 4.1 | 0.8 | 1.0 | −0.1 | 2.2 | 2.1 | 4.0 |
| 30 | *Japan* | -0.1 | −0.6 | −0.5 | −0.3 | −0.7 | −9.6 | −0.4 | −1.3 | −10.0 |
| 31 | *Kenya* | 3.0 | 1.7 | | 8.0 | 4.8 | 4.9 | 11.3 | 6.6 | |
| 32 | *Jordan* | 3.2 | 0.7 | | 6.9 | 4.7 | 9.5 | 10.3 | 5.4 | |
| 33 | *Lebanon* | 1.1 | 0.1 | 10.5 | 5.9 | 2.5 | 7.0 | 7.0 | 2.6 | 18.3 |
| 34 | *Malaysia* | 4.4 | 1.6 | | 5.9 | 1.9 | 1.9 | 10.6 | 3.5 | |
| 35 | *Mexico* | 3.7 | 2.5 | 3.3 | 4.3 | 2.8 | 4.6 | 8.2 | 5.4 | 8.1 |
| 36 | *Moldova* | 8.5 | 4.4 | 6.3 | 7.5 | 5.4 | 4.0 | 16.7 | 10.0 | 10.5 |
| 37 | *Morocco* | 2.1 | 0.4 | 0.1 | 4.0 | 1.2 | 2.6 | 6.2 | 1.6 | 2.7 |
| 38 | *Mozambique* | 5.5 | 3.5 | | 7.1 | 4.4 | 4.5 | 13.0 | 8.1 | |
| 39 | *Netherlands* | 1.5 | 1.2 | 0.1 | 0.7 | 0.8 | 1.2 | 2.2 | 1.9 | 1.3 |
| 40 | *New Zealand* | 3.0 | 1.0 | 0.4 | 2.6 | 1.4 | 1.5 | 5.7 | 2.4 | 1.9 |
| 41 | *Niger* | 2.7 | 1.2 | | 4.7 | 2.3 | 3.0 | 7.6 | 3.6 | |
| 42 | *Nigeria* | 11.4 | 5.4 | | 10.8 | 9.9 | 9.5 | 23.5 | 15.8 | |
| 43 | *Norway* | 3.0 | 1.4 | −0.8 | 4.5 | 2.7 | 6.0 | 7.6 | 4.1 | 5.1 |
| 44 | *Oman* | 4.7 | 2.3 | 3.6 | 9.7 | 4.5 | 6.1 | 14.9 | 6.9 | 9.9 |
| 45 | *Paraguay* | 6.1 | 4.6 | 11.6 | 6.7 | 3.6 | 7.5 | 13.2 | 8.4 | 20.0 |
| 46 | *Peru* | 2.2 | 0.9 | 5.3 | 6.3 | 2.3 | 8.7 | 8.7 | 3.3 | 14.4 |
| 47 | *Poland* | 2.2 | 1.1 | 0.9 | 3.9 | 1.6 | 1.7 | 6.2 | 2.7 | 2.6 |
| 48 | *Portugal* | 1.8 | 1.3 | | 0.4 | 0.7 | −2.0 | 2.2 | 2.0 | |
| 49 | *Serbia* | 14.0 | 10.7 | | 6.5 | 5.0 | 5.5 | 21.4 | 16.2 | |
| 50 | *Slovakia* | 3.9 | 1.8 | −1.7 | 2.2 | 0.8 | −0.2 | 6.2 | 2.6 | −1.9 |
| 51 | *South Africa* | 4.8 | 2.9 | 3.5 | 6.3 | 4.0 | 5.3 | 11.4 | 7.1 | 9.0 |
| 52 | *South Korea* | 2.7 | 1.2 | 1.7 | 2.9 | 1.2 | 0.7 | 5.7 | 2.4 | 2.4 |
| 53 | *Spain* | 3.2 | 1.7 | 16.9 | 0.6 | 0.8 | −7.5 | 3.8 | 2.6 | 8.2 |

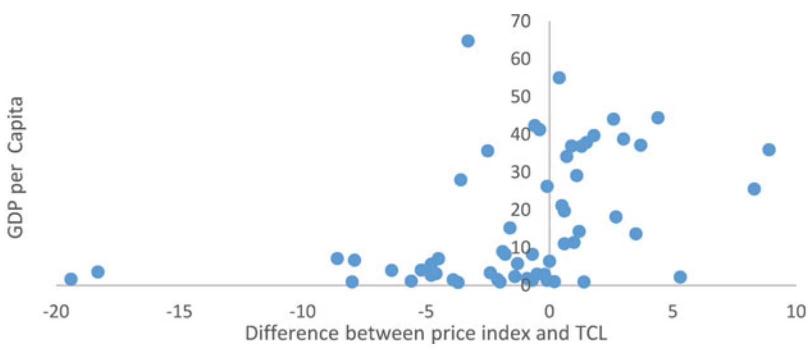
*(continued)*

Copyright © 2017 by the IAEE. All rights reserved.

