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Journal of Open Innovation: Technology, Market, and Complexity

## Provided in Cooperation with:

Society of Open Innovation: Technology, Market, and Complexity (SOItmC)

*Suggested Citation:* Niankara, Ibrahim (2020) : Youths interests in the biosphere and sensitivity to nuclear power technology in the UAE: With discussions on open innovation and technological convergence in energy and water sectors, Journal of Open Innovation: Technology, Market, and Complexity, ISSN 2199-8531, MDPI, Basel, Vol. 6, Iss. 4, pp. 1-24,  
<https://doi.org/10.3390/joitmc6040180>

This Version is available at:

<https://hdl.handle.net/10419/241566>

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Article

# Youths Interests in the Biosphere and Sensitivity to Nuclear Power Technology in the UAE: With Discussions on Open Innovation and Technological Convergence in Energy and Water Sectors

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Received: 10 October 2020; Accepted: 1 December 2020; Published: 4 December 2020



**Abstract:** Nuclear power technology (NPT) perception and acceptance have globally emerged as the most critical questions for the successful integration of NPT into any national energy mix. In its combination with seawater desalination, NPT provides a sustainable alternative for the security and economic efficiency of both energy and fresh water supply, the latter of which has been identified as “the bloodstream of the biosphere”. Integrating econometric analysis into energy research with social science ramifications, this paper relies on bivariate ordered probit regression to study the impact of youths’ interests in the biosphere on their awareness and optimism toward NPT in the UAE. The model is estimated using maximum likelihood methods, with the results showing each level increase in UAE youths’ biospheric interests, to increase their NPT awareness by 13.5%, while conjointly reducing their optimistic expectations toward the technology by 2.4%. In addition, awareness and expectations about NPT are found to vary heterogeneously across the seven Emirates of the country. Moreover, accounting for all relevant factors (including respondents’ biospheric interests), formed expectations about NPT are not significantly shaped by NPT awareness. Given that the first unit of the UAE’s nuclear power plant “Barakah” just became operational in August 2020, our results provide important insights for evidence-based policy making to sustain the nascent nuclear energy program in the long run.

**Keywords:** biosphere; energy–water nexus; nuclear power; public acceptance; sustainable development; technological convergence

**JEL Classification:** D84; D9; P46; Q42; Q55; Q57

## 1. Introduction

The rhetoric of energy transitions and the sociotechnical imageries surrounding energy systems, especially during their formative years, has been the subject of growing interest to scholars in energy research [1–3]. On the issue, Sovacool suggested in [4] that:

“How people imagine energy technologies and their futures is clearly important to understand how and why people invest in them financially, personally, professionally, and otherwise, and it is thus a critical social facet of energy transitions”.

In a recent follow-up review, Edwards et al. [5] identified a limited number of studies reporting on individuals’ psychological experiences of living with NPT; they concluded by reiterating the need

for more studies on the topic. Therefore, in line with the above, the present analysis is carried out to specifically examine the following question: How are youths' attitudes toward nuclear power technology in society shaped by their interests in the biosphere, with its atmosphere, hydrosphere and lithosphere components?

Indeed, NPT development has become controversial amid widespread costs and environmental concerns [6]. In addition to observed lead-time escalations for nuclear plant construction projects [7], prohibitive overnight construction, and waste management costs [8], the general public often has a high risk perception of NPT because of nuclear accidents, radioactive nuclear waste contamination, and the proliferation of nuclear weapons, among other concerns [9–11]. Nuclear incidents such as Pennsylvania's Three Mile Island incident in 1979, Chernobyl's nuclear disaster in 1986, and the Fukushima Daiichi nuclear accident in 2011 [12] have all contributed to the observed public dissent against NPT over the past few decades [13]. As a result, public acceptance of NPT has taken center stage in recent nuclear energy policy debates [14–18].

Among the most commonly reported factors with causal influence on public acceptance of NPT are perceived costs and benefits [19–22], environmental beliefs [23], and perceived risks [24–26], while usually reported mediators of NPT include the discursive politics of nuclear waste [27,28], trust in nuclear governance institutions [29–31], nuclear knowledge [11,32], political inclinations [33,34], geographical proximity [35–37] and sociodemographic factors [28,38]. Few studies also report on the impact of “protected values”, which are defined as critically non-negotiable values for individuals contemplating the adoption of NPT [39]. To date, however, the question of how “biospheric values” influence NPT adoption remains unanswered in the scientific discourse.

Defined as “Earth's underpinning natural systems that provide the essential life sustaining ecosystem services such as food, fuel, water, and shelter, on which the human civilization depends” [40], the biosphere (with its three constituent parts—the atmosphere, the hydrosphere, and the lithosphere) is directly impacted by the adoption of NPT as part of a national energy mix. One commonly used key indicator of this impact is the greenhouse gas contribution of nuclear energy, which is estimated to average 66 gCO<sub>2</sub>e/kwh [41]. For example, in evaluating the avoided CO<sub>2</sub> emissions and lives saved from lower greenhouse gas emissions, Kharecha et al. [42] reported that nuclear energy generation historically saved over a million lives from fossil-fuels-based air pollution, and could save even more lives by the middle of the century. Similarly, using least squares dynamic methods to investigate the relationship between per-capita CO<sub>2</sub> emission and the share of nuclear energy in the national energy mix for 18 countries, Lee et al. [43] indicated a per capita reduction in CO<sub>2</sub> emissions in the order of 0.26% to 0.32%, from a 1% rise in nuclear energy production in the long run. Moreover, in their review of nuclear energy's contribution to sustainable low-carbon energy generation, Prävālie et al. [44] concluded by highlighting the value of pairing it with renewable energy sources [45]. Other aspects of the use of NPT with reported externalities on the biosphere and the ecosystem services it provides include (i) the risks of nuclear meltdowns and (ii) the continual need to maintain the caches of spent radioactive nuclear fuel [5,46,47].

Given the above impact of NPT on the biosphere, it is reasonable to conjecture that individuals' valuation of the biosphere and its provided ecosystem services within a given community or nation directly influence their attitudes and acceptance of NPT in that community or nation. Indeed, as a reflection of the community's preferences for the biosphere, individuals' valuation of the ecosystem services it provides to the community has been of interest to scholars since the Millennium Ecosystem Assessment was published by the United Nations [48]. Three main categories of ecosystem services (ES) were identified by the Common International Classification of Ecosystem goods and services (CICES) [49]: cultural ES (e.g., identity, inspiration, and serenity), regulating ES (e.g., pollination, floods, and pest controls), and provisioning ES (e.g., meat, cork, grass, and firewood) [50].

