Households and Sustainable Green Technologies: A Review

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Abstract: There is widespread consensus in the climate research community that households show different attitudes toward the broad spectrum of technologies and policy instruments implemented to reduce CO2 emissions. The aim of this paper is to investigate the monetary aspect of socio-economic acceptability of four sustainable green technologies development: green electricity, energy savings in residential buildings, smart meters and alternative fuel vehicles. We obtained information on willingness to pay, and/or willingness to accept, for such technologies from a sample of 35 papers taken from the literature. We homogenize this information computing an implicit price of a Kg of CO2 avoided, named PCO2. A qualitative analysis is carried out to explain the households' attitude to avoid CO2 in monetary terms. Results show that on average PCO2 is positive. There are, however, some negative attitudes only in the case of alternative fuel vehicles. In conclusion, empirical results show that households have a favorable attitude toward sustainable green technologies, but further research is desirable to design new policies to make the future of the sustainable society more plausible.

1 INTRODUCTION

Two-thirds of global greenhouse-gases (GHG) emissions and CO2 emissions are related to the energy sector. GHG emissions have been growing over time. Indeed, in 1990 they amounted to 20.6 gigatonnes, and it is expected that GHG emissions will amount to 36.7 gigatonnes in 2040 (IEA, 2015). For this reason, global policies are aimed at the mitigation of climate change, through the implementation of sustainable patterns of consumption and production. Consumption and production are the core of the world economy, but the current models have a negative impact on the environment. On the demand-side, households play an important role through the adoption of environmental friendly behavior. For the reduction of CO2 emissions it is important to assess public environmental awareness, namely willingness to accept (WTA) and/or willingness to pay (WTP) (Banfi et al., 2008; Achtnicht, 2012). Our paper fits in the current debate on measures to combat climate change (COP21, December 2015), with the aim of reviewing and evaluating the socio-economic acceptability of four main sustainable green technologies (SGT). In particular, we recognize that acceptability is strongly related to the socio-economic barriers for SGT development. We homogenize the heterogeneous information acquired in the literature to compute the implicit price of a Kg of CO2 avoided, here named PCO2. The paper is organized as follows. Section 2 provides the description of the SGT. Section 3 presents data and methods. Section 4 presents results and discussion. Section 5 draws conclusions.

2 SUSTAINABLE TECHNOLOGIES BACKGROUND

For this research, we have considered the available information related to the main four SGT: electricity production from renewable energy sources, e.g. green electricity (GE), energy savings in residential buildings (ESB), smart meters (SM) and alternative fuel vehicles (AFV), such as electric vehicles and biofuels (the energy storage technology is not considered). So far, there has been active research on households' attitude toward GE. Renewable energy sources (RES) mitigate environmental degradation, the depletion of the world's conventional energy sources and environmental

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issues such as GHG effect and the ozone hole. However, on average, GE is characterized by higher costs with respect to conventional fuels. Public authorities support RES because their market price is not yet competitive with existing technologies in the electricity market. A number of studies have explored the preference for and use of GE by households (Bigerna and Polinori, 2014). Results show that public interests in GE arise as efficient technologies, but households perceive that costs of renewable energy are still high (see among others Stigka et al., 2014).

ESB, such as facades and ventilation, are an opportunity to reduce energy consumption and CO2 emissions. Many buildings are facing comprehensive renovations in terms of energy savings measures and new residential buildings are built as energy-optimal as possible. Studies on households' attitudes towards ESB show that households with high income have a significant WTP for such measures with respect to households with a lower income (Banfi et al., 2008). Moreover, one of the major barriers for people not to energy-renovate their buildings seems to be lack of knowledge and interest (Tommerup and Svendsen, 2006). This lack is related to a shortcoming of transparent information about the benefits of ESB (Pelenur and Cruickshank, 2012).

Smart grids technologies have created significant opportunities for electric-grid modernization. These technologies connect producers and consumers, integrating behaviours and actions of all users connected to it. For the households, the first step towards the smart grid is the installation of a SM (Krishnamurti et al., 2012). Most of the economic literature studying households' perceptions of SM shows that households value smart metering and are even willing to pay for it. In particular, the higher the expected energy saving, the higher households' WTP for SM is (Gangale et al., 2013). However, barriers for the deployment of SM are represented by households' concerns about costs, security and privacy (Bigerna et al., 2015).