**Table 4: Total cost, price level, cost of living – annual average growth rates 2000–2012 CLI : Cost of Living Index** *(continued)*

| | | Annual average growth rate 2000 to 2005 | | | Annual average growth rate 2005 to 2012 | | | Annual average growth rate 2000 to 2012 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Country | Cost | Deflator | TCL | Cost | Deflator | TCL | Cost | Deflator | TCL |
| 54 | *Sudan* | 5.9 | 4.0 | 7.0 | 10.0 | 5.8 | 25.2 | 16.5 | 10.1 | 34.0 |
| 55 | *Sweden* | 1.5 | 0.6 | −2.7 | 2.2 | 1.1 | −1.5 | 3.8 | 1.7 | −4.2 |
| 56 | *Switzerland* | 0.8 | 0.3 | 1.7 | 1.6 | 0.6 | 0.2 | 2.5 | 1.0 | 1.9 |
| 57 | *Thailand* | 3.2 | 1.0 | 0.1 | 3.5 | 1.9 | 2.1 | 6.8 | 2.9 | 2.1 |
| 58 | *Tunisia* | 3.3 | 1.3 | | 5.1 | 2.1 | 20.4 | 8.6 | 3.4 | |
| 59 | *Turkey* | 12.3 | 9.9 | | 6.2 | 4.4 | 5.1 | 19.3 | 14.8 | |
| 60 | *Ukraine* | 10.2 | 5.0 | | 14.7 | 9.2 | 9.5 | 26.5 | 14.7 | |
| 61 | *UAE* | | | | 6.3 | 4.7 | 8.3 | | | |
| 62 | *UK* | 2.5 | 0.9 | 0.5 | 1.6 | 1.4 | −0.1 | 4.1 | 2.4 | 0.4 |
| 63 | *USA* | 2.3 | 1.0 | 1.3 | 1.9 | 1.1 | 1.7 | 4.2 | 2.1 | 3.0 |
| 64 | *Vietnam* | 5.6 | 2.7 | | 11.2 | 7.3 | 8.5 | 17.4 | 10.2 | |

**Figure 3: Overestimation of the statistical index and GDP per Capita**




trast, underestimation of the price index is shown in France, Italy, Mexico, the Philippines, Morocco and Brazil. In general, the bias is within a reasonable range.

### 4.4 Scenarios for Renewables Penetration in 2035

We constructed different scenarios for RES penetration in 2035, according to several assumptions for price dynamics of RES and fossil fuels. The scenarios were constructed using the data derived from equation (8) and (9), which are available for 105 countries,[8] as follows (see Table 5).

Scenario 1 is constructed with the assumption of inertial development of RES and prices. Scenario 2 includes a $P_{fossil}$ gradual increase according to the Hotelling rule at a 0.5% real increase per year. Scenario 3 comprises Scenario 2 plus a moderate target increase in the penetration of RES—an additional 30% with respect to the present (year 2014)—which represents a moderate policy effect. Scenario 4 is made up of Scenario 2 plus a more aggressive target increase in

8. Out of the 117 countries for which we estimated the demand system, we were able to compile data of LCOE for 105 countries. That explains the difference in the total.

Copyright © 2017 by the IAEE. All rights reserved.

**Table 5: Description of various scenarios in 2035**

| *Scenario* | *Description* |
|---|---|
| 1 | RES development and prices: inertial growth |
| 2 | Fossil price development: 0.5% annual growth |
| 3 | Fossil price development: 0.5% annual growth<br>Moderate RES policy: max RES penetration +30% |
| 4 | Fossil price development: 0.5% annual growth<br>Aggressive RES policy: max RES penetration +50% |

RES of an additional 50%, reflecting a more dedicated policy intervention. For each country we take the technological constraint of maximum feasible capacity of wind and solar development and we incorporate this binding constraint in Scenarios 3 and 4. For example, if a country starts in 2014 with 5% of solar capacity and has a potential target of +30%, but a technical constraint results in a maximum 25% share for solar in projected energy consumption in 2035, then we limit the additional increase in 2035 to +20%—the initial 5% plus the feasible addition of 20%—to reach the binding level of 25%. We include in all Scenarios a projected reduction of the price of RES, according to the forecast of the learning rate and expected technological development to 2035, as discussed in Section 2.

We report the new expenditure changes and the percentage change in consumer surplus changes for the countries according to the four Scenarios in Table 6.

These represent the welfare benefits for households according to the net effect of the Hotelling increase in fossil fuel prices and the price reduction of RES associated with technological advancement. The overall net effect is negative. In other words, the increase in fossil fuel use is mitigated by the penetration of RES, which have a trend toward cost reduction. Our results show that some countries with the capacity to develop higher RES shares can as a result experience lower cost increases. For example, these include some developing Latin American countries, like Bolivia, Ecuador, Guatemala, Panama, but also some energy-rich countries like Nigeria, Egypt, UAE and, to a lesser extent, Saudi Arabia. In other words, we expect energy expenditure would increase in the absence of RES, according to Hotelling's predictions, but diffusion of RES tempers this trend. The general forecast of the Scenario simulations is that RES implementation can partially reduce the cost increase that results from the growing scarcity of fossil sources in 2035.

The correlation of the surplus change with the GDP per capita is shown in Figure 4, with a weak positive correlation of 0.19. The correlation of the surplus change with the HDD measure is shown in Figure 5. There is a negative correlation between surplus change and HDD, which is stronger in the case of high HDD countries. This implies that the RES benefit is positively associated with climatic advantage.

In absolute terms, the group of countries which benefit most in Scenario 4 includes Greece, Indonesia, Algeria, Slovakia and Italy. They can achieve a net cost reduction, compared with the inertial baseline (Scenario 1), of up to 3%. In the medium range of increased benefit we find countries such as South Korea, New Zealand and other European economies on the lower band of GDP. Among the least performing group of countries in term of additional benefits of RES implementation are Nigeria, Romania, Peru and Bangladesh.

In relative terms, the beneficial increase from Scenarios 2 to 4 demonstrates the validity of an aggressive RES friendly policy and is set to achieve the maximum outcome for the following

Copyright © 2017 by the IAEE. All rights reserved.