Typically, studies attempting to value ES rely on a revealed preference approach to estimate what an individual or a household or community would willingly pay for ES or their conservation [51,52]. Though the classification and valuation of ES are still debated, a widespread consensus that the

overall value of ES can be represented by their opportunity costs exists among ecologists and economists [53,54]. For the purpose of this study, we use the individual's self-reported interest in the biosphere (referred to as "biospheric interest") [55] to indicate the true but latent value that the individual attaches to the biosphere and its provided ES. The underlying logical link between them, which ensures construct validity, is as follows: the higher the level of interest an individual expresses in the biosphere and its ecosystem services, the higher the underlying economic value the individual attaches to the biosphere, and vice versa. Our above conjecture can therefore be restated more clearly as follows: Individuals' biospheric interests within a community or nation significantly influence their attitudes and acceptance of NPT in the community or nation.

This conjecture is tested here, within the specific context of the United Arab Emirates (UAE) using a cross-sectional data of adolescent youths' environmental attitudes [56]. As a secondary data source, originally designed, collected, and redistributed to researchers by the Organization for Economic Cooperation and Development (OECD) through its 2015 wave of the Programme for International Students Assessment (PISA) survey, the data provide a unique opportunity to address the following general question: How do youths' biospheric interests influence their attitudes toward NPT in the UAE?

Though studies relying on primary data through experimentation tend to use evaluations and acceptability of nuclear energy to operationalize attitudes toward NPT [19,26], here, given the observational and retrospective nature of the research design and the reliance on a cross-section of revealed market preference data, we use instead self-expressed awareness and expectations about NPT to characterize youth respondents' attitudes toward the technology. In doing so, we adopt the encompassing view under which youths' evaluation and acceptability of NPT are the direct reflection of their levels of awareness and expectations about the technology. Hence, the above general research question is more specifically restated as: What impacts do youths' biospheric interests have on their awareness and expectations about NPT in the UAE?

Given the exploratory nature of the study and the above discussion and conjecture, the following organizational structure is adopted in the quest to provide a definite answer to the above-raised research question. First, in Section 2, a background discussion on NPT acceptance around the world, including the setting in the UAE, is provided. Next, the adopted methodology is presented with the data, variables, and econometric framework described in in Section 3. Then, the findings are presented in Section 4, followed by their discussion in Section 5. Finally, in Section 6, the analysis is concluded.

## 2. Literature Review

### 2.1. Previous Studies of NPT Attitude and Acceptance

Although numerous studies have addressed the issue of public attitude toward (or acceptance of) NPT in various country settings, investigations focusing specifically on the youth population remain relatively scarce. For example, relying on survey data from 506 university students in China, Wang and Li [20] tested the causal influence of perceived risks and environmental and energy supply benefits on NPT acceptance among youths in China. Their findings revealed that Chinese youths' NPT acceptance is predominantly shaped by their perceptions of the benefits provided by a nuclear energy supply, with trust strongly mediating the effect of the three factors. Thus, the authors suggested that emphasizing the energy supply security benefits of NPT in communications with university students in China could effectively ensure its acceptance among this stakeholder group. Similar findings were reported by Yildiz and Erkan [57], using survey data on 521 Turkish university students to investigate the causal influence of determinant factors of NPT acceptance and sensitivity among Turkish youths. Relying on the evidence from studies using the theory of planned behavior in the United States, Craig and Sayers [58] reported young millennial risk perceptions and awareness of local clean energy initiatives, environmental orientation, and messaging to influence their attitudes toward federal clean energy policies. Similarly, in their recent cross-country investigation focusing on

youths within NAFTA, Niankara & Adkins [59] reported a non-convergence in youths' awareness and expectations about NPT between the USA, Canada, and Mexico. However, their study found a 6.7% increased optimistic expectations from each level increase in NAFTA youths' NPT awareness.

With respect to nuclear energy acceptance in the the general public, more studies from diverse country settings appear in the literature. In the UAE however, only one peer-reviewed study focusing on the specific context of transient residency and life satisfaction addressed the issue of public acceptance of NPT in the country [60]. The authors relied on stated preferences data from 1961 adult respondents, collected between June and July 2015, to study the willful acceptance of NPT in the country. Their results revealed an overall cautious stance toward nuclear energy acceptance, with 32% of study participants reporting the perceived benefits of nuclear energy, including its climate change mitigation characteristics, to justify the risks associated with NPT, and only 11% expressing opposition to the idea of nuclear investment in the UAE. Transient adults, with more favorable perceptions of the benefits of NPT over its risks, were significantly less likely to express opposing views to the construction of new nuclear plants in the country.

In China, relying on a sample of adult respondents from 30 Chinese provinces collected between 20 November 2011 to 20 February 2012, Wang et al. [61] introduced "unconditional support" to measure public acceptance of NPT from the perspective of environmental values, energy security, and climate change. Their findings revealed that environmental values and individuals' concerns about energy security positively correlated with unconditional support for NPT, while a negative correlation was observed between climate change concerns and unconditional support for NPT. Similarly, based on survey data collected from respondents in the Shandong province, He et al. [62] investigated public acceptance of NPT through the exploration of the contemporary public's knowledge and trust in NPT. The study concluded by pointing out a different landscape of nuclear power information, knowledge, and trust in China, compared to many other nations with NPT, and explaining why the continued development of NPT in China is achievable without much public debate. Furthermore, relying on regulatory focus theory, He et al. [31] reported trust in government to positively influence public acceptance of NPT in China, though this relationship was mediated by perceived risk and benefit of NPT and moderated by regulatory actions focusing on promoting NPT while preventing nuclear incidents.

More recently, using survey data from 516 experienced respondents in public participation within the nuclear industry in China, Wang et al. [23] examined how environmental beliefs influence public acceptance of NPT, controlling for the mediating effects of nuclear engagement and place attachment. Their findings revealed that environmental beliefs positively and significantly influenced public acceptance of NPT through individuals' nuclear engagement, though it was negatively moderated by place attachment. Furthermore, differentiating "perceived benefits" into general and local benefits, Wang et al. [22] reported perceived general and local benefits to both positively influence rebuilding acceptance in a local Chinese community, although perceived local benefit had a stronger effect. Contrary to expectations, their findings also revealed that environmental concerns positively mediated the impact of perceived benefits, while place attachment negatively mediated perceived risks; with both contributing positively to local rebuilding acceptance.