Policies to reduce gasoline consumption increasingly promote AFV as a means, among others, to enhance energy security and reduce CO2 emissions (Graham-Rowe et al., 2012). Currently, AFV represent a small market share of vehicles in service. Despite these potential advantages, significant barriers remain to the widespread adoption of AFV. The literature shows that households' WTP for AFV increases with youth, education and green life style (Ito et al., 2013). Given that these technologies are, on average, quite young, the related literature is investigating the consumers' potential WTP and WTA for SGT through the stated preference methods. The main objective of these studies is to identify people's preferences towards such technologies.

3 DATA AND METHOD

An Internet literature survey has been developed to collect information on households' WTP for the SGT. We have considered the combination of the following keywords. GE: *willingness to pay/accept, green electricity, renewable electricity, sustainable electricity*. AFV: *willingness to pay/accept, electric vehicle and alternative fuel vehicle.* ESB: *willingness to pay/accept, energy saving and residential buildings.* SM: *willingness to pay/accept, smart meters and smart metering.* All the papers have been analyzed to extrapolate information for computing the PCO2. We model the households' attitudes and perceptions towards SGT in monetary terms. With this aim we survey the literature collecting the elicited WTPs to attain some environmental benefit, possibly modifying the households' lifestyle. We identify the environmental benefit with the reduction of CO2 emissions. Consequently, the monetary values of such WTPs can be negative, if the perceived benefits are outweighed by the perceived adjustment costs. In this latter case, we refer to the concept of the WTA that is the monetary compensation required for the introduction of new SGT. We used monetary information about the WTP or WTA for each SGT, expressed in EUR per Kg of CO2 avoided per year.

First, considering the introduction of AFV, the consumers' PCO2 is computed using information on the average life, fuel efficiency, and of the average mileage of the new vehicles:

$$PCO2 = (W \,/\, Y)(V \,/\, T) \qquad (1)$$

where W is the WTP expressed as the nominal capital expenditure, Y is the vehicles' average life in years, K is the average Km per vehicle, T is the technical factor which represents the reduction of a Kg of CO2 emission per Km of the AFV with respect to conventional vehicles.

Second, considering ESB, the consumers' PCO2 is calculated taking into account the WTP expressed as the capital price (K) of dwelling for owners and, alternatively, the rental price (R) for rented apartments per month. The percentage premium the respondents are willing to pay for a given retrofitting measure is distinguished in PRh for homeowners and PRr for rented apartments. Then, the CO2 emissions (E) are computed multiplying the average TOE per dwelling consumption (C) by the conversion factor of TOE into tons of CO2:

$$E = C \cdot 2.331 \qquad (2)$$

In order to compute the PCO2, the reported energy savings percentage (S) is considered for each retrofitting measure and the number of years (N) for the amortization of the retrofitting investment. Then, the PCO2 in the case of homeowners is:

$$PCO2 = [(K\ /\ N) \cdot PRh]/(E\ /\ S) \qquad (3)$$

while, in the case of rented homes the PCO2 is:

$$PCO2 = (R \cdot 12 \cdot PRr)/(E\ /\ S) \qquad (4)$$

Thirdly, considering SM, the measure of PCO2 is constructed considering the consumers' WTP for the installation of the new device in their homes. This payment can be a one-time capital expenditure (D) or a monthly rent on the electricity bill (M) for the usage of the device. All other variables are as defined above. In the case of capital expenditure the PCO2 is:

$$\mathrm{PCO2} = (\mathrm{D/N})/(\mathrm{E} \cdot \mathrm{S}) \qquad (5)$$

and in the case of monthly rent the PCO2 is:

$$PCO2 = (M \cdot 12)/(E \cdot S) \qquad (6)$$

Fourthly, considering GE, the consumer preferences are modeled as the households' WTP for a KWh generated with RES. We compute a measure of PCO2, using an estimation of the CO2 emissions' saving. Consequently, the PCO2 is:

$$PCO2 = W \cdot \Delta G \cdot H \cdot F \qquad (7)$$

where W is the WTP for a percentage variation in the GE share, H is the households' electricity average annual consumption, ΔG is the variation in the share of GE and F is the specific CO2 emissions factor for KWh produced. This latter is specific to the electricity generation mix for each country in each period. An example of PCO2 computation for GE is now described. Bigerna and Polinori (2014) estimated eight bimonthly values of households' WTP for GE development that lie between 4.62 and 15.09 EUR. The annual average households' consumption (H) in Italy was 2,793 kWh and the RES target was 26%, implying an increase of 11% (ΔG). Given that, at the time, the RES share in Italian fuel generation mix was 15% the specific CO2 emissions factor (F) was equal to 0.3985. Applying equation (7) yields eight PCO2 values, which range from 0.26 to 0.84 EUR/Kg taking also into account the inflation adjustment of the data.

