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DETERMINANTS OF SOLAR PANEL ADOPTION IN SMALL AND MEDIUM-SIZED COMMERCIAL AND SERVICE FIRMS: EVIDENCE FROM AGUASCALIENTES, MEXICO

TESINA

QUE PARA OBTENER EL TÍTULO DE

LICENCIADO EN ECONOMÍA

PRESENTA

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A mis padres,

por siempre apoyarme y creer en mí.

A Anaid,

por acompañarme incansablemente.

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Abstract

This study analyzes the determinants of solar panel adoption, focusing on small and medium-sized commercial and service firms. To find correlation between solar panel adoption and potential determinant variables, the study uses the ENCENRE 2019: a novel dataset that gathers electric consumption and socioeconomic data from 812 surveyed firms located in the city of Aguascalientes, Mexico. With this information, one econometric specification is proposed to find marginal effects of selected variables on the probability of a firm having solar panels installed using OLS and logit models. Four types of variables are found to have significant effects: electric consumption levels, specific characteristics of the firm, high energy consuming equipment, and solar and thermal related technology.

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Abbreviations

CO_2: Carbon Dioxide

DSP: Dominant Social Paradigm

ENCENRE: Aguascalientes Metropolitan Area Non-Residential Electric Consumption Survey

KWh: Kilowatt-Hour

NEP: New Ecological Paradigm

NOx: Nitrogen Oxide

NPV: Net Present Value

SO_2: Sulfur Dioxide

SPV: Solar Photovoltaic

SPVP: Solar Photovoltaic Panels

Wp: Watt-peak

1. Introduction

Climate crisis has led governments to set pollution emissions reduction goals to lessen the effects of human activity on the environment. Particularly, in the 2016 United Nations Climate Change Conference, Mexico set the goal of reducing its contaminant emissions by half on the year 2050 compared to its emission generated on the year 2000. To accomplish this goal, one of the options is to increase the participation rate of clean, not polluting energies on the national energy balance. During 2018, 23.18% of gross energy generated was produced by clean energies, with hydropower accounting for 44.10% of that fraction, nuclear power 7.30%, and other renewable sources such as wind, solar and biomass add up to 20.68% of clean energy production in Mexico (SENER, 2020). Accordingly, the Mexican government expects that half of the energy produced in the country comes from clean sources by year 2050 (SENER, 2018). Nonetheless, external reports estimate that Mexico has the potential to produce up to 75% of its energy with environmentally friendly technologies (Camba et al., 2019).

Nevertheless, some clean energy technologies, like wind and hydroelectrical energies, are only possible to implement with millionaire investments sponsored by the government or big private companies. Solar energy, on the other hand, is more easily accessible for its relatively cheaper prices and yields the opportunity to democratize emissions reduction and take energy transition to more people. However, solar energy technology has still little participation among all energy generation alternatives, since less than one percent of energy produced in Mexico during 2018 came from solar photovoltaic (SPV) systems (SENER, 2020). Fortunately, SPV generation is also the energy source with the fastest production growth in Mexico among all the alternatives available. SPV energy generation increased 523.20% from 2017 to 2018. This growth rate is over 20 times the growth rate of the second fastest-growing source on the list: nuclear energy. Therefore, solar energy is on the rising and has the potential of becoming a reliable alternative for regular households and businesses who want to save money on electric bills and also be part of the energy transition.

To maximize the growth and adoption rates of solar energy, it is necessary to gather information from the final users who choose to enter the solar energy market, but also dig into the reason why some users might not be willing to enter this market. With better understanding of the reasons behind solar energy adoption in Mexico, policymakers will be able to focus on the most effective incentives and also take into account particularities of the Mexican market.

In this work I study the determinants of solar panel adoption, focusing on small and medium-sized commercial and service firms located in the city of Aguascalientes, Mexico. To find correlation between solar panel adoption and potential determinant variables, I use a novel dataset that gathers electric consumption and socioeconomic data from surveyed firms using OLS and logit models. With this information I run an econometric specification to find marginal effects of selected variables on the probability of a firm having solar panels installed. This study contributes to the literature of solar energy markets by identifying conditions that affect likelihood of solar panel adoption among private firms.

Section 2 provides a concise literature review about existing research regarding solar panel adoption and the energy efficiency gap. Section 3 presents the novel dataset used in this work, provides descriptive statistics about the firms under study, and estimates the potential environmental savings from increasing solar panel adoption. Section 4 introduces the econometric specification and models used to estimate the marginal effects of a group of selected variables on the likelihood of a firm having solar panels installed. Sections 5 presents the estimation results of the econometric models while section 6 discusses these results and gives some policy recommendations. Section 7 concludes the study.

2. Literature review

Solar panel markets in Mexico have just been recently studied by works like Hancevic et al. (2017) or Rosas-Flores et al. (2019), who study the potential and benefits of photovoltaic-generated electricity for the residential sector. An important result from these studies is that the subsidized tariff schemes in the country make it less attractive for residential users to adopt solar energy technology. Hancevic and López-Aguilar (2017) and Hancevic et al. (2019) study further the residential electric tariff scheme and the changes needed to create stronger incentives for solar panel adoption among residential users. However, the solar energy market for non-residential users in Mexico has not been appropriately studied so far. Frey and Mojtahedi (2018) is one of the few international research papers focused on the non-residential market for solar panels. This work studies the California market and it is the closest reference available for the Mexican case. Given that the subsidized residential tariff scheme disincentivizes solar photovoltaic technology adoption, studying the non-residential sector offers the opportunity to investigate the behavior of users under a different price structure.

Other aspects to take into account when studying solar panel adoption are the technology adoption processes, the potential costs and benefits of the market and the price and expectations mechanisms for potential solar panel adopters. In first place and regarding technology adoption processes, Bollinger and Gillingham (2012) find that, due to peer effects, electric users in a close area shared by solar panel adopters have higher chances of adopting solar panels themselves. Additionally, Caamaño-Martín et al. (2008) study the impact of SPV generation projects in electric networks and remark the heterogeneity of the structure of electric networks among countries. Thus, independent research for each country-case is relevant. In Mexico, differences between rural and urban electric infrastructure should be consider when planning the expansion of the solar energy market. With respect to public subsidies, Hughes and Podolefsky (2015) study the effects of reducing solar panel prices for residential users in California. They find that, without public subsidies, solar panel installations from 2007 to 2012 would have been 53% lower.