In addition to the above Chinese context, studies have also addressed NPT acceptance in other Asian economies. For example, using a methodology incorporating the comprehensive risk perception model with the risk perception mapping framework in ethnography, Hung and Wang [24] studied the determinants of local NPT risk perceptions to explain the heterogeneous nature of individuals' NPT risk attitudes across communities in Taiwan. The study revealed that respondents attached a high degree of risk to NPT, leading them to object to the building of a second nuclear power plant and to reject the compensation payment for continued nuclear plant operation. In addition, NPT risk perceptions were shaped by factors including socioeconomic attributes, psychological, social trust, and proximity to and perceived quality of life effects from the nuclear plant. Similarly, in Thailand, relying on structural equation modeling, Tantitaechochart et al. [37] investigated the causal relationships between latent



variables such as perceived information, trust, benefit, risk, and social status on acceptance of a nuclear reactor installation in the local community while distinguishing local residents' perceptions based on site proximity (within 5 km v.s. 5–15 km). Their findings revealed that both inner and outer perimeter respondents' acceptances of NPT were greatly influenced by perceived trust and benefit in provided NPT information, with outer perimeter residents showing relatively more acceptance.

A similar finding was reported in South Korea, where, using mixed logistics modeling and data collected from a discrete choice experiment, Huh et al. [36] confirmed heterogeneity in residents' preferences for economic incentives provided during the construction and operation of nuclear power plants in the country. Their results also showed that residential distance from the plant's site and electricity bill cost savings were crucial conditions for acceptance, though the level of acceptance rapidly decreased with close proximity to the plant's site. Furthermore, relying on source credibility theory and focus group discussions with Singaporeans aged 18–69 while drawing from the psychometric paradigm, Ho et al. [30] revealed significant inter-generational differences in not only media use and perceived credibility of communicated nuclear information but also in perceived benefits, risks, and support for NPT in Singapore.

In addition to the above Asian context, the issue of public acceptance of NPT has also received attention in the European and North American contexts. In Switzerland, for example, relying on a telephone survey among a representative sample of the Swiss population while distinguishing between the climate change mitigation benefits and those linked to energy supply security, Visschers et al. [63] examined an explanatory model of the public's acceptance of NPT. Their findings revealed that acceptance mainly depended on risk perception and perceived benefits from energy supply security and climate change mitigation, with affective factors appearing to play a significant role in the model. This latter influence of cognitive and affective factors on attitudes toward nuclear energy in Switzerland was subsequently reiterated by Rinscheid and Wüstenhagen [34] using a longitudinal data set on 1014 Swiss respondents. The authors of the study reported that risk and benefit perceptions of NPT played important roles in Swiss voters' declining support for reduced investment in nuclear energy, with affect appearing to be the most significant driver. Moreover, relying on a sample of 1221 local German- and French-speaking respondents in Switzerland to examine willingness to substitute old reactors with new-generation nuclear plants, Keller et al. [64] reported greater acceptance among German speakers, with individuals opposing such a rebuilding initiative having more diverse and concrete associations with nuclear power plants than those in favor and those undecided. Indeed, participants who associated NPT with risk, negative feelings, and consequences for health and the environment were seen to oppose to the substitution, while those who favored the rebuilding action mainly associated nuclear power plants with energy security, aesthetic appearances, and necessity.

In the United Kingdom (UK), relying on a representative sample of 1822 respondents, Corner et al. [65] reported divided attitudes toward nuclear energy, with unconditional acceptance observed for only a minority. The study found more support for NPT among those with high environmental values and those who expressed greater climate change and energy security concerns. However, when the nuclear energy discourse was re-framed to allow for and against argumentation, then climate change and energy security concerns became positive predictors of NPT support. More recently, drawing on the findings of a representative sample of 948 respondents, de Groot et al. [26] integrated inter-personal with intra-personal factors in the "risk–benefit acceptability" model to evaluate NPT acceptability in the UK. Their findings revealed benefit perceptions to importantly explain nuclear energy acceptability. However, when people were less familiar with NPT, then risk perceptions became more important. They also reported social networks to significantly shape NPT-related risks and benefits perceptions, and thereby contributing indirectly to shaping NPT acceptance. Furthermore, relying on stated consumer preferences data collected in four states in the USA and in Japan after the nuclear incident in Fukushima, Murakami et al. [66] used the willingness to pay approach for a comparative analysis of attitudes toward NPT in the two nations. Their findings revealed negative preferences for continued nuclear

investment in both nations, with a much stronger effect observed in Japan. They also reported a monthly willingness to pay of \$0.31 and \$0.26 for every 1% reduction in greenhouse gas emission in the USA and Japan, respectively.

Finally, authors have also considered holistic approaches combining the output of studies conducted in diverse settings. For example, in their meta-analysis of 34 studies covering 32,938 participants, Ho et al. [28] examined determinants of public perceptions of the benefits, risks, and acceptance of NPT. Their findings revealed that acceptance of NPT by the public significantly depended not only on socio-demographic factors such as gender and education but also on perceived benefits, risk, costs, knowledge, and trust in nuclear-related information. Similarly, in a systematized review conducted as a follow-up to the historical overview in the inaugural issue [4], Edwards et al. [5], identified 26 studies reporting on psychological aspects of living with NPT, with an array of described themes that include trust in nuclear power authorities and the perception-mediating role of factors including familiarity and sense of place. The authors then concluded their review by reiterating the initial call and pointing out the need for further research in the area.

As the above extensive literature highlights, not only are investigations in NPT acceptance in the youth population limited in number, the case of acceptance within the context of the United Arab Emirates (UAE) also remains to be addressed. Therefore, in the following, we provide a background on the UAE energy context.

## 2.2. Historical Context of the UAE

Founded in 1971 by the union of seven Emirates (Abu Dhabi, Ajman, Dubai, Fujairah, Ras Al Kaimah, Sharjah, and Umm Al Quwain), the United Arab Emirates (UAE) is one of the Gulf Nations in the Middle East, with an economy historically dependent on oil production and export. The Emirate of Abu Dhabi, which accounts for 86% of the UAE land area and 95% of its oil, represents the federal capital of the country, while Dubai is seated as the UAE's largest city [67]. Electricity production plays a vital role in many sectors of the UAE economy including potable water production, much of which takes place through sea water desalination [68].

Population and economic growth have created a sharp increase in energy demand in the past decade [69,70]. Between 2000 and 2013, for example, electricity production increased more than 13.5% at an average annual increase of 5.39 TWh, while electric power consumption during the same period rose by 13.3% annually at an average of 5.14 TWh [71]. As of 2012, the UAE ranked number 10 in the world with 10.13 MWh per capita electricity consumption [70]. With respect to per capita carbon dioxide (CO<sub>2</sub>) emissions, the UAE was reported in second position worldwide between 2000 and 2004, then moved to eighth position in 2010, and by 2013 was back in second position [71]. By 2015, electricity production in the country had reached 127 TWh, most of which came from fossil fuels (125.5 TWh) and natural gas (1.5 TWh) [72].