**Table 6: Scenarios of RES deployment leading to 2035 Energy expenditure and changes**

| | | *Scenario 1* | | *Scenario 2* | | *Scenario 3* | | *Scenario 4* | |
|---|---|---|---|---|---|---|---|---|---|
| | | Exp | Surp | Exp | Surp | Exp | Surp | Exp | Surp |
| 1 | *Albania* | 100.00 | 0.00% | 110.92 | −11.61% | 106.26 | −6.96% | 103.15 | −3.61% |
| 2 | *Algeria* | 99.96 | 0.06% | 108.86 | −11.63% | 102.60 | −3.72% | 98.54 | 2.23% |
| 3 | *Angola* | 100.00 | 0.00% | 112.91 | −11.51% | 107.52 | −7.03% | 103.92 | −3.79% |
| 4 | *Australia* | 99.87 | 0.23% | 106.39 | −11.00% | 103.80 | −6.64% | 102.01 | −3.56% |
| 5 | *Austria* | 99.90 | 0.19% | 106.19 | −10.95% | 103.86 | −6.99% | 102.28 | −4.20% |
| 6 | *Bahrain* | 100.00 | 0.00% | 110.44 | −11.64% | 106.72 | −7.76% | 104.24 | −5.01% |
| 7 | *Bangladesh* | 100.00 | 0.00% | 112.81 | −11.51% | 109.73 | −8.99% | 107.67 | −7.22% |
| 8 | *Belarus* | 100.00 | 0.00% | 112.54 | −11.52% | 108.85 | −8.41% | 106.38 | −6.21% |
| 9 | *Belgium* | 99.53 | 0.72% | 107.19 | −10.22% | 103.83 | −5.62% | 101.56 | −2.34% |
| 10 | *Benin* | 100.00 | 0.00% | 108.69 | −11.73% | 106.54 | −9.03% | 105.10 | −7.16% |
| 11 | *Bolivia* | 100.00 | 0.00% | 106.86 | −11.83% | 106.65 | −11.47% | 106.51 | −11.23% |
| 12 | *Bosnia-Herzegovina* | 100.00 | 0.00% | 112.57 | −11.53% | 107.34 | −7.06% | 103.85 | −3.82% |
| 13 | *Brazil* | 100.00 | 0.00% | 107.51 | −11.59% | 105.40 | −8.47% | 103.97 | −6.30% |
| 14 | *Brunei* | 100.00 | 0.00% | 119.37 | −11.20% | 110.85 | −6.71% | 105.21 | −3.38% |
| 15 | *Bulgaria* | 99.46 | 0.55% | 111.60 | −10.53% | 105.46 | −5.24% | 101.36 | −1.36% |
| 16 | *Burundi* | 100.00 | 0.00% | 106.32 | −11.87% | 103.28 | −6.29% | 101.18 | −2.30% |
| 17 | *Cameroon* | 100.00 | 0.00% | 110.54 | −11.63% | 107.86 | −8.91% | 106.08 | −7.01% |
| 18 | *Canada* | 99.99 | 0.01% | 112.67 | −11.32% | 108.77 | −8.10% | 106.16 | −5.83% |
| 19 | *Chile* | 99.94 | 0.08% | 109.39 | −11.34% | 105.82 | −7.27% | 103.43 | −4.37% |
| 20 | *China* | 99.95 | 0.08% | 108.47 | −11.36% | 105.68 | −7.83% | 103.81 | −5.35% |
| 21 | *Colombia* | 100.00 | 0.00% | 111.59 | −11.57% | 108.25 | −8.47% | 106.01 | −6.30% |
| 22 | *Congo DR* | 100.00 | 0.00% | 103.36 | −12.04% | 102.49 | −9.06% | 101.91 | −7.02% |
| 23 | *Costa Rica* | 100.00 | 0.00% | 112.12 | −11.55% | 107.24 | −7.22% | 103.98 | −4.10% |
| 24 | *Cote d'Ivoire* | 100.00 | 0.00% | 110.26 | −11.65% | 106.45 | −7.60% | 103.91 | −4.72% |
| 25 | *Croatia* | 99.95 | 0.05% | 111.97 | −10.89% | 107.99 | −7.54% | 105.33 | −5.16% |
| 26 | *Czech Rep.* | 99.72 | 0.34% | 110.06 | −11.09% | 104.69 | −5.44% | 101.09 | −1.31% |
| 27 | *Denmark* | 99.85 | 0.32% | 103.31 | −6.86% | 101.46 | −3.11% | 100.22 | −0.48% |
| 28 | *Dominican Rep.* | 100.00 | 0.00% | 100.79 | −12.20% | 100.50 | −7.79% | 100.30 | −4.75% |
| 29 | *Ecuador* | 100.00 | 0.00% | 109.53 | −11.69% | 107.04 | −8.81% | 105.36 | −6.81% |
| 30 | *Egypt* | 100.00 | 0.01% | 105.54 | −11.80% | 103.76 | −8.34% | 102.60 | −5.92% |
| 31 | *El Salvador* | 100.00 | 0.00% | 105.63 | −11.91% | 103.47 | −7.53% | 102.01 | −4.45% |
| 32 | *Estonia* | 100.00 | 0.00% | 112.67 | −11.00% | 108.69 | −7.82% | 106.05 | −5.57% |
| 33 | *Ethiopia* | 100.00 | 0.00% | 111.47 | −11.02% | 108.05 | −7.99% | 105.77 | −5.86% |
| 34 | *Finland* | 100.00 | 0.00% | 106.76 | −11.68% | 105.09 | −8.94% | 103.96 | −7.04% |
| 35 | *France* | 99.89 | 0.15% | 108.87 | −11.14% | 105.45 | −7.05% | 103.14 | −4.14% |
| 36 | *Gabon* | 100.00 | 0.00% | 102.21 | −12.11% | 101.66 | −9.04% | 101.28 | −6.94% |
| 37 | *Gambia* | 100.00 | 0.00% | 124.90 | −10.96% | 114.05 | −6.64% | 106.83 | −3.40% |
| 38 | *Georgia* | 100.00 | 0.00% | 107.15 | −11.82% | 104.70 | −7.93% | 103.04 | −5.20% |
| 39 | *Germany* | 99.34 | 0.92% | 107.43 | −9.49% | 103.64 | −4.82% | 101.09 | −1.48% |
| 40 | *Ghana* | 100.00 | 0.00% | 111.09 | −11.60% | 108.21 | −8.81% | 106.28 | −6.86% |
| 41 | *Greece* | 99.20 | 1.54% | 104.92 | −8.90% | 101.49 | −2.78% | 99.14 | 1.65% |
| 42 | *Guatemala* | 100.00 | 0.00% | 109.36 | −11.70% | 106.80 | −8.72% | 105.09 | −6.64% |
| 43 | *Honduras* | 100.00 | 0.00% | 102.84 | −12.07% | 101.43 | −6.24% | 100.47 | −2.12% |
| 44 | *Hong-Kong* | 100.00 | 0.00% | 110.16 | −11.65% | 105.15 | −6.19% | 101.78 | −2.22% |
| 45 | *Hungary* | 99.97 | 0.03% | 110.91 | −11.32% | 107.41 | −7.94% | 105.06 | −5.55% |
| 46 | *Iceland* | 100.00 | 0.00% | 122.01 | −8.01% | 112.64 | −4.90% | 106.45 | −2.62% |
| 47 | *India* | 99.94 | 0.05% | 113.48 | −11.26% | 110.90 | −9.26% | 109.16 | −7.88% |
| 48 | *Indonesia* | 99.17 | 0.71% | 113.56 | −10.43% | 103.41 | −2.82% | 96.48 | 3.08% |
| 49 | *Ireland* | 100.00 | 0.00% | 104.53 | −9.74% | 102.86 | −6.27% | 101.74 | −3.86% |
| 50 | *Italy* | 99.35 | 1.31% | 104.66 | −9.05% | 101.77 | −3.52% | 99.78 | 0.44% |
| 51 | *Jamaica* | 100.00 | 0.00% | 113.01 | −11.50% | 107.35 | −6.84% | 103.58 | −3.45% |
| 52 | *Japan* | 99.88 | 0.34% | 104.06 | −11.36% | 101.79 | −5.12% | 100.22 | −0.65% |
| 53 | *Jordan* | 100.00 | 0.00% | 111.92 | −11.56% | 107.89 | −7.94% | 105.20 | −5.36% |