4 RESULTS AND DISCUSSION

We reviewed a vast literature comprising 35 papers published in the period 2000-2015 and we extracted from each paper the primary information (220 observations) to compute PCO2 according to equations (1) to (7) and as reported in Table 1.

We have computed the average values of PCO2 for the four technologies (Table 2), over time and for continents (Table 3) underlining the existing heterogeneity by the computation of the coefficient of variation (C.V.). The overall average value of PCO2 for the whole sample is positive, 0.065 EUR/Kg CO2. The implication of such computation is that the sample of households analyzed shows a positive amount to avoid emissions, irrespective of the type of technology. Subsequently, we have analyzed PCO2, distinguished by the four different technologies. We obtain a negative value of PCO2 for AFV, -0.066 EUR/Kg of CO2. This implies that the sample of households analyzed shows an expectation of being subsidized to implement this technology. Values are distributed in a decisive skewed pattern, with large negative values (the extreme is around -3 EUR/Kg CO2). We find positive and significant values of PCO2 for the other three technologies: 0.262 EUR/Kg for EBS, 0.418 EUR/Kg for GE and 0.134 EUR/Kg for SM. It is important to note the extreme minimum value for these last three technologies is positive. This implies that the whole sample of households analyzed shows a positive PCO2. The extreme maximum positive value for the PCO2 for ESB is around 0.916 EUR/Kg CO2, a definitely plausible value. Most of the studies on households WTP for the SGT have been conducted in Europe, followed by Asia and North America (Panels B, Table 3). Considering the analysis of the households' attitude pre and post-crisis (Panel A, Table 3), we find that the PCO2 values decrease overtime. This is the result of the impact of the economic crisis similar to the findings of Loureiro and Loomis (2010) and Metcalfe and Baker (2012). However, this difference, between pre and post crises studies, might not be robust due to the different sample size. For this reason, it is not possible to compare results over the years. Focusing on the variability of the results, there exists a great heterogeneity, especially if the authors have used different methods (Table 1), yielding a coefficient of variation range from 0.02 to 3.33. In particular, there is great variability in studies using different approaches e.g. stated and revealed preferences.

Table 1: PCO2 descriptive statistics (EUR 2014, purchasing power parity) by study.

Author(s)	Year	Observations (Obs.)	SGT	Method[1]	Mean	S.D.	C.V.
Banfi et al.	2008	16	EBS	CE	0.240	0.294	1.225
Kwak et al.	2010	4	EBS	CE	0.092	0.069	0.750
Farsi	2010	3	EBS	CE	0.034	0.032	0.941
Kesternich	2010	1	EBS	CE	0.079	--	--
Alberini et al.	2013	2	EBS	CE	0.058	0.036	0.621
Achtnicht and Madlener	2014	1	EBS	CE	0.817	--	
Zalejska and Jonsson	2014	8	EBS	CV-OE	0.479	0.084	0.175
Kaufmann et al.	2010	1	SM	CE	0.480	--	--
Gerpott and Paukert	2013	2	SM	CV-OE	0.253	0.322	1.273
Pepermans	2014	10	SM	CE	0.168	0.030	0.179
Rihar et al.	2015	5	SM	CV-DC	0.041	0.027	0.659
Ida et al.	2014	6	SM-AFV	CA	0.057	0.023	0.404
Hidrue et al.	2011	4	AFV	CE	0.023	0.036	1.565
Hackbarth and Madlener	2013	4	AFV	CE	0.061	0.037	0.607
Hoen and Koetse	2014	6	AFV	CE	-0.032	0.023	0.719
Potoglou and Kanaroglou	2007	3	AFV	CE	0.026	0.011	0.423
Mabit and Fosgerau	2011	2	AFV	CE	0.013	0.002	0.154
Achtnicht	2012	32	AFV	CE	0.019	0.046	2.421
Koetse and Hoen	2014	3	AFV	CE	-0.021	0.018	0.900
Axsen et al.	2009	5	AFV	CE-RP	-0.642	1.405	2.188
Helveston et al.	2015	28	AFV	DC-CA	-0.078	0.158	2.026
Bočkarjova et al.	2013	15	AFV	CE-RP	-0.123	0.409	3.325
Dimitropoulos	2014	9	AFV	CE-RP	-0.337	0.862	2.558
Dagsvik et al.	2002	24	AFV	CE	0.025	0.014	0.560
Bigerna and Polinori	2012	1	GE	BG	0.378	--	--
Bigerna and Polinori	2013	1	GE	BG	0.465	--	--
Bigerna and Polinori	2014	8	GE	MBDC	0.561	0.211	0.376
Kim et al.	2012	1	GE	CV-DC	0.09	--	--
Grösche and Schröder	2011	2	GE	CE	0.369	0.041	0.108
Zoric and Hrovatin	2012	2	GE	CV_DC	0.373	0.013	0.035
Yoo and Kwak	2009	4	GE	CV-DC	0.180	0.041	0.228
Ivanova	2005	2	GE	CV-DC	0.539	0.120	0.223
Batley et al.	2000	1	GE	CV	0.358	--	--
Batley et al.	2001	2	GE	CV-DC	0.381	0.009	0.024
Bollino	2009	2	GE	MBDC	0.519	0.431	0.830