In terms of projections, a comprehensive energy policy published in April 2008 initially anticipated rising electricity demand from 15.5 GWe in 2008 to over 40 GWe by 2020 [73]. Natural gas was set to account for half of this needed power, and renewable energy for about 6–7% [74], while coal was deemed unfeasible because of its relative inefficiency and environmental impact [75]. Nuclear electrical power, however, emerged as an environmentally promising and commercially competitive option that could significantly contribute to the UAE's economy and long-term energy security needs [41,76]. This latter realization led to the initiation of a nuclear power program in the UAE, with a selected plant site at "Barakah", and the creation of a regulatory framework to oversee the nation's nuclear industry [77].

## 2.3. The UAE Nuclear Electrical Power Program

Following the creation of its regulatory framework, and the recommendations from the international atomic energy agency (IAEA), a Nuclear Energy Program Implementation Organization was established to set up the Emirates Nuclear Energy Corporation (ENEC) as a publicly traded

company headquartered in Abu Dhabi, and initially capitalized at \$100 million, with the mission to evaluate and develop the UAE's nuclear energy program [72]. In December 2009, ENEC selected a bid from the Korea Electric Power Corporation (KEPCO)-led consortium to build four advanced pressurized water nuclear reactors (APR1400) [78]. The contract was valued at \$20.4 billion, with a greater share being offered under a fixed-price arrangement for the construction, commissioning, and fuel loads of the four APR1400 units [79]. Expected additional earnings for KEPCO, from the joint operation of the four reactors for 60 years, were also estimated at \$20 billion, with KEPCO awarding a \$5.59 billion construction contract in March 2010 to Hyundai and Samsung for the first plants at the "Barakah" site, approximately 53 km west-southwest of the city of Ruwais. Construction started in July 2012 [72], following receipt of the construction license and environmental approval. The plant was due to begin operating in 2017, but delays were faced until August 2020 [80].

#### 2.4. Operation of the UAE "Barakah" Nuclear Power Plant

To produce the needed energy, nuclear reactors are typically loaded with uranium oxide fuel  $UO_2$  [81]. The long run operation of the reactors produces nuclear wastes, which is a collection of left over nuclides of spent nuclear fuel [82]. Many of the resulting isotopes are typically extremely radioactive, causing the spent nuclear fuel to continue emitting heat long after removal from the reactor [83]. Due to its hazardous nature, the spent fuel is typically kept shielded underwater for years to allow the radiation to decay to levels that can be shielded in concrete storage casks.

According to the profile on nuclear power in the United Arab Emirates published by the World Nuclear Association in 2018 [72], by August 2012, six contracts worth \$3 billion had been awarded by ENEC in relation to the supply of natural uranium concentrates, in addition to the individual services of conversion and enrichment. The contracts for uranium concentrates supply involved companies such as Uranium One in Canada, Areva in France, Rio Tinto in the United Kingdom, and Russia's Techsnabexport (Tenex). The conversion services were awarded to Converdyn, Tenex, and Areva in the USA, while Europe-based Urenco, Areva, and Tenex were granted enrichment services. Finally, Kepco Nuclear Fuels, a subsidiary of KEPCO, received the contract to manufacture the fuel assemblies.

The UAE also committed to developing a national storage and disposal program, with a parallel exploration of regional cooperation options, involving other Gulf Countries [84]. Further considered options for the spent nuclear fuel was supplier take-back. Overall, however, used fuel is expected to remain in storage in reactor ponds for 20 years; then, it is transferred to dry storage facilities, where it remains for six years [85]. After that, ownership and responsibility for the used fuel will be transferred to the UAE government. Prospective studies of geological repositories for the spent fuel were also undertaken by Sweden's SKB and the Arab Atomic Energy Agency (AAEA), in conjunction with a wider group of participating countries in the Middle East and North African (MENA) region, in the manner of the European Union precedents [86].

Despite this emerging status of the UAE nuclear program [80], and the strategic position of nuclear energy in the UAE energy mix [76,87], only one study's authors reported on the public's perception of this energy alternative in the country [60]. No prior study in the scientific discourse addressed public awareness and expectations about the technology in the country. Moreover, as pointed out in the North American context, youths play a vital role in the long-run development of nuclear energy programs [59]. It is therefore critical to get a clearer picture of contemporary UAE youths' awareness and expectations about the technology, so as to properly plan for the sustainable development of NPT in the country. To this end, we now describe our adopted methodology.

### 3. Methods

In the presentation of our methodology, we describe first the data along with the study variables; then, we describe the econometric modeling framework.



### 3.1. Description of the Data and Study Variables

The present analysis relies on the UAE extract from the published data [56], which reports on the environmental attitudes of 187,821 students from 50 economies across the world. The report by the Organization for Economic Cooperation and Development [88] (pp. 67–91) contains additional information on its sampling design. The UAE subsample (its summary statistics are presented in Table A1 (Appendix A)) contains information on 6919 respondents. Adopting the same methodological approach as in [55,59,89], respondents' observed levels of awareness and expectations about NPT in the UAE are defined as:

- SENA: Self-Expressed-Awareness about NPT (mean = 2.62, standard deviation = 0.98); ordinal response with levels (1-Never heard, 2-Heard but cannot explain, 3-Know and can provide general explanation 4-Familiar and can provide detail explanation).
- SENE: Self-Expressed-Expectation about NPT (mean = 2.07, standard deviation = 0.82); also ordinal with levels (1-Worse, 2-Same, 3-Improve).

where “SENA” indicates each respondent's answer to the question: “How much do you know about nuclear power technology?”, while “SENE” captures each respondent's answer to the question: “What is your expectation about the evolution of nuclear power technology for the next 20 years?”

### 3.2. Bivariate Ordered Probit Model Specification

Our econometric model follows the bivariate specification in [55], which was extended in [59,89]. They are all derived based on the bivariate latent variable framework presented in [90]. Here, we assume the existence of a latent awareness ( $A^*$ ) and expectation ( $E^*$ ) about NPT, for respondent  $i$  in region  $j$  within the UAE, such that:

$$\begin{aligned} A_{ij}^* &= \alpha_{1j} + \mathbf{x}'_{1i}\beta_1 + \epsilon_{1ij} \\ E_{ji}^* &= \alpha_{2j} + \mathbf{x}'_{2i}\beta_2 + \gamma A_{ij}^* + \epsilon_{2ij} \end{aligned} \quad (1)$$

where  $\beta_1$  and  $\beta_2$  are estimated model parameters and the scalar capturing the effect of respondents' NPT awareness on their NPT expectations is  $\gamma$ .  $\epsilon_{1ij}$  and  $\epsilon_{2ij}$  are the random disturbance terms for the latent awareness and expectations equations, respectively.  $\alpha_{1j}$  and  $\alpha_{2j}$  are fixed regional effects capturing the unobserved heterogeneity in NPT awareness and expectations across the  $j = 7$  regions (Emirates) in the UAE. These region-specific effects  $\alpha_{ij}$  in Equation (1) are the leftover sources of variation in respondents' NPT awareness and expectations that cannot be explained solely by respondents' interests in the biosphere and the other included explanatory factors in the model. Here, these may include spatial variations in respondents' NPT awareness and expectations, potentially linked to their locational proximity to the newly functional “Barakah” nuclear power plant in the UAE. Since the plant is much closer to Abu Dhabi than the remaining six Emirates, Abu Dhabi is chosen as the region of reference, in addition to being the federal capital of the nation.