*(continued)*

Copyright © 2017 by the IAEE. All rights reserved.

**Table 6: Scenarios of RES deployment leading to 2035 Energy expenditure and changes** *(continued)*

| | | ***Scenario 1*** | | ***Scenario 2*** | | ***Scenario 3*** | | ***Scenario 4*** | |
|---|---|---|---|---|---|---|---|---|---|
| | | Exp | Surp | Exp | Surp | Exp | Surp | Exp | Surp |
| 54 | *Kazakhstan* | 100.00 | 0.00% | 100.17 | −12.24% | 100.10 | −6.95% | 100.05 | −3.27% |
| 55 | *Kenya* | 100.00 | 0.00% | 108.27 | −8.09% | 104.81 | −4.87% | 102.51 | −2.59% |
| 56 | *Kyrgyz Rep.* | 100.00 | 0.00% | 111.38 | −11.59% | 108.38 | −8.78% | 106.38 | −6.82% |
| 57 | *Lebanon* | 100.00 | 0.00% | 111.74 | −11.57% | 107.00 | −7.19% | 103.82 | −4.03% |
| 58 | *Luxembourg* | 99.64 | 0.35% | 112.78 | −11.00% | 108.96 | −7.98% | 106.42 | −5.85% |
| 59 | *Mauritania* | 100.00 | 0.00% | 99.22 | −12.30% | 99.68 | −6.18% | 99.92 | −1.91% |
| 60 | *Mexico* | 99.99 | 0.02% | 110.52 | −11.19% | 107.38 | −8.04% | 105.26 | −5.82% |
| 61 | *Moldova* | 100.00 | 0.00% | 112.19 | −11.55% | 106.75 | −6.71% | 103.11 | −3.20% |
| 62 | *Mongolia* | 100.00 | 0.00% | 113.39 | −11.48% | 107.63 | −6.89% | 103.79 | −3.55% |
| 63 | *Morocco* | 100.00 | 0.00% | 106.26 | −11.87% | 103.13 | −6.10% | 100.98 | −1.95% |
| 64 | *Nepal* | 100.00 | 0.00% | 128.45 | −10.81% | 113.33 | −5.64% | 103.49 | −1.59% |
| 65 | *Netherlands* | 99.92 | 0.11% | 109.00 | −10.94% | 105.93 | −7.42% | 103.87 | −4.94% |
| 66 | *New Zealand* | 99.98 | 0.03% | 105.20 | −9.42% | 103.20 | −5.92% | 101.86 | −3.48% |
| 67 | *Nicaragua* | 100.00 | 0.00% | 109.06 | −11.71% | 105.67 | −7.60% | 103.41 | −4.69% |
| 68 | *Niger* | 100.00 | 0.00% | 105.70 | −11.90% | 103.81 | −8.11% | 102.53 | −5.45% |
| 69 | *Nigeria* | 100.00 | 0.00% | 112.90 | −11.51% | 109.28 | −8.55% | 106.86 | −6.46% |
| 70 | *Norway* | 100.00 | 0.00% | 107.80 | −11.61% | 105.49 | −8.32% | 103.92 | −6.03% |
| 71 | *Oman* | 100.00 | 0.00% | 114.66 | −11.42% | 107.70 | −6.24% | 102.90 | −2.42% |
| 72 | *Pakistan* | 100.00 | 0.00% | 110.98 | −11.58% | 107.86 | −8.56% | 105.78 | −6.44% |
| 73 | *Panama* | 100.00 | 0.00% | 108.02 | −11.77% | 106.05 | −9.05% | 104.72 | −7.16% |
| 74 | *Paraguay* | 100.00 | 0.00% | 112.02 | −11.55% | 107.96 | −7.94% | 105.25 | −5.36% |
| 75 | *Peru* | 100.00 | 0.00% | 109.55 | −11.69% | 106.96 | −8.72% | 105.22 | −6.65% |
| 76 | *Philippines* | 99.81 | 0.24% | 109.26 | −10.26% | 106.23 | −7.11% | 104.21 | −4.90% |
| 77 | *Poland* | 100.00 | 0.00% | 110.64 | −11.13% | 107.50 | −8.07% | 105.40 | −5.93% |