In second place, concerning potential costs and benefit from the solar panel market, Borenstein (2017) finds that wealthier users with greater electric consumption levels are the ones who benefit the most from adopting solar energy technology. Therefore, it could be expected that large industrial and commercial users in Mexico would find profitable to create SPV energy adoption projects. Burr (2016), by her side, estimates the social cost-benefit of solar panel subsidies in terms of carbon emission reductions in California from 2007 to 2012. She finds that net social benefit was neutral, so the pollutant emission reductions compensated the cost of subsidizing solar panels. Nevertheless, she remarks that the welfare costs of encouraging solar panel adoption in suboptimal scenarios are high. Lastly, Gerarden (2017) estimates possible reactions of the solar panel market to public subsidies. On one hand, subsidies incentivize demand and keep prices unchanged; on the other hand, subsidies would incentivize innovation, which would lead to lower production costs and a lower equilibrium price on the market. Mauritzen (2017) finds, with empirical estimations, that the actual market reaction is the costs reduction process. Thus, solar panel prices are expected to drop gradually thanks to innovation and lower production costs.

In third place, regarding price and expectations mechanisms, Gillingham et al. (2016), Ito (2014), Reguant (2019) and Liang et al. (2020) are referential studies who research on different price mechanisms appliable to the solar panel market. Each mechanism yields different results in terms of efficiency and technological adoption, without a clear optimal path to follow. Furthermore, there is also literature about expectations and intertemporal consumption decision. De Groote et al. (2019) model intertemporal consumption decision of solar panels based on lower future prices expectations. Analogously, Langer and Lemoine (2017) estimate the optimal subside rate considering intertemporal consumption expectations to incentivize adoption among potential solar panel users.

One last relevant topic to review is the energy-efficiency gap. This concept is used to describe suboptimal clean energy adoption rates due to structural and market barriers. On one side, Hirst and Brown (1990) argue that main barriers include distortions in energy prices, uncertainty about future energy prices, limited access to capital, government fiscal and regulatory policies, industry codes and standards, and supply infrastructure limitations. Alcott and Greenstone (2012), on the other side, find that empirical evidence is not substantial enough to make claims of pervasive energy-efficiency gaps. The authors claim that it is crucial for public policies to be correctly targeted, as welfare gains will be larger when public interventions are prioritized for potential users with investments inefficiencies.

In this study, I contribute to the above-mentioned literature by analyzing the case of small and medium-sized commercial and service firms in the Metropolitan Area of Aguascalientes, Mexico, using primary data collected by the Center for Research and Teaching in Economics (CIDE). To the best of my knowledge, this is the first research addressing this topic with microdata at the firm level in Mexico.

3. Context and data

3.1 Context

The energy transition is regulated in Mexico since 2015 by the Energy Transition Law. This law sets the goal that, out of all the energy produced in the country by the year 2024, 35% should come from clean energies. In this sense, Aleman-Navas et al. (2014) show that Mexico is one of the countries with the highest solar energy potential. Thanks to the location of the country along the solar belt, solar radiation exceeds 5 Kilowatt-Hour (KWh) per square meter per day. Thus, Mexico can take advantage of its solar power potential with solar photovoltaic generation systems to accomplish its clean energy generation goals. Furthermore, Fu et al. (2018) illustrate that costs of commercial photovoltaic units have decreased 66.30% in the

United States from 2010 and 2018. The reasons behind prices falling in the SPV market are increasing competition, improved productivity and decreasing supplies costs. Hence, with high energy generation potential and declining costs, SPV technology is an attractive clean alternative to implement in Mexico.

Electric tariffs for the private sector in Mexico are divided into four main groups: residential, industrial, commercial, and rural sector. As stated by Hancevic et al. (2017), more than 95% of residential users have an average subsidy of 60% of their electric consumption costs. As a result, the tariff scheme for residential users does not incentivize the adoption of SPV systems among most of this type of users because of the low electricity prices they face. A similar situation is observed in the farming sector and the cattle industry, which also face highly subsidized electricity rates.

Figure 1

Photovoltaic power potential of Mexico

Source: Global Solar Atlas.

Nevertheless, the non-residential tariff scheme applied to businesses is not subsidized, so the incentive mechanism is different from the existing one in the residential sector. The average electricity price that businesses face is higher than the average price domestic users pay and the incentives to reduce that cost are greater. So far there is no existing work related to SPV technology adoption in the non-residential Mexican sector. Therefore, finding determinants of SPV technology adoption could grant useful information to foster, accelerate and improve energy transition in Mexico. This study focuses on small and medium-sized commercial and service firms and does not consider the manufacturing sector.

3.2 Survey description and descriptive statistics

The dataset used comes from the Aguascalientes Metropolitan Area Non-Residential Electric Consumption Survey (ENCENRE) 2019.[1] The ENCENRE collects information from the metropolitan area of the city of Aguascalientes, capital of the Mexican state of Aguascalientes, Mexico. The ENCENRE surveys small and medium-sized commercial and service firms regarding their electric consumption and practices, establishment equipment and electric service costs, as well as some environmental attitudes and beliefs. This survey was collected by the Center for Research and Teaching in Economics (CIDE) with funding from the Mexican Ministry of Energy (SENER) and the National Science and Technology Council (CONACYT). It compiles information from 812 private firms spanning massive media, wholesale and retail trade, and services like financial, real estate, cleaning, education and health services. Information about electricity consumption and spending is collected directly from the electricity bills issued by the state-owned national company (CFE).

Out of the 812 firms surveyed, 790 present complete information on the relevant variables, from which 9.24% report having adopted solar photovoltaic panels (SPVP) or solar panels for short.[2] These firms will be known as adopters, adopting firms or adopting respondents interchangeably, whereas firms without solar panels installed are going to be called non-adopters, non-adopting firms or non-adopting respondents interchangeably as well. Furthermore, 56.16% of all adopters claim to own the establishment where the firm operates, percentage which almost doubles the value for non-adopters, where only 30.26% of firms own their establishment. Additionally, 54.79 % of adopting firms are dedicated to commercial trading while 48.54% of non-adopters have the same line of business. Regarding electric billing, 90.40% of adopting respondents affirm knowing how much the firm spends on electricity bills. This percentage goes down to 83.54% for non-adopting respondents. Lastly, in adopting firms the average number of workers is 30 (rounded) whereas the average number of workers in non-adopting firms is 14 (rounded). These and further descriptive statistics are shown on table 1.

[1] The ENCENRE 2019 dataset is not publicly accessible.
[2] I also use SPV systems as synonym for SPVP and solar panels throughout this study.

Table 1
Descriptive statistics: adopters vs non-adopters

Characteristic	Global	Adopter	Non-adopter
N	790	73	717
Percentage	100%	9.24%	90.76%
Establishment owner	32.66%	56.16%	30.26%
Commercial firm	49.11%	54.79%	48.54%
Knows electric spending	84.18%	90.41%	83.54%
Solar water heater	3.29%	13.70%	2.23%
Voltage regulator	39.37%	54.79%	37.80%
Roof thermal insulator	8.30%	19.18 %	7.25%
Number of workers (mean)	15.72 (47.37)	29.81 (115.88)	14.28 (33.08)

Source: own elaboration based on ENCENRE 2019.
Standard deviations in parenthesis.