Because the sample space covers all seven Emirates, our approach generates  $7 - 1 = 6$  regional fixed effects, representing the average differences in NPT awareness and expectations between respondents in the Emirate of Abu Dhabi (the reference region), and those in the other remaining six emirates in the UAE. To accommodate the potential correlations between the fixed regional effects and the explanatory factors in the model, we rely here on the fixed effect estimator as implemented through the Rchoice package [91]. The independent predictors are assumed to be statistically exogenous [ $E(\mathbf{x}'_{1i}\epsilon_{1ij}) = E(\mathbf{x}'_{2i}\epsilon_{2ij}) = 0$ ], such that the post-estimation recovery of the fixed regional effects is achieved with:

$$\begin{aligned} \hat{\alpha}_{1j} &= \bar{A}_{ij}^* - \bar{\mathbf{x}}_i' \hat{\beta}_1 \\ \hat{\alpha}_{2j} &= \bar{E}_{ij}^* - \bar{\mathbf{x}}_i' \hat{\beta}_2 - \bar{A}_{ij}^* \hat{\gamma} \end{aligned} \quad (2)$$

Abstracting from the regional subscript  $j$ , latent awareness ( $A^*$ ) and expectation ( $E^*$ ) in Equation (1) relate to their observed indicators of respondent's reported NPT awareness ( $SENA$ ) and expectations ( $SENE$ ) as:

$$SENA_i = \begin{cases} 1 & \text{if } A_i^* \leq \mu_1 \\ 2 & \text{if } \mu_1 \leq A_i^* \leq \mu_2 \\ 3 & \text{if } \mu_2 \leq A_i^* \leq \mu_3 \\ 4 & \text{if } \mu_3 < A_i^* \end{cases} \quad (3)$$

$$SENE_i = \begin{cases} 1 & \text{if } E_i^* \leq \delta_1 \\ 2 & \text{if } \delta_1 \leq E_i^* \leq \delta_2 \\ 3 & \text{if } \delta_2 < E_i^* \end{cases} \quad (4)$$

In the above Equations (3) and (4), the threshold parameters satisfy the following conditions:  $\mu_1 < \mu_2 < \mu_3$  and  $\delta_1 < \delta_2$ . As in [59], identification of the model is achieved by fixing the first threshold parameter in each outcome  $\mu_1 = \delta_1 = 0$  while setting the boundary cases  $\mu_0 = \delta_0 = -\infty$  and  $\mu_4 = \delta_3 = +\infty$ . For  $j$  and  $k$ , any two indices on the two latent scales, the joint likelihood of  $SENA_i = j$  and  $SENE_i = k$  is:

$$\begin{aligned} Pr(SENA_i = j, SENE_i = k) &= Pr(\mu_{j-1} < A_i^* \leq \mu_j, \delta_{k-1} < E_i^* \leq \delta_k) \\ &= Pr(A_i^* \leq \mu_j, E_i^* \leq \delta_k) \\ &\quad - Pr(A_i^* \leq \mu_{j-1}, E_i^* \leq \delta_k) \\ &\quad - Pr(A_i^* \leq \mu_j, E_i^* \leq \delta_{k-1}) \\ &\quad + Pr(A_i^* \leq \mu_{j-1}, E_i^* \leq \delta_{k-1}) \end{aligned} \quad (5)$$

As in [59], we assume a bivariate normal joint distribution for the error terms  $\epsilon_{1i}$  and  $\epsilon_{2i}$  with correlation coefficient  $\rho$  such that the contribution to the likelihood function for each respondent is given by:

$$\begin{aligned} Pr(SENA_i = j, SENE_i = k) &= \Phi_2(\mu_j - \alpha_j - \mathbf{x}'_{1i}\beta_1, (\delta_k - \alpha_k - \gamma\mathbf{x}'_{1i}\beta_1 - \mathbf{x}'_{2i}\beta_2)\zeta, \tilde{\rho}) \\ &\quad - \Phi_2(\mu_{j-1} - \alpha_{j-1} - \mathbf{x}'_{1i}\beta_1, (\delta_k - \alpha_k - \gamma\mathbf{x}'_{1i}\beta_1 - \mathbf{x}'_{2i}\beta_2)\zeta, \tilde{\rho}) \\ &\quad - \Phi_2(\mu_j - \alpha_j - \mathbf{x}'_{1i}\beta_1, (\delta_{k-1} - \alpha_{k-1} - \gamma\mathbf{x}'_{1i}\beta_1 - \mathbf{x}'_{2i}\beta_2)\zeta, \tilde{\rho}) \\ &\quad + \Phi_2(\mu_{j-1} - \alpha_{j-1} - \mathbf{x}'_{1i}\beta_1, (\delta_{k-1} - \alpha_{k-1} - \gamma\mathbf{x}'_{1i}\beta_1 - \mathbf{x}'_{2i}\beta_2)\zeta, \tilde{\rho}) \end{aligned} \quad (6)$$

with  $\Phi_2$  representing the bivariate standard normal distribution while  $\tilde{\rho} = \zeta(\gamma + \rho)$  and  $\zeta = \frac{1}{\sqrt{1+2\gamma\rho+\gamma^2}}$ . As explicitly described, this model is equivalent to the simultaneous bivariate ordered probit model in [59], and is therefore estimated under the same weighted seemingly unrelated specification, within the R statistical software [92].