| 78 | *Portugal* | 99.95 | 0.16% | 103.24 | −9.25% | 101.99 | −5.76% | 101.14 | −3.34% |
| 79 | *Qatar* | 100.00 | 0.00% | 112.95 | −11.51% | 108.33 | −7.71% | 105.24 | −4.99% |
| 80 | *Romania* | 99.59 | 0.42% | 111.70 | −10.59% | 108.80 | −8.18% | 106.86 | −6.49% |
| 81 | *Russia* | 100.00 | 0.00% | 112.89 | −11.51% | 109.15 | −8.45% | 106.66 | −6.29% |
| 82 | *Saudi Arabia* | 100.00 | 0.00% | 99.69 | −12.27% | 99.83 | −7.15% | 99.92 | −3.60% |
| 83 | *Senegal* | 100.00 | 0.00% | 111.75 | −11.57% | 107.89 | −8.05% | 105.31 | −5.56% |
| 84 | *Serbia* | 100.00 | 0.00% | 112.64 | −11.52% | 108.45 | −8.00% | 105.66 | −5.49% |
| 85 | *Slovakia* | 99.72 | 0.42% | 108.15 | −11.17% | 102.67 | −3.86% | 98.95 | 1.57% |
| 86 | *Slovenia* | 99.73 | 0.28% | 112.07 | −11.18% | 103.66 | −3.67% | 98.05 | 2.07% |
| 87 | *South Africa* | 99.88 | 0.09% | 115.11 | −11.23% | 106.91 | −5.38% | 101.24 | −1.00% |
| 88 | *South Korea* | 99.94 | 0.08% | 109.58 | −11.57% | 105.50 | −6.85% | 102.71 | −3.45% |
| 89 | *Spain* | 99.80 | 0.62% | 103.32 | −10.08% | 102.46 | −7.51% | 101.87 | −5.75% |
| 90 | *Sri-lanka* | 100.00 | 0.00% | 111.74 | −11.57% | 106.15 | −6.39% | 102.42 | −2.60% |
| 91 | *Sudan* | 100.00 | 0.00% | 112.05 | −11.55% | 106.42 | −6.43% | 102.60 | −2.69% |
| 92 | *Sweden* | 100.00 | 0.01% | 107.24 | −10.97% | 104.91 | −7.62% | 103.34 | −5.28% |
| 93 | *Switzerland* | 99.91 | 0.17% | 106.21 | −11.64% | 102.50 | −4.85% | 99.94 | 0.11% |
| 94 | *Tajikistan* | 100.00 | 0.00% | 100.81 | −12.20% | 100.27 | −9.13% | 100.03 | −7.02% |
| 95 | *Tanzania* | 100.00 | 0.00% | 88.10 | −13.13% | 93.45 | −7.06% | 97.11 | −3.08% |
| 96 | *Thailand* | 99.91 | 0.13% | 108.65 | −11.51% | 104.23 | −5.84% | 101.21 | −1.71% |
| 97 | *Tunisia* | 100.00 | 0.00% | 111.76 | −11.57% | 105.14 | −5.38% | 100.70 | −0.77% |
| 98 | *Turkey* | 100.00 | 0.00% | 110.61 | −11.18% | 107.56 | −8.13% | 105.49 | −5.99% |
| 99 | *Uganda* | 100.00 | 0.00% | 107.06 | −11.82% | 103.53 | −6.11% | 101.13 | −1.99% |
| 100 | *Ukraine* | 99.94 | 0.06% | 113.27 | −11.35% | 107.58 | −6.82% | 103.79 | −3.52% |
| 101 | *United Arab Emirates* | 100.00 | 0.00% | 112.90 | −11.51% | 108.03 | −7.47% | 104.77 | −4.57% |
| 102 | *United Kingdom* | 99.85 | 0.19% | 108.42 | −10.45% | 105.30 | −6.76% | 103.20 | −4.15% |
| 103 | *United States* | 99.90 | 0.11% | 111.17 | −10.93% | 107.16 | −7.24% | 104.46 | −4.61% |
| 104 | *Uruguay* | 100.00 | 0.00% | 112.19 | −11.55% | 107.08 | −7.03% | 103.67 | −3.77% |
| 105 | *Vietnam* | 100.00 | 0.00% | 112.96 | −11.50% | 110.95 | −9.90% | 109.62 | −8.79% |

Copyright © 2017 by the IAEE. All rights reserved.