Descriptive statistics show that the average adopting firm has a larger staff and owns more frequently the establishment where the firm operates. Also, the majority of adopting firms are wholesale and retail trading businesses, while non-adopting firms are dominated by service business, although not for much in neither case. The proportion of respondents who know their electric billing spending is slightly greater in the case of adopters too. So far, data indicates that adopters are more prone to own electric and thermal related equipment than non-adopters. Sections 3.3 and 3.4 look further into environmental beliefs and billing data respectively.

3.3 Environmental beliefs

The ENCENRE contains a set of 15 affirmations about the environmental beliefs of the respondent corresponding to the New Ecological Paradigm (NEP) scale. The NEP scale was designed by Dunlap & Van Liere (1978) and refined by Dunlap et al. (2000) and measures the pro-ecological orientation of the respondent. Agreement with the 8 odd-numbered items indicates pro-NEP beliefs, whereas agreement with the 7 even-numbered items indicates stronger beliefs corresponding to the Dominant Social Paradigm (DSP).[3] The NEP scale is

[3] Dunlap & Van Liere (1978) define the DSP as the "world view through which individuals or, collectively, a society interpret the meaning of the external world and a mental image of social reality that guides expectations in a society."

useful to measure whether adopting firms have stronger pro-ecological beliefs than non-adopting firms. If adopters and non-adopters have statistically similar NEP scales, then environmental beliefs might be ruled out as a solar panel adoption determinant.

First, it is necessary to account for different types of respondents based on their hierarchy in the firm because unequal distributions could lead to biased estimates. Table 3 shows the distribution of respondents by hierarchy divided into three groups: manager, administrative and operative. For both adopters and non-adopters, hierarchy distribution looks fairly similar. The difference between the two groups in each category never surpasses 1.04 per cent, thus signaling equal distributions.

Table 2

Respondents by hierarchy

Hierarchy of respondent	Global	Adopter	Non-adopter
Manager	56.58%	57.53 %	56.49%
Administrative	25.44%	24.66%	25.52%
Operative	17.97%	17.81%	17.99%

Source: own calculations using ENCENRE 2019.

The NEP scale assigns a score from 1 to 7 to each item based on the answer of the respondent (answers go from "completely agree" to "completely disagree") and the resulting scale of and individual is equal to the average score of her answers. Scores closer to zero mean stronger pro-ecological beliefs. Then individual can be arranged in six different categories based on their individual scale value. Respondents on the first category have stronger pro-NEP beliefs and respondents on the sixth category have beliefs closer to DSP ideals.

Table 3

NEP scale estimates and distribution

Category	Global	Adopter	Non-adopter
Mean	2.94 (0.6445)	3.00 (0.6363)	2.93 (0.6455)
1	3.81%	4.11%	3.78%
2	53.81%	49.32%	54.27%
3	35.79%	38.36 %	35.52%
4	6.47%	8.22%	6.29%
5	0.13%	0%	0.14%
6	0%	0%	0%

Source: own calculations using ENCENRE 2019.
Standard deviations in parenthesis.

Table 3 shows mean NEP scales estimates and categories distributions. Both adopters and non-adopters have an average NEP scale equal or close to three, which means that surveyed firms "mildly agree" on the New Ecological Paradigm. Even though non-adopting respondents show an average scale slightly closer to zero, running a two-sample t-test for equal means results in a p-value of 0.40. Thus, the null-hypotheses of equal means is not rejected and the NEP scales of both groups are not considered statistically different. Since adopting and non-adopting firms have statistically equal NEP scales, environmental beliefs can be ruled out as a determinant of solar panel adoption. For further information and statistics on the NEP scale, see Appendix A.

3.4 Billing data and plans on adopting

Regarding electric consumption, adopters consume, on average, 3,050 KWh and spend 9,012 pesos per month.[4] Non-adopters consume 1,776 KWh and spend 6,274 pesos per month on average. Expectedly, the mean price per KWh consumed is lower for adopters, who pay 2.96 pesos on average per KWh. Meanwhile, non-adopting firms pay an average price of 4.73 pesos per KWh consumed.[5] This significant 60% price difference is a result of the presence of solar panels which produce electricity and reduce costs margins for adopting firms. Nevertheless, accounting for the presence of solar panels and the electricity they produce for adopting firms, net electricity consumption for adopters reduces to 2,149, resulting in an average net price of 4.80 pesos per KWh consumed.

Table 4
Mean electricity consumption, spending and price (monthly)

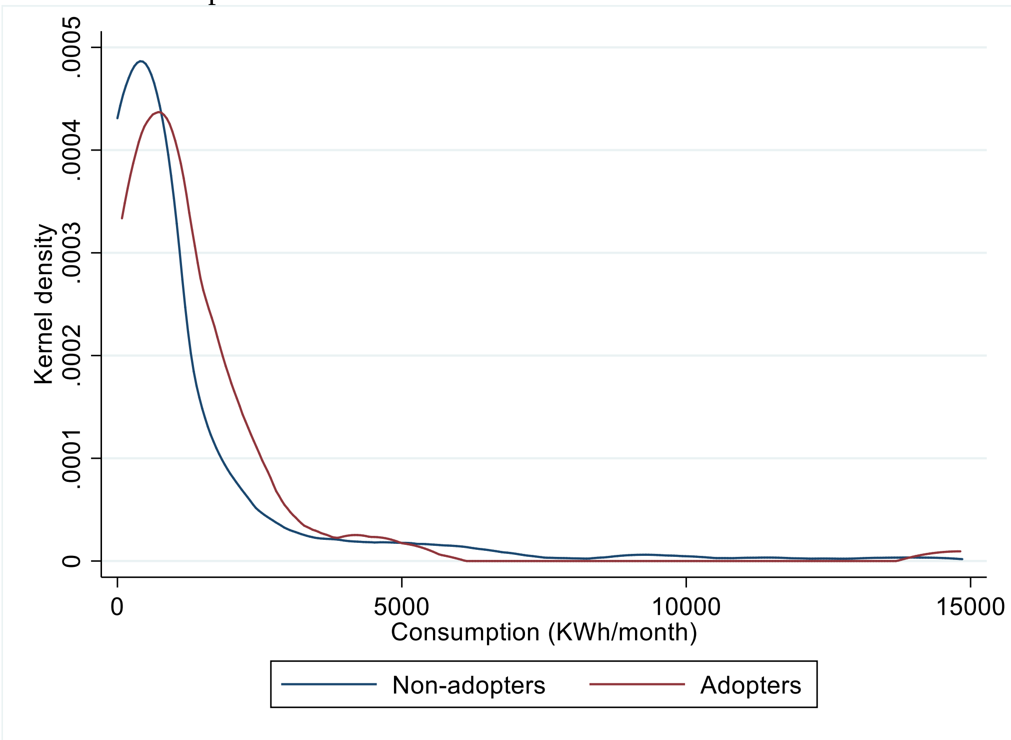
Variable	Global	Adopter (Gross)	Adopter (Net)	Non-adopter
Consumption (KWh)	1,894.54 (5,839.46)	3,050.98 (12,691.59)	2,149.16 (12,868.27)	1,776.79 (4,607.38)
Spending ($)	6,527.54 (17,640)	9,012.15 (36,289.20)	9,012.15 (36,289.20)	6,274.578 (14,4583.79)
KWh price ($)	4.57 (3.93)	2.96 (1.95)	4.80 (9.43)	4.73 (4.04)

Source: own calculations using ENCENRE 2019.
Standard deviations in parenthesis.