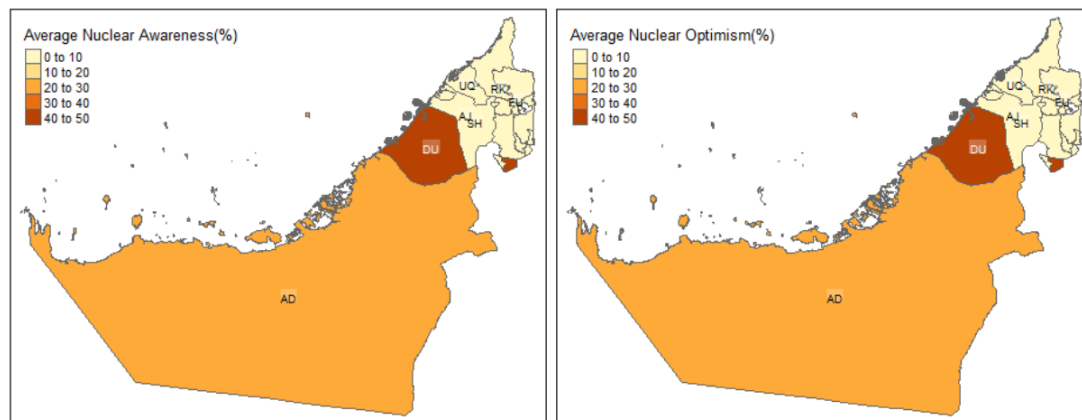
#### 4. Findings

The findings described in this section are organized in two parts; the focus of the first part is on the descriptive findings from the data, while the econometric results are presented in the second part.

##### 4.1. Descriptive Results

Figure 1 below shows the spatial plot of respondents' unconditional NPT awareness and expectations across the UAE's seven Emirates. It can be noted from the map that the greatest awareness and optimistic expectations are expressed in Dubai (46.9% and 47.5%, respectively), followed by Abu Dhabi (23.8% and 23.7%), with fairly similar average levels across the remaining five Emirates

(Sharjah 7.3% for both; Ras Al-Kaimah 7.1% and 6.8%; Ajman 6.2% for both; Fujairah 6.2% and 6.1%; Umm al-Qaywayn 2.5% and 2.3%).



**Figure 1.** Mapping of youth nuclear power technology (NPT) awareness (**left**) and expectations (**right**) across the seven Emirates.

#### 4.1.1. Descriptive Summary of the Data and Variables

The summarized findings in Table A1 show that, overall, most respondents live in Dubai (47.98%), followed by Abu Dhabi (23.65%), then Sharjah (7.30%), Ras Al Kaimah (6.65%), Ajman (6.11%), and finally Fujairah (6.01%). The average adolescent is somewhat interested (3.36) in the biosphere, but highly interested (3.99) in science-based disease prevention. The standardized index of adolescents' science enjoyment shows that the average youth respondent has a 0.59 standard deviation above the mean index value across all 2015 PISA respondents [93]. Furthermore, Table A1 shows that, on average, respondents regularly visit ecological websites (3.02), and somewhat regularly visit news blogs (2.83). Respondents also sometimes visit websites (2.65) and read books (2.93) on broad science.

The descriptive summary on the socioeconomic and demographic factors show that 54.78% of UAE youth respondents are females, with an average age of 15.80 years. The mean value of the standard normalized scale of the index of economic, social and cultural status (see ESCS in [59]), suggests that the average UAE adolescent is 0.63 standard deviation above the mean index value across all 2015 PISA respondents [93]. The distribution of respondents by immigration status suggests that 38.17% are UAE natives, 38.76% are first generation expatriates, while the remaining 23.07% are second generation expatriates. With respect to grade level in school, Table A1 shows that 0.36% of the youth respondents are 7th graders, 1.29% are 8th graders, 10% are 9th graders, 55.73% are 10th graders, 31.26% are 11th graders, and finally 1.36% are 12th graders or more.

#### 4.1.2. NPT Awareness and Expectations across Levels of Interest in the Biosphere

The spatial distribution of youth NPT awareness and expectation across the seven emirates is presented in Figure 1. Table 1 summarizes the marginal relative frequency, and joint relative frequency distributions of youth's NPT awareness (SENA) and expectation (SENE), with their biospheric interest levels (IntBiosph) in the UAE.

With respect to the marginal relative frequencies of youths' biospheric interests (IntBiosph), the last row of Table 1 shows that the majority of UAE youth (38.69%) report being interested in ecosystem services, followed by 24.27% that report being hardly interested, then by 19.57% that report not being interested, and 13.01% that report being highly interested, and finally 4.47% that report not knowing about it. Similarly, it can be noted from Table 1 that the greatest share (33.33%) of UAE youths report knowing about NPT to explain it in general terms; followed by 30.41% reporting to have heard about NPT, though unable to explain it; then by 21.52% reporting to be familiar with NPT, and able to explain it in detail, and finally by 14.74% reporting to have never heard about NPT. With regards to

respondents' expectations about NPT development in the next 20 years (SENE), most UAE youths (37.07%) feel optimistic with the believe that it will improve overtime, followed by 32.55% believing NPT development will remain the same, while the remaining 30.38% have pessimistic expectations, and believe that NPT development in the UAE will worsen over time.

**Table 1.** Relative and conditional frequencies of respondents' NPT awareness and expectations.

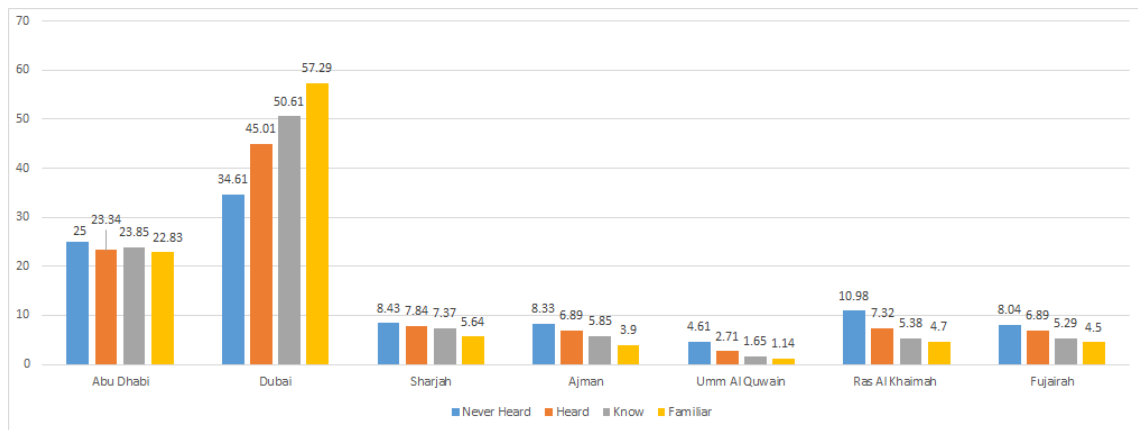
		IntBiosph					Rel. Freq.	Chi <sup>2</sup> Stat.
		1	2	3	4	5	(%)	
SENA	1	6.76	35.78	23.53	26.37	7.55	14.74	X-squared = 537.37 *** df = 12, $p$ -value < $2.2 \times 10^{-16}$
	2	4.52	22.67	27.95	36.74	8.13	30.41	
	3	4.16	14.44	24.63	44.15	12.62	33.33	
	4	3.29	12.02	19.01	41.44	24.24	21.52	
SENE	1	4.52	17.84	23.36	40.06	14.22	30.38	X-squared = 20.74 ** df = 8, $p$ -value = 0.00787
	2	4.17	19.63	25.75	39.21	11.23	32.55	
	3	4.68	20.94	23.70	37.12	13.57	37.07	
Rel. Freq.	(%)	4.47	19.57	24.27	38.69	13.01		

Source: Author's own, using the UAE extract from [56]; \*\*\*  $p < 0.001$ , \*\*  $p < 0.01$ .