**Figure 4: RES Scenario 4 and GDP per Capita**

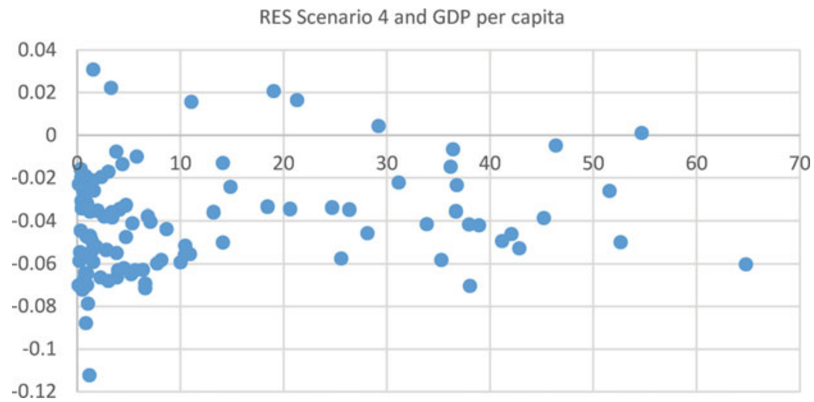
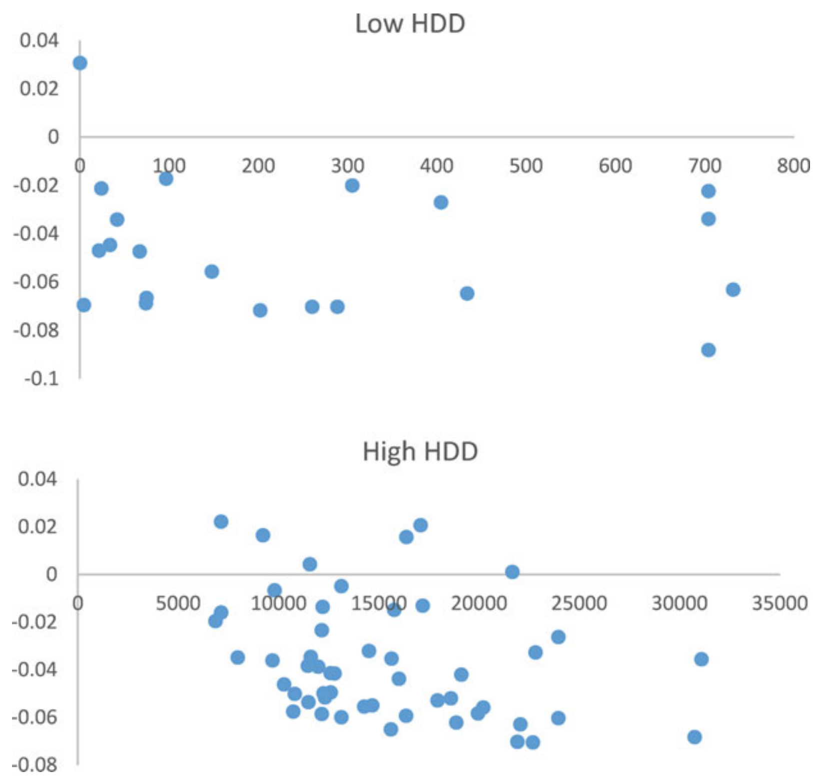



**Figure 5: RES Scenario 4 and Heating degree days countries**




countries: Algeria, Indonesia, Switzerland, Tunisia, Greece, Japan and South Africa. The bottom group includes Ghana, Cameroun, Spain, India and Vietnam among others.

## 5. SUMMARY AND POLICY IMPLICATIONS

This paper quantifies the impact of Renewables implementation on the welfare of consumers, when it is constrained by weather conditions. We have constructed a theoretical model of

Copyright © 2017 by the IAEE. All rights reserved.

household behavior for a group of 64 economies—which represent over two-thirds of the world population—that includes an empirical measure of Equivalence Scale (ES) and the True Cost of Living (TCL) for the residential sector worldwide.

We find that the equivalence scale of the temperature variables is positive and increasing, implying that an increase in degree days, all else being equal, has a positive effect on energy demand. In other words, countries with extreme weather conditions need to spend more on energy than those that have milder temperatures. In addition, we find differences between the TCL and the consumer price index as a measure of household welfare, which varies according to the level of a country's development.

We also quantify a differentiated welfare impact across countries, according to simulations of alternative scenarios for renewable energy implementation to 2035. We find an expected increase in energy cost due to higher fossil fuel prices, which rise according to Hotelling's rule, but this can be tempered if a higher share of the energy composite is met using renewable energy. This is because for renewable energy sources, unlike fossil fuel prices, renewable capital costs are expected to decline as a result of technological innovation.

Our results suggest that countries with mild weather conditions, such as sub-tropical African and Asian countries, benefit more from the deployment of RES. These countries can achieve up to 3% of net benefit in the most favorable RES scenario, compared with the inertial baseline scenario.

Our results have two general policy implications. First, a household's potential welfare improvement is conditional on the need for energy subsidies for the implementation of RES. This imposes a fiscal discipline on the policymaker to take into account resource constraints when financing renewables subsidies. Second, it allows us to offer to policymakers some basis for designing appropriate scenarios for the deployment of renewables with the aim of fostering consumer welfare in a least-cost-manner on a world scale. There is no one-size-fits-all policy recipe, so policymakers should consider the specificity of their geo-economic structure to achieve the intended results. This should alert policymakers that there is an empirical basis for undertaking more effective international negotiations on topics that have traditionally been contentious.