[4] CFE bills electric consumption once or twice every two months depending on the tariff.
[5] Average KWh price may change because different tariffs have different fixed costs and some tariffs have extra costs related to voltage and hour demand.

Graphic 1

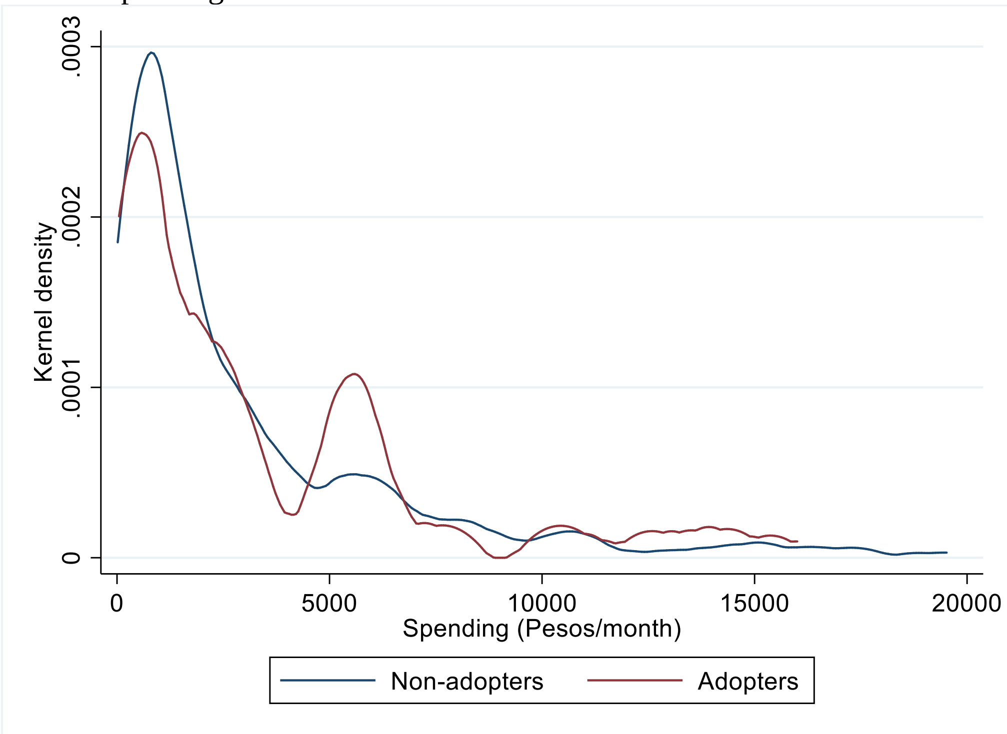
Electric consumption distribution



Source: own elaboration using ENCENRE 2019.

Graphic 2

Electric spending distribution



Source: own elaboration using ENCENRE 2019.

Recalling section 3.2, the proportion of adopting firms who own their establishment is almost two times the proportion of non-adopting firms who do so. Hence, establishment ownership has repeatedly appeared as a marked difference between adopters and non-adopters. Sectioning the observations between "owner" and "non-owner," the main reasons for not installing solar panels in the non-owner group are "because the establishment is rented or borrowed" (45.75%), "does not need solar panels" (10.38%) and "does not have economic resources nor access to credit" (10.38%). In the case of owners, main reasons are "because of lack of information (price, installation, functioning, sales place)" (25.15%), "does not need solar panels" (16.77%) and "does not have economic resources nor access to credit" (16.17%).

Almost half of non-owners report they are not willing to install solar panels in a rented or borrowed establishment, whereas a quarter of owners think they do not have enough information to choose adopting solar panels. On one side, it is understandable that non-owners do not want to make a sunk investment in an establishment that does not belong to them, even if they were interested in adopting solar panels. On the other side, a significant percentage of owners might not consider investing in solar panels simply because they do not know it is a viable option to cut on electricity spending. The fractions of firms who were willing to install solar panels within 12 months, controlling for ownership, are 23.64 % for owners and 15.07 % for non-owners. Ownership increases the likelihood of a firm having solar panels and might have a determinant correlation with adoption.

Table 5

Plans on installing solar panels and main reasons not to adopt (non-adopters only)

Item	Global	Owners	Non-owners
Non-adopters	717	217	500
Ownership percentages	100%	30.26%	69.74%
Planning to install solar panels within 12 months	17.46%	23.64 %	15.07 %
Reasons not to install solar panels (not planning on acquiring panels only)			
Because the establishment is rented or borrowed	33.50 %	2.40%	45.75%
Because of lack of information	13.71 %	25.15%	9.20%
Does not have economic resources	12.01 %	16.17 %	10.38%
Does not need solar panels	12.18 %	16.77%	10.38%

Source: own calculations using ENCENRE 2019.

3.5 The adoption gap and environmental savings

Exploring further solar panel data, 77.42% of adopters report having installed solar panels between 2017 and 2019. Additionally, the average installation cost reported is 396,000 pesos, however, this distribution is biased to the right and the median installation cost reported goes down to 200,000 pesos.[6] On average, firms with solar panels produce 6,626.65 KWh per year, with a median annual production of 4,269 KWh. Consequentially, the mean cost per Watt-peak (Wp) of potency installed is 370.10 pesos.[7] However, the installation cost distribution is biased to the right and the median cost per Wp installed is 65.36 pesos. Additionally, 7.04% of adopting firms are estimated to cover their complete electric consumption with the energy generated by the SPV system installed.

Table 6

Installation costs and SPVP production

Variable	Mean	Median
Installation cost ($)	396,009.90 (680,416.80)	200,000
Cost per Wp installed ($)	370.10 (1,582.94)	65.36
Annual SPVP production (KWh)	6,625.65 (8,044.86)	4,269

Source: own calculations using ENCENRE 2019.
Standard deviations in parenthesis.