Moreover, as youths' biospheric interests levels rise from 1-do not know, to 5-highly interested, the joint relative frequency distribution, also in Table 1, shows significant variations in percent relative cell frequencies, at every level of youths' NPT awareness and expectation in the UAE. This latter result finds further confirmation from the chi-squared test results in the last column of Table 1. Indeed, a highly significant dependence relationships ( $\alpha = 0.1\%$ ) is found between youths' biospheric interests and their NPT awareness and expectations in the UAE.

#### 4.1.3. NPT Awareness across the Seven Emirates

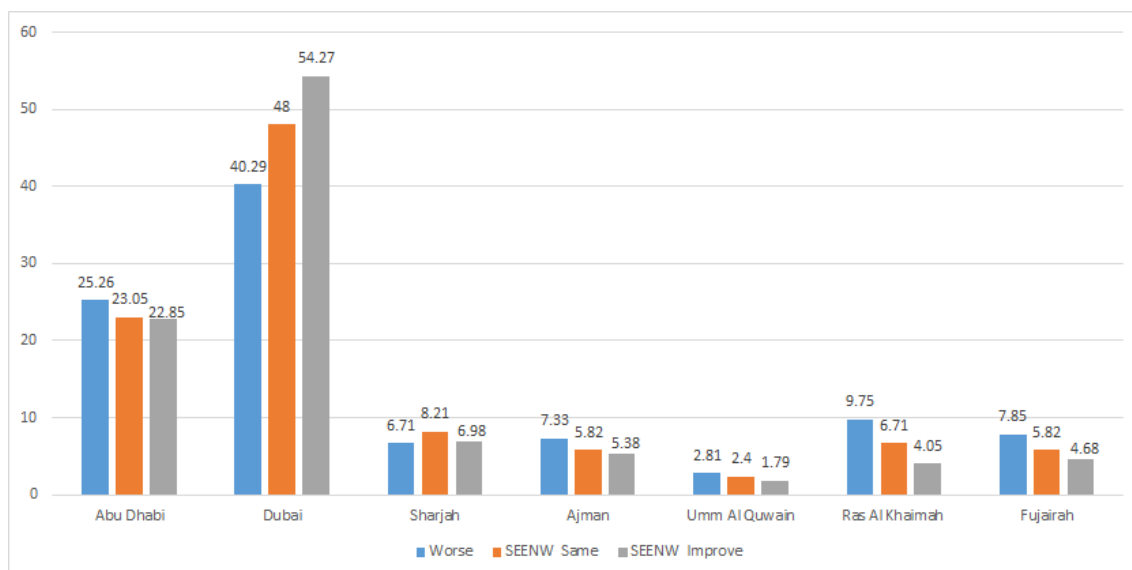
The between and within emirates relative frequency distributions of UAE youth's NPT awareness are shown in Figure 2. With regards to the between emirates distribution, it can be noted from the blue bars that among the UAE youth that report having never heard of nuclear electrical power technology, the greatest majority live in Dubai (34.61%), followed by Abu Dhabi (25%), then Ras Al Kaimah (10.98%), Sharjah (8.43%), Ajman (8.33%), Fujairah (8.04%), and finally Umm Al Quwain (4.61%). Among the youth that report having heard of nuclear electrical power technology but unable to explain it as shown by the orange bars, the majority also live in Dubai (45.01%), followed by Abu Dhabi (23.34%), then Sharjah (7.84%), Ras Al Kaimah (7.32%), then Ajman and Fujairah (6.89%), and finally Umm Al Quwain (2.71%). Furthermore, among those reporting to knowing about NPT and able to explain it in general terms, as shown by the gray bars, the majority live in Dubai (50.61%), followed by Abu Dhabi (23.85%), then Sharjah (7.37%), Ajman (5.85%), Ras Al Kaimah (5.38%), Fujairah (5.29%), and finally Umm Al Quwain (1.65%). Moreover, among those reporting to be familiar with the technology and able to explain it in details, as shown by the yellow bars, the greatest majority once more come from Dubai (57.29%), followed by Abu Dhabi (22.83%), then Sharjah (5.64%), Ras Al Kaimah (4.7%), Fujairah (4.5%), and finally Umm Al Quwain (1.14%). The within emirate distributions suggest that except for Dubai, where the relative frequency of respondents increases with increasing levels of NPT awareness; for all the other emirates, the tendency is reversed.



**Figure 2.** Conditional percent frequency of UAE youth's NPT awareness across the seven Emirates.

#### 4.1.4. NPT Expectations across the Seven Emirates

The between and within emirates relative frequency distributions of UAE youth's NPT expectations are shown in Figure 3. With regards to the between emirates distribution, it can be noted from the blue bars that among the UAE youth that reported pessimistic expectations about nuclear electrical power technology, the greatest majority live in Dubai (40.29%), followed by Abu Dhabi (25.26%), then Ras Al Kaimah (9.75%), Fujairah (7.85%), Ajman (7.33%), Sharjah (6.71%), and finally Umm Al Quwain (2.81%). Among the youth with stable expectations as shown by the orange bars, the majority also live in Dubai (48%), followed by Abu Dhabi (23.05%), then Sharjah (8.21%), Ras Al Kaimah (6.71%), then Ajman and Fujairah (5.82%), and finally Umm Al Quwain (2.4%). Moreover, among the youth with optimistic expectations as shown by the gray bars, the majority live in Dubai (54.27%), followed by Abu Dhabi (22.85%), then Sharjah (6.98%), Ajman (5.38%), Fujairah (4.68%), Ras Al Kaimah (4.05%), and finally Umm Al Quwain (1.79%). The within emirate distributions of youth expectations about NPT suggest that except for the emirate of Dubai, where the relative frequency of youth increases with increasing levels of optimism in NPT, the tendency is reversed for almost all the other emirates.