Our results come with three caveats. The first is that there is some uncertainty in the net effect of Hotelling's rule predicting higher fossil fuel prices resulting from long-run scarcity and short-run technological improvements and associated reductions in capital costs. The second is that households do not consume 'renewable energy' but electric power. Electricity prices, however, depend on a number of variables such as resource availability, regulatory framework, fuel costs, etc. We also need to take into greater account each country's particular characteristics when making worldwide comparisons. We judge that further research is needed to fine tune these results in the future.

Third, is the input data. The full cost of renewables is made up of system costs, which include capital costs, and resource costs, which are location based. While capital costs might be expected to decrease as more renewable technologies are deployed, locational costs are likely to increase, as the easiest sites are used first and the more difficult or expensive ones at a later date (Keay, 2013). The combined effect of these two trends is uncertain.

However, in order to facilitate broad comparisons between countries, which is one of the aims of this paper, we focus only on capital costs of the two most scalable technologies today, wind and solar, as the main driver of the 'renewable cost'.

There are also a few caveats in using LCOE as a proxy for the cost of renewables to measure welfare effects. Power generation technologies' value depends on how well their produc-

Copyright © 2017 by the IAEE. All rights reserved.

tion aligns with demand peaks, but RES are not controllable. For simplicity, however, we treat renewable sources as providing energy that is readily available for consumption. This may underestimate the total cost of meeting energy needs with renewable technologies, as more backup would be needed compared with fossil fuel technologies. Also, there is the risk of underestimating the impact on welfare from the spread of renewable generation by treating it as a technology that delivers energy and overlooking its environmental benefits. The environment is a key factor affecting wellbeing, and demand for environmental quality increases as disposable income increases, in the same way as for other consumer goods.

Nonetheless, using LCOE and the quantum of the calculations would still be valid to have an approximation of the welfare effects of the penetration of RES in many different countries throughout a long period of time. Our analysis could, of course, be refined by drilling down in specific cases and recalculating the actual integration costs with more detailed information by country or region. Our theoretical framework would support that effort.

## REFERENCES


Abraham, K., (2003). Toward a Cost-of-Living Index: Progress and Prospects, *The Journal of Economic Perspectives* 17(1), pp. 45–58. https://doi.org/10.1257/089533003321164949.

Atalla, T. N., S. Gualdi, and A. Lanza (2015). *A Global Degree Days Database for Energy-Related Applications*. KAPSARC working paper KS-1514-DP08A. Available at SSRN https://papers.ssrn.com/sol3/papers.cfm?abstract_id = 2586960, accessed on November 30, 2016.

Atalla, T. N., S. Bigerna, and C. A. Bollino (2016). *Energy Demand Elasticities and Weather Worldwide*. Available at SSRN: https://ssrn.com/abstract = 2697214, accessed on November 30, 2016.

Atalla, T. N., and L. C. Hunt (2016). Modelling residential electricity demand in the GCC countries. *Energy Economics*, 59, 149–158. http://dx.doi.org/10.1016/j.eneco.2016.07.027.

Auffhammer, M. and E. T. Mansur (2014). Measuring climatic impacts on energy consumption: A review of the empirical literature, *Energy Economics* 46, pp.522–530. https://doi.org/10.1016/j.eneco.2014.04.017.

Banks J., R. Blundell, and A. Lewbel (1997). Quadratic Engel Curves and Consumer Demand, *The Review of Economics and Statistics* 79(4), pp. 527–539. https://doi.org/10.1162/003465397557015.

Bašta, M. and K. Helman (2013). Scale-specific importance of weather variables for explanation of variations of electricity consumption: The case of Prague, Czech Republic, *Energy Economics* 40, pp.503–514. https://doi.org/10.1016/j.eneco.2013.07.023.

Beaver, R. D. and H. G. Huntington (1992). A comparison of aggregate energy demand models for global warming policy analyses, *Energy Policy* 20(6), pp. 568–574. https://doi.org/10.1016/0301-4215(92)90024-V.

Bollino, C. A., F. Perali, and N. Rossi (2000). Linear Household technologies, *Journal of Applied Econometrics* 15(3), pp.275–288. https://doi.org/10.1002/1099-1255(200005/06)15:3<275::AID-JAE560>3.0.CO;2-Q.

Bollino, C. A. (1987). Gaids: a generalized version of the almost ideal demand system. *Economic Letters* 23(2), pp.199–202. https://doi.org/10.1016/0165-1765(87)90039-5.

Deaton, A. S. and J. Muellbauer (1980), An almost ideal demand system, in American Economic Review, 70(3), pp. 312–326.

Deaton, A. S. and J. Muellbauer (1986), On Measuring Child Costs: With Applications to Poor Countries, *Journal of Political Economy* 94(4), pp.720–744. https://doi.org/10.1086/261405.

EIA, (2016), Levelized Cost and Levelized Avoided Cost of New Generation Resources in the *Annual Energy Outlook 2016*. Available at https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf (accessed on February 7, 2017)

Elshurafa, A. M. and S. R. Albardi (2015). The KAPSARC Solar Photovoltaic Toolkit. *Publication number KS-1630-MP024A*. available at: https://www.kapsarc.org/wp-content/uploads/2016/06/KS-1633-MP027A-Solar-Photovoltaic-Toolkit1.pdf, accessed 15 Dec. 2016.

European Council, (2014). European Council (23/24 October 2014) – *Conclusions. EUCO 169/14; 2014*. Available at: http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/145397.pdf, accessed 15 Dec. 2016.

Flaig, G. (1990). Household production and the short- and long-run demand for electricity, *Energy Economics* 12(2), pp 116–121. https://doi.org/10.1016/0140-9883(90)90045-H.