With this information, I am able to make two estimations First, it is possible to estimate the proportion of adopting respondents that will actually profit from installing solar panels based on installation and maintenance costs, electricity rates, and annual SPVP electricity production. Second, I am able to calculate the proportion of non-adopters who could potentially benefit from installing solar panels if they decided to enter the SPVP market. In order to estimate the adoption profitability, I compute the Net Present Value (NPV) of electric savings with data from annual SPVP electricity production, KWh price and assuming a discount factor of 8%.[8] I compute the NPV to 5 time horizons (5, 10, 15, 20 and 25 years) to see how long it would take for adopting firms to recover the corresponding investment.

[6] Installation costs include the SPVP, workforce to install the panel and administrative fees.
[7] For the state of Aguascalientes, every Wp installed is estimated to produce 1.5 KWh per year.
[8] The discount factor of 8% is based on the interbank interest rate set by the Mexican Central Bank (Banxico) as of August, 2019.

Table 7 shows the proportion of adopting and non-adopting firms who would profit from installing SPV systems. Out of all adopting firms, about 60% will actually save more in electricity bills during the 25-year lifespan of the solar panels than what they spent on acquiring them. This proportion shrinks three times to only 19.35% when the time horizon chosen is 5 years. From year 5 to year 20, the proportion of firms who profit increases by 10 to 14 percent each lapse. It is possible that firms who would not profit from installing solar panels bought over costed equipment, installed a suboptimal generation capacity or miscalculated potential savings.

Table 7
Estimated profitability of investing in solar panels

Time horizon	Proportion of firms who profit (Adopters)	Proportion of firms who profit (Non-adopters)
5 years	19.35%	0.99 %
10 years	33.87%	8.05%
15 year	43.55%	14.69%
20 years	56.45%	58.05%
25 years	59.68%	72.74%

Source: own calculations using ENCENRE 2019.

To estimate potential benefits that non-adopters could obtain from investing in solar panels, I assume that firms can install any amount of Wp they need past a lower bound of 400 Wp.[9] Thus, the minimal Wp installed is assumed to be 400 Wp. The cost per Wp installed assumed is the median Wp cost for adopters: 65.36 pesos. Because each Wp installed is estimated to produce 1.5 KWh per year for the Aguascalientes state, each Wp installed would save 1.5 times the price of a KWh per year. Then, the NPV of the estimated annual savings for each Wp installed must surpass 65.36 pesos for a firm to find it profitable to adopt solar panels.[10] The same time horizons are considered for this evaluation.

In total, a little less than three quarters of all non-adopting respondents would find cost-effective to install solar panels. Interestingly, there is a remarkable jump from year 15 to year

[9] 400 Wp is the potency of the smallest solar panels available on the market.
[10] Firms whose annual electric consumption is less than 600 KWh (and would need less than 400 WP) would have unutilized potency and I assume they cannot sell electricity produced by solar panels. Therefore, Wp costs for these firms increase depending on their actual annual electric consumption (e.g., 300 KWh of annual electric consumption leads to twice the regular Wp price assumed).

20, where almost half of surveyed firms go from non-profiting to profit thanks to solar panel adoption. Assuming there is a relation between actual adoption levels and estimated rentability levels for non-adopters, it is possible to argue that the patience to recover the investment of installing SPVP ranges from 10 to 15 years among adopters. Even though solar panels can be useful for up to 25 years, firms most likely do not want to wait for so long to recover what they spend on a money-saving apparat. In that case, there are very low chances of seeing high adoption levels since the majority of firms who could benefit would need up to two decades to start profiting. Uncertainty about long-run future would discourage firms from making a sunk investment like this.

Finally, potential emission reductions and potential savings from reduced emissions are presented on table 8 and 9 respectively. Based on the average percentage of consumption covered by SPVP generated (54.17%), I estimate annual electric savings for the adoption rates set by each time horizon presented. Furthermore, thanks to the emissions factors published by SENER (2017), I estimate annual emission reductions of SO_2, NOx, and CO_2, as well as water annual potential savings. Assuming values of 13 US Dollar per ton of CO_2 and 3 US Dollar per cubic meter of water, environmental annual savings are estimated for different adoption rates.[11] If the 25-year horizon is considered, where all firms who profit after 25 years of installing solar panels actually adopt this technology, over 2 million KWh would stop being demanded from the electric network every year and potential environmental savings could equal more than 16 thousand dollars each year only for the 717 non-adopting firms considered in the ENCENRE survey.

Table 8
Potential annual emission reductions

Time horizon	Electricity (KWh)	SO_2 (Kg)	NOx (Kg)	CO_2 (Kg)	Water (Lts)
5 years	21,885.71	61.94	40.71	10,451.08	11,782.39
10 years	154,199.50	436.38	286.81	73,634.88	83,014.84
15 year	210,345.20	595.28	391.24	100,446.10	113,241.40
20 years	1,030,192	2,915.44	1,916.16	491,947.40	554,613.90
25 years	2,080,970	5,889.14	3,870.60	993,725.50	1,120,311

Source: own calculations using ENCENRE 2019 and SENER (2017).

[11] The value of CO_2 tons is extracted from the mean price of the California tap and trade program in 2016-2017 and the water metric cubes values is extracted from Conagua (2016).

Table 9
Potential annual savings from reducing emissions (US Dollars)

Time horizon	CO_2	Water	Total
5 years	135.86	35.35	171.21
10 years	957.25	249.04	1,206.30
15 year	1,305.80	339.72	1,645.52
20 years	6,395.32	1,663.84	8,059.16
25 years	12,918.43	3,360.93	16,279.36

Source: own calculations using ENCENRE 2019 and SENER (2017).

4. Empirical model

In this section, I present a model to determine statistically significant correlation of a group of selected variables with the likelihood of having solar panels installed. The variable of interest in the model is going to be the discrete variable "adopter," which indicates whether a firm has bought, installed and connected a SPV system to the electrical network. Because the dependent variable is discrete and the marginal effects of independent variables impact on the probability of seeing a realization, a Random Utility Model (RUM) suits the best to measure the statistical correlation. In any RUM, the aim is to model the choices of individual firms among discrete sets of alternatives. Concretely, firms choose between two alternatives: not adopt or adopt SPVP (j=0,1, respectively). It is assumed that the preferences of the firm among the available alternatives can be described by a utility function, and the firm chooses the alternative with the highest utility. Let the utility of alternative j for firm i be

$$U_{j,i} = X'_{j,i}\beta + \varepsilon_{j,i}$$

where $X_{j,i}$ is a vector of observed attributes or characteristics of alternative j and firm I, b is a conformable vector of parameters, and the random term $e_{j,i}$ is the effect on preferences of unobserved attributes of the alternative and firm.[12]