[1] CE, choice experiment; CA, conjoint analysis; CV, contingent valuation; OE, open ended; DC, dichotomous choice; BG, bidding game; MBDC, multiple bounded dichotomous choice; RP, revealed preferences.

Table 2: PCO2 descriptive statistics by technology (EUR 2014, purchasing power parity).

Sample	Obs.	Mean	S.D.	[C.V.]
Overall	220	0.065	0.375	[5.769]
AFV	135	-0.066	0.385	[5.833]
EBS	35	0.262	0.268	[1.203]
SM	24	0.134	0.124	[0.925]
GE	26	0.418	0.208	[0.498]

Table 3: PCO2 descriptive statistics by period and Continent (EUR 2014, purchasing power parity).

Panel A: By period.					
Years	SGT	Obs.	Mean	S.D.	[C.V.]
2000 - 2007 (pre-crisis)	AFV/GE	32	0.090	0.158	[1.756]
2008 - 2015 (post crisis)	AFV/EBS/SM/GE	188	0.061	0.400	[6.557]
Panel B: By Continent (Oceania is omitted due the small sample size, # = 2)					
Continent	SGT	Obs.	Mean	S.D.	[C.V.]
Asia	AFV/EBS/SM/GE	29	0.042	0.102	[2.429]
Europe	AFV/EBS/SM/GE	163	0.104	0.336	[3.231]
North America	AFV	26	-0.189	0.625	[3.307]

Among several SGTs considered (Table 2) AFV shows the greatest variability, possibly because of the heterogeneity of the good under evaluation in these primary studies. AVF varies according to type of fuel, type of technology determining a great variability in the original WTP estimated. Finally, the geographical scale does not affect the results variability; indeed, in the more populous continents, which include main SGT, the coefficient of variation are close to each other.

5 CONCLUSIONS

In the current debate on measures to combat climate change, this paper provides a homogeneous measure of CO2 reduction related to the development of four major SGT. In line with the new COP21 scenario, an implicit CO2 reduction price is computed using useful information available from the prominent economic and technical literature. The reviewed papers indicate a relatively good stated acceptability of the investigated SGT as a whole even if a great heterogeneity exists. This great variability largely depends on methods used to elicit the WTP and on the difficulty to define properly the good under evaluation in the primary studies. However, results also suggest that households tend to be resistant and less supportive to new technologies especially if they are asked to bear high initial costs. In particular, households expect to be supported in monetary terms to deploy AFV.

The remaining technologies exhibit positive PCO2 values. Our results show both spatial and temporal heterogeneity in PCO2 values.

In conclusion this paper highlights that, despite barriers, households' are likely to adopt SGT to make the future of the sustainable society closer. Follow-up research will apply a quantitative method to analyze information from the reviewed papers in a deeper way in order to assess the robustness of our findings.

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