Fry V. and P. Pashardes (1989). Constructing the True Cost of Living Index from the Engel Curves of the Piglog Model, *Journal of Applied Econometrics* 4, pp.41–56. https://doi.org/10.1002/jae.3950040104.


Copyright © 2017 by the IAEE. All rights reserved.

Gorman, W. M. (1959). Separable Utility and Aggregation, *Econometrica* 27(3), pp. 469–481. https://doi.org/10.2307/1909472.

Gorman, W. M. (1981). "Some Engel Curves," in *The Theory and Measurement of Consumer Behaviour*; Angus Deaton (ed.), Cambridge, UK: Cambridge University Press.

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K. C. Mo, C. Ropelewski, J. Wang, A. Leetmaa, R. Reynolds, R. Jenne, and D. Joseph (1996). The NCEP/NCAR 40-year reanalysis project, *Bulletin of the American Meteorological Society* 77(3), pp.437–472. https://doi.org/10.1175/1520-0477(1996)077＜0437:TNYRP＞2.0.CO;2.

Keay, M. (2013). *Renewable Energy Targets: the Importance of System and Resource Costs*. Oxford Energy Comment, OIES. Available at; https://www.oxfordenergy.org/wpcms/wp-content/uploads/2013/02/Renewable-energy-targets-the-importance-of-system-and-resource-costs.pdf, accessed 15 Dec. 2016.

International Energy Agency (2016). *World Energy Outlook 2015*, OECD/IEA, Paris.

International Renewable Energy Agency (2012). *Renewable Power Generation Cost in 2012*. IRENA, Abu Dhabi. available at: https://costing.irena.org/media/2769/Overview_Renewable-Power-Generation-Costs-in-2012.pdf , accessed 30 Nov. 2016.

International Renewable Energy Agency (2015). *Renewable Power Generation Cost in 2014*, IRENA, Abu Dhabi. available at: https://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Power_Costs_2014_report.pdf

Lewbel, A. and K. Pendakur (2009). Tricks with Hicks: The EASI Demand System. *American Economic Review* 99(3), pp. 827–63. https://doi.org/10.1257/aer.99.3.827.

National Renewable Energy Laboratory (2011). *Cost and Performance Data for Power Generation Technologies*. NREL, Denver. Available at: http://www.nrel.gov/analysis/data_resources.html, accessed 30 nov 2016.

Meier, H., T. Jamasb, and L. Orea (2013). Necessity or Luxury Good? Household Energy Spending and Income in Britain 1991–2007, *Energy Journal* 34(4), pp. 109–128. https://doi.org/10.5547/01956574.34.4.6.

OECD, (2008). Environmental Outlook to 2030. Organisation for Economic Co-operation and Development (OECD), available at: http://www.oecd.org. https://doi.org/10.1787/9789264040519-en.

Pollak, R. A. (1991). "Welfare comparisons and situation comparisons", *Journal of Econometrics* 50(1–2), pp. 31–48. https://doi.org/10.1016/0304-4076(91)90088-U.

Pollak, R. A. and T. Wales (1979). Welfare Comparisons and Equivalence Scales, *The American Economic Review* 69(2), Papers and Proceedings of the Ninety-First Annual Meeting of the American Economic Association, pp. 216–221.

Pollak, R. A. and T. Wales (1981). Demographic Variables in Demand Analysis, *Econometrica* 49(6), pp. 1533–1551. https://doi.org/10.2307/1911416.

Rowland, C. S., J. W. Mjelde, and Dharmasena (2017). Policy Implications of Considering Pre-commitments in U.S. Aggregate Energy Demand System, *Energy Policy* 102, pp 406–413. https://doi.org/10.1016/j.enpol.2016.12.041.

Schaffrin, A. and N. Reiblin (2015). Household energy and climate mitigation policies: Investigating energy practices in the housing sector *Energy Policy* 77, pp. 1–10. https://doi.org/10.1016/j.enpol.2014.12.002.

Sener (2012a). *Iniciativa para el Desarrollo de las Energias Renovables en Mexico: Energia Eolica*, Mexico D.F., available at: www.amdee.org, accessed 30 Nov. 2016.

Sener (2012b). *Iniciativa para el Desarrollo de las Energias Renovables en Mexico: Energia Solar FV*, Mexico D.F. available at: www.amdee.org, accessed 30 Nov. 2016.

SOLARGIS (2016). *GIS data and maps*. http://solargis.com/products/maps-and-gis-data/?_ga = 1.16688115.414012670.1490200826, accessed 30 Nov., 2016.

Steinbuks, J. and K. Neuhoff (2014). Assessing energy price induced improvements in efficiency of capital in OECD manufacturing industries, *Journal of Environmental Economics and Management* 68, pp. 340–356. https://doi.org/10.1016/j.jeem.2014.07.003.

Triplett, J. E. (2001). Should the Cost-of-Living Index Provide the Conceptual Framework for a Consumer Price Index?, *The Economic Journal* 111, pp. F311-F334. https://doi.org/10.1111/1468-0297.00633.

VASALA (2016). *3TIER Data, Power and Energy section*. http://www.vaisala.com/ en/energy/pages/default.aspx?utm_medium = direct&utm_source = alias&utm_content = energy, accessed November 30, 2016.

Willett, K. and S. Naghshpour (1987).Residential demand for energy commodities: A household production function approach, *Energy Economics* 9(4), pp.251–256. https://doi.org/10.1016/0140-9883(87)90032-6.

World Bank (2014), *World Development Indicators 2014*, available at: http://data.worldbank.org/data-catalog/world-development-indicators, accessed on May 21, 2016.

Copyright © 2017 by the IAEE. All rights reserved.

Connect with
IAEE
on facebook