Assuming that $\varepsilon'_i = (\varepsilon_{0,i}, \varepsilon_{1,i})$ are independently and identically distributed (*i.i.d.*) as a type 1 extreme value random variable, the probability that the individual i chooses alternative 1 is given by the expression

[12] See Train (2009) for a complete discussion of the theory of random utility modeling and its empirical applications.

$$Prob(1|X_i) = \exp(X'_{1,i}\beta)/[1 + \exp(X'_{0,i}\beta)]$$

The set of variables included in X to model likelihood of solar panel adoption can be divided into two groups: consumption and characteristics of the firm, and installed equipment. The first group of variables —consumption and characteristics of the firm— consists of KWh price, log average monthly electric consumption (AMEC), log AMEC squared, log number of workers, a dummy variable indicating whether the firm is a commercial store, and a dummy variable indicating whether the firm owns its establishment. The second group —installed equipment— consists exclusively of dummy variables indicating whether the firm has solar water heater, voltage regulator, roof thermal insulator, sheet roof, air conditioning (AC) units, kitchen and commercial refrigerator/freezer.

Further explained, a linear probability model (or Ordinary Least Squares, OLS) and a logit model will be used to estimate the correlation and the marginal effects of the independent variables on the adopter dependent variable. The specification to estimate is of the form

$$\begin{aligned} Prob(adopter_i = 1 \mid X_i) \\ &= \beta_0 + \beta_1 price_i + \beta_2 \log(consumption_i) + \beta_3 \log(consumption_i)^2 \\ &+ \beta_4 \log(workers\ number_i) + \beta_5 commerce_i + \beta_6 ownership_i \\ &+ \beta_7 solar\ heater_i + \beta_8 voltage\ regulator_i + \beta_9 roof\ insulator_i \\ &+ \beta_{10} sheet\ roof_i + \beta_{11} AC_i + \beta_{12} kitchen_i + \beta_{13} commercial\ refrigerator_i \\ &+ \varepsilon_i \end{aligned}$$

The variables selected ought to estimate, first, how electric consumption levels and prices influence marginally the probability of adopting solar panels; secondly, whether structural characteristics of the firms increase the likelihood of having solar panels installed; and lastly, whether the presence of selected items and equipment indicate greater predisposition to invest in SPV systems.

5. Estimation results

The estimation results of the linear probability model and the logit model are shown on table 10. On both estimations, all variables are statistically significant at the 10 percent level. All variables on each model have effects with positive sign with the exception of *log (consumption)*^{2} and *sheet roof*, whose effects on the likelihood of adopting solar panels are negative. Then, the effect of increasing electric consumption on the probability of having solar panels installed is positive and decreasing. Likewise, having sheet roof decreases probability of adopting solar panels, likely because this type of material might not offer enough structural support for photovoltaic units.

The variables with greater effects on the linear probability model are *solar water heater* (0.247), *commercial refrigerator* (0.086) and *roof thermal insulator* (0.082) in that order. These estimates would indicate that having solar or thermal roof related equipment are strongly correlated with the acquisition of SPVP. It is possible that firms who invest in solar and thermal infrastructure that, additionally, is installed on top of roofs become more conscious about potential benefits from adopting SPV technology. At the same time, commercial refrigerators consume a lot of electricity and they are linked to the electric consumption level and, redundantly, to commercial shops, which are also significant variables in this model.

Marginal effects of the logit model estimation are reported on table 11. As in the logit estimates, all variables are significant at the 10 percent level. Most variables maintain similar magnitudes to those of the linear probability model with four exceptions: *price*, *log (consumption)*, *log (consumption)*^{2} and *solar water heater*. The continuous price and consumption variables have marginal effects 3 to over 25 times greater on the logit model, whereas the *solar water heater* variable has less than half of the magnitude estimated on the OLS model. The variables with greater marginal effects are *log (consumption), solar water heater* —once again— and *sheet roof* in that order. These estimations would lead to consider that, unsurprisingly, greater levels of electric consumption are strongly correlated with the adoption of solar panels. Nonetheless, this positive correlation is decreasing as larger levels of electric consumption yield smaller marginal changes on the likelihood of adoption. Meanwhile, when an establishment has its roof made out of sheet-like material, the likelihood of installing solar panels diminishes possibly for the lack of enough structural support as it was mentioned before.

Table 10
Linear probability and logit models estimation results

Variable	Linear probability (OLS)	Logit
Price	0.0003***	0.136***
	(0.00006)	(0.035)
Log (consumption)	0.062**	3.580***
	(0.027)	(1.008)
Log $(\text{consumption})^2$	-0.006***	-0.276***
	(0.002)	(0.075)
Log (worker number)	0.024*	0.506**
	(0.014)	(0.213)
Commercial store	0.061***	0.647**
	(0.021)	(0.314)
Ownership	0.075***	1.037***
	(0.021)	(0.300)
Solar water heater	0.247***	1.674***
	(0.056)	(0.508)
Voltage regulator	0.051**	0.715**
	(0.021)	(0.307)
Roof thermal insulator	0.082**	0.905**
	(0.036)	(0.421)
Sheet roof	-0.063**	-1.362**
	(0.030)	(0.662)
AC units	0.054**	0.744**
	(0.023)	(0.328)
Kitchen	0.039*	0.584*
	(0.022)	(0.353)
Commercial refrigerator	0.086***	0.951***
	(0.027)	(0.367)

Source: own calculations using ENCENRE 2019.
Standard deviations in parenthesis.

***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

Table 11
Logit model marginal effects

Variable	Logit marginal effect
Price	0.008*** (0.002)
Log (consumption)	0.218*** (0.068)
Log (consumption)^2	-0.017*** (0.005)
Log (worker number)	0.031** (0.013)
Commercial store	0.039** (0.019)
Ownership	0.063*** (0.019)
Solar water heater	0.102*** (0.031)
Voltage regulator	0.043** (0.019)
Roof thermal insulator	0.055** (0.026)
Sheet roof	-0.083** (0.041)
AC units	0.045** (0.020)
Kitchen	0.036* (0.022)
Commercial refrigerator	0.058*** (0.023)

Source: own calculations using ENCENRE 2019.
Standard deviations in parenthesis.

***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

6. Discussion

6.1 Estimation results discussion

All 13 variables included in the model presented in section 4 were significant at the 10 percent level and 11 of them had positive marginal effects on the probability of having solar panels installed. The first group of variables, consumption and characteristics of the firm, yielded estimation results that align with economic logic for the most part. On one side, increasing electric consumption and greater electric prices would lead to larger probabilities of adopting SPVP due to the incentive of reducing cost in the long run. Nevertheless, as a firm consumes more and more electricity, marginal probability effects diminish. It is possible that larger consumers either do not consider electric expenses a priority or consider the investment suggested too expensive or impractical. It is important to consider that rooftop areas, where SPVP are installed, are limited and heavy electricity consumers may lack the space required to mount the number of solar panels that meet their necessities. Seemingly, a SPV system would need to cover a substantial amount of the electric consumption of a firm to be attractive. Firms with high electricity demand would then need to make greater investments in order to adopt solar panels, which might not be possible for economic reasons.