**Figure 3.** Conditional percent frequency of UAE youth's NPT expectations across the seven Emirates.



## 4.2. Econometric Results

### 4.2.1. Youths' Biospheric Interests and NPT Awareness and Expectations

The estimated impact of respondents' biospheric interests on their NPT awareness and expectations are shown in Table A2. Focusing first on its effect on NPT awareness as shown in the first column, the statistically significant coefficient value of 0.135 suggests that, each level increase in respondents' biospheric interests raises their NPT awareness by 13.5%. On the opposite, the expectation result in the second column shows a statistically significant coefficient value of  $-0.024$ , suggesting that each level increase in youths' biospheric interests reduces by 2.4% their optimistic expectations about NPT. Together, these two results seem to suggest that youths' "biospheric values" as reflected in their interests in the biosphere significantly shape their awareness and expectations about NPT in the UAE. However, although stronger biospheric values appear to create more NPT awareness among UAE youths, it conjointly contributes to less optimistic expectations about the future course of the technology in the UAE.

### 4.2.2. Control Variables and UAE Youths' NPT Awareness

The effects of the control variables on respondents' NPT awareness are shown in column one of Table A2. First, looking at the affective control variables, it can be noted that each level increase in UAE youths' interests in science-based disease prevention leads to a 6.2% increase in their NPT awareness. Similarly, every increased standard deviation in youths' science enjoyment index raises by 15.9% their NPT awareness in the UAE.

The estimated effects for the socioeconomic control variables indicate that although age and grade level do not seem to significantly affect youths' NPT awareness, factors including economic, social, and cultural status, gender, and immigration status do affect youths' NPT awareness. In fact, it can be noted that compared to females, young males show 8.7% more awareness about NPT. Similarly, compared to natives of the UAE, first and second generation expatriates are respectively 21.6% and 39.6% more aware about NPT. Furthermore, the results indicate that every increased standard deviation in youths' index of economic, social, and cultural status, raises their NPT awareness by 13.6% in the UAE.

As shown in Table A2, sources of information/knowledge also appear to significantly affect youths' NPT awareness in the UAE. In fact, every increased level of youths' frequency of ecological website visits raises their NPT awareness by 2.9%. On the opposite, each increased level of their frequency of news blogs visits, book reading on broad science, and web browsing on broad science, appear to respectively reduce by 4.9%, 5.1% and 4.6% UAE youth's NPT awareness.

The regional control dummy variables shown at the bottom of Table A2, highlight a heterogeneous NPT awareness among UAE youths across the 7 Emirates. Indeed, compared to their youth counterparts from Abu Dhabi, it can be noted that at the exception of Dubai youths that show 9.3% more awareness, youths from Sharjah, Ajman, Umm Al Quwain, Ras Al Kaimah, and Fujairah, show respectively 10%, 11.3%, 37.9%, 22% and 12.4% less awareness about NPT in the UAE.

### 4.2.3. Control Variables and UAE Youths' NPT Expectations

The effects of the control variables on UAE youths' expectations about NPT are shown in column two of Table A2. Starting with the affective control variables, it can be noted that the interest shown by UAE youths to science-based disease prevention has no significant bearing on their expectations about NPT in the country. However, every increased standard deviation in UAE youths' normalized science enjoyment index increases by 2.3% their optimistic expectations toward NPT.

The estimated effects of the socioeconomic control variables show that factors including age, economic, social, and cultural status, immigration status, grade level, and gender significantly affect youths' optimistic expectations toward NPT in the UAE. In fact, it can be noted that each annual age increase reduces youths' optimistic expectations toward NPT by 10%. Moreover, relative to their

female counterparts, male respondents are 5.2% less optimistic toward NPT in the UAE. Conversely, the results indicate a 10% rise in optimistic expectations toward NPT for every increased standard deviation in UAE youth's index of economic, social, and cultural status.

Moreover, compared to natives of the UAE, first and second generation expatriates are 26.1% and 39.3%, respectively, more optimistic about NPT. Unlike in the case of youth's NPT awareness, grade level seems to significantly shape youths' NPT expectations. Indeed, compared to youths in grade 7, those in grades 8, 10, 11, and 12 show respectively 34.7%, 28.7%, 39.1%, and 33.1% more optimism toward NPT in the UAE. Furthermore, as shown in the second column of Table A2, sources of information/knowledge are also significant determinants of youths expectations about NPT in the UAE. In fact, youths are 9.6% more optimistic about NPT for every increased level of their frequency of ecological website visits. Similarly, each level increase in UAE youth's frequencies of book reading and web browsing on broad science, appear to raise by 3.6% and 2.4% respectively their optimistic expectations toward NPT.

The regional control variables in the lower part of Table A2, also highlight heterogeneous NPT expectations among UAE youths across the 7 Emirates. Indeed, it can be noted that at the exception of the youths in Ajman and Umm Al Quwain, youths from all four remaining emirates (Dubai, Sharjah, Ras Al Kaimah, and Fujairah) show significantly different levels of optimism toward NPT, compared to their counterparts from Abu Dhabi. For instance, while youths from Dubai and Sharjah show respectively 9.3% and 5.2% more optimism than those in Abu Dhabi, the youths from Ras Al Kaimah and Fujairah have respectively 22.7% and 11.3% less optimistic expectations, compared those in Abu Dhabi.

Finally, the estimated impact of youths' NPT awareness on their optimistic expectations about NPT in the UAE, which is captured by  $\gamma$  in the equation system (1) suggests that controlling for all relevant factors (including youths' biospheric interests), UAE youths' NPT awareness does not significantly affect their optimistic expectations about the technology.

## 5. Discussion

The discovery and usage of NPT in various aspects of life is continuing to shape modern civilization. Because of its high capital cost and great hazard potential however, NPT has remained a very controversial energy source. Consequently, social acceptance (as the influence from the fourth helix) has grown to become a key aspect of NPT adoption in any quadruple helix innovative socioeconomic system. Since the UAE has just started operations of its first nuclear power plant in August 2020, the present study sought to examine factors influencing attitudes toward NPT in the country's youth population, with a focus on their interests in the biosphere, and its provided ecosystem services.

The analysis revealed that increased interest in the biosphere among UAE youths leads to more NPT awareness, but conjointly less optimistic expectations about the technology in the country. This result contrasts with the findings in [58], which reported clean energy initiatives' awareness, in addition to risk perception, environmental messaging and orientation to significantly affect youths' support for federal clean energy policy in the USA. It corroborates however the results of [61] which reported climate change concerns to reduce NPT support in China, while environmental values and energy security concerns increased NPT support. It also aligns with the