On the other side, regarding the characteristics of the firms, the workers number can be seen as a proxy for the size of a firm, and it is natural to think that larger firms with more workers need more equipment and thus consume more electricity. In addition, being a commerce could indicate the presence of electronic devices with high electricity demands. As it will be discussed later, high electricity demanding equipment like refrigerators or air conditioning are likely to be found at commercial stores.[13] Then, these two characteristic variables are both linked with higher levels of electric consumption.

Ownership, for its part, is relevant because it would be too risky for non-owners to make an infrastructure investment at a place that does not belong to the firm. Information by the Mexican National Institute of Statistics and Geography (INEGI) points out that the life expectancy of a businesses in Aguascalientes is less than 8 years and only 14% of all businesses reach 20 years operating. Given that SPVP have a lifespan of up to 5 lustrums and investment recuperation periods can take several years, firms cannot be certain whether they will survive

[13] The *commercial store* variable can be divided into wholesale and retail shops. When running a regression with a specification including these sub-variables, *retail shop* shows to be significant at the 5 percent level, whereas *wholesale shop* is not even close to be statistically significant (p-value of 0.567 on the logit model).

long enough to benefit from their solar panel investments. Therefore, if a firm fails and goes bankrupt but owns the establishment where it used to operate, there are alternative ways to take advantage of SPVP. That it not the case with non-owners, who would lose their investment. There is practically no market for used solar panels in Mexico at the moment, so it would not be feasible for a firm to relocate and sell its used SPVP to recover part of the acquisition costs of installing solar panels.

The second group of variables included in the estimation models, installed equipment, are related to electric consumption habits but a couple of those variables may also indicate predisposition to invest in solar panels. First, *AC unit*, *kitchen* and *commercial refrigerator* variables indicate whether a firm has these items on their inventory. Considering an AC unit turned on 9 hours per day can consume up to 540 KWh every month and commercial refrigerators with similar usage can consume up to 600 KWh every month, these apparats can be considered as high electricity demanding. Consequently, a firm with a kitchen for employees equipped with a refrigerator, a freezer and a microwave will have a higher electric demand compared to a firm without kitchen.

Lastly, *solar water heater*, *voltage regulator*, *roof thermal insulator* and *sheet roof* variables could indicate predisposition or willingness to have solar panels installed. On one hand, the *sheet roof* variable yielded a negative-sign estimation likely because it is more difficult or simply not possible in some cases to build a SPV system on top of this type of roof. Perhaps some sheet roofs are capable of carrying some weight, but not enough to install the optimal number of panels. On the other hand, the three remaining variables mentioned might show that the decision maker of a firm is aware of rooftop and electric technology. Particularly, solar water heating and roof thermal insulation are closely related to solar panels in terms of space. Firms with any of these additaments has better chances of having information about solar panels. As shown on section 3.4, lack of information regarding solar panels was the main reason why owner firms were not planning on investing in SPVP. In that sense, awareness of solar energy and its potential benefits can be considered a good indicator of predisposition or willingness to adopt solar related technology.

Potential limitations in this study come from possible errors on the data collection and processing that could lead to imprecise estimations, but also from unavailable information not considered on the ENCENRE 2019 survey. First, the data available regarding solar panels is limited. Relevant information like Wp potency installed, rooftop area used or detailed monthly electric generation would have been useful to get better estimations of electric consumption and prices, as well as more accurate profitability calculations. In this sense, there is no information concerning electric surplus prices for firms who produce more electricity than they consume with SPVP, so this section of the market remains unstudied. Second, total rooftop area is reported but as a categorical variable and potential obstructions like water tanks are not reported, limiting the information regarding available area to install solar panels. Rooftop area is limited and indispensable for SPVP installations, but no analysis could be completed considering physical constraints.

Additional variables could had also been introduced into the model and yield marginally significant estimations, but for the sake of parsimony in the model, they were excluded from the final specification. For example, the variable *knows spending* —which indicates if the respondent knows how much the firm spends on electricity bills— yields p-values between 0.16 and 0.20 on the models this study considers, not far away from the 10% significance threshold. In a different context or in a different geographical region, these excluded variables might become relevant if a similar study were carried out. However, these marginal variables were not discussed and creates the risk of omitting relevant information from the econometric specification.

6.2 Policy recommendations

In order to foster and accelerate energy transition through SPVP adoption, I suggest three policy recommendations based on the results that this study presented. First, the government could offer subsidies or low-interest credit to businesses to make solar panels more accessible. Lower prices or better financing options would undoubtedly rise the demand for solar panels. Besides, this option has been the most applied and studied regarding SPV technology adoption. For example, Frey and Mojtahedi (2018) find that a 10% increase in solar panels subsidies in California lead to an increase between 1.36% and 2.55% of solar capacity installed among non-residential user. Thus, not only more businesses could enter the solar technology market, either on the demand or the supply side, but firms that are already willing to invest in SPVP would increment the capacity they plan on installing. As long as the tariff scheme in the residential sector does not change and keeps being subsidized, encouraging solar panel adoption among private firms is one of the safest bets to advance energy transition in Mexico.

On second place, a public policy that would take into account the risks of operating a business is to incentivize or require commercial areas or malls to install SPV systems. The reason to do this is because having solar panels installed at commercial areas would allow firms to consume solar energy without the risk of going out of the market and losing hypothetical investments made on acquiring solar panels. Section 3.4 showed that firms whose establishment was rented or borrowed were less willing to adopt SPVP mainly because of that same situation. Solar panels are a long-term investments and small and medium-sized firms cannot be certain whether they will still be active many years into the future. Alternatively, firms who rent might not have permission from the owner of the property to make substantial structural changes.

Given that about two thirds of the firms surveyed were in this situation, projects that lessen the risks of installing solar panels could help increasing adoption rates. Risk of solar panel adoption for commercial areas would be less because an empty store left by a firm exiting the market could always be filled with a new one. Additionally, solar panels are able to become a marketable asset. The commercial area or mall and firms operating in there could marketize themselves as climate change conscious to attract customers interested in consuming on environmentally friendly businesses.

Lastly, a least direct policy that could boost awareness about solar related technology are information campaigns. On sections 6.1 it was discussed how some equipment like solar water heaters and roof thermal insulation might increase the willingness or predisposition of firms to own solar panels. It was argued that people with this type of devices or installments could become more aware of potential benefits from having SPVP, or simply be conscious that installing solar panels is a viable option nowadays. Besides, section 3.4 showed that the main reason for owner firms to not having plans on installing solar panels was the lack of information. Then, information campaigns or obsolete-technology replacement projects could be applied to inform general public about resources available to reduce electric consumption. Firms will not invest on things they do not know how they could profit from. However, this policy is admittedly weak on its own and would be better implemented along with some of the policies recommended before.

7. Conclusion

This work studied some determinants of solar panel adoption among small and medium-sized firms. Using data from ENCENRE 2019, a linear probability model and a logit model were run to find the marginal probability effects of a group of selected variables in the likelihood of a firm having solar panels installed. Four types of variables were found to be significant: electric consumption levels, characteristics of the firm (like size and ownership of the firm's establishment), high energy consuming equipment, and solar and thermal related technology. Then, three policy projects were suggested to accelerate solar panel adoption: subsidies or low-interest credit to acquire SPVP, incentives on solar panel adoption projects focused on commercial areas or malls and information campaigns to raise awareness of green technology available like solar panels.

The relevance of these findings comes from the lack of information regarding solar panel adoption among commercial and service firms. Most literature in existence focus on the residential adoption and consumption habits. However, the difference between the residential and commercial electricity tariff schemes in Mexico changes the incentives present in each sector. Therefore, separate research and policies must be conducted for the non-residential sectors in order to attain better results in the search of greater solar panel adoption rates. Future research could explore further the optimal level of subsidies or economic incentive, regulatory issues concerning SPV products in Mexico, or the best incentives mechanisms to maximize solar technology adoption and, consequently, maximize savings from harmful emissions reduction.

Appendix A

The New Ecological Paradigm (NEP) scale that Dunlap et al. (2000) present is composed by 15 affirmations that indicate pro-NEP beliefs for odd-numbered items and pro-Dominant Social Paradigm (DSP) beliefs for even-numbered items. The items are equally subdivided into five categories that compress "the five hypothesized facets of an ecological worldview." These categories are "the reality of limits to growth" (items 1, 6, 11), "antianthropocentrism" (2,7,12), "the fragility of nature's balance" (3, 8, 13), "rejection of exceptionalism" (4, 9,14) and "the possibility of an ecocrisis" (5, 10, 15). NEP-scale items are shown on figure 2.

Figure 2
NEP scale items

1. We are approaching the limit of the number of people the earth can support.
2. Humans have the right to modify the natural environment to suit their needs.
3. When humans interfere with nature it often produces disastrous consequences.
4. Human ingenuity will ensure that we do NOT make the earth unlivable.
5. Humans are severely abusing the environment.
6. The earth has plenty of natural resources if we just learn how to develop them.
7. Plants and animals have as much right as humans to exist.
8. The balance of nature is strong enough to cope with the impacts of modern industrial nations.
9. Despite our special abilities, humans are still subject to the laws of nature.
10. The so-called "ecological crisis" facing humankind has been greatly exaggerated.
11. The earth is like a spaceship with very limited room and resources.
12. Humans were meant to rule over the rest of nature.
13. The balance of nature is very delicate and easily upset.
14. Humans will eventually learn enough about how nature works to be able to control it.
15. If things continue on their present course, we will soon experience a major ecological catastrophe.

Source: Dunlap et al. (2000).

The respondents surveyed by the ENCENRE should answer each item with one of the following options: completely agree, agree, mildly agree, unsure, mildly disagree, disagree or completely disagree. The answers assign a score from 1 to 7 to each item. Scores closer to zero indicate pro-NEP beliefs, while scores closer to seven signal pro-DSP beliefs. For pro-NEP odd-numbered items, a "completely agree" answer assigns 1score point to that item and a "completely disagree" answer assigns 7 score points. Correspondently, for pro-DSP even-numbered items, a "completely disagree" answer yields now 1 score point because disagreeing with a pro-DSP item indicate stronger pro-NEP beliefs, whereas a "completely agree" answer gives 7 score points. The NEP scale of a respondent is then the average score of her answers. Global score distributions and average scores for each item are presented on table 12.

Table 12
NEP scale scores and distributions

	Scores							
Item	1	2	3	4	5	6	7	Mean score
1	33.63%	28.17%	14.09%	7.23%	3.81%	7.99%	5.08%	2.64
2	17.39%	23.98%	7.11%	5.96%	12.06%	15.74%	17.77%	3.90
3	58.38%	29.19%	6.22%	1.02%	1.65%	1.65%	1.90%	1.71
4	4.57%	13.71%	8.50%	14.47%	14.97%	22.72%	21.07%	4.74
5	70.18%	23.10%	2.28%	0.89%	0.51%	1.27%	1.78%	1.49
6	1.40%	2.28%	2.41%	4.82%	9.77%	30.20%	49.11%	6.06
7	74.75%	21.19%	1.52%	0.38%	0.13%	1.14%	0.89%	1.37
8	23.35%	35.41%	14.59%	4.70%	6.85%	8.25%	6.85%	2.88
9	37.56%	39.09%	7.11%	2.92%	2.92%	7.11%	3.30%	2.29
10	32.11%	37.06%	5.46%	3.05%	4.31%	9.90%	8.12%	2.73
11	18.40%	27.54%	14.21%	9.64%	7.99%	16.62%	5.33%	3.32
12	21.98%	29.86%	8.77%	9.66%	9.78%	12.71%	7.24%	3.22
13	51.65%	31.35%	6.98%	3.05%	1.78%	2.92%	2.28%	1.90
14	7.74%	18.02%	7.87%	11.55%	20.05%	20.18%	14.59%	4.37
15	69.80%	20.56%	4.19%	1.14%	0.76%	1.27%	2.28%	1.55
Mean percentage	34.86%	25.37%	7.42%	5.36%	6.49%	10.64%	9.84%	NEP scale: 2.94

Source: own calculations using ENCENRE 2019.

Items that showed the greatest pro-NEP beliefs are 7 (plants and animals have as much right as humans to exist), 15 (if things continue on their present course, we will soon experience a major ecological catastrophe) and 3 (when humans interfere with nature it often produces disastrous consequences) in that order. For its part, items with the greatest pro-DSP are 6 (the earth has plenty of natural resources if we just learn how to develop them), 4 (human ingenuity will ensure that we do NOT make the earth unlivable) and 14 (humans will eventually learn enough about how nature works to be able to control it) in that order. Summed up, respondents tend to believe, on average, that the ecological crisis is real and that nature and animals have the right to exist and be preserved. Nonetheless, at the same time, the average respondent tends to believe that mankind will eventually figure out how to overcome environmental problems and will keep exploding natural resources for human consumption without major inconvenient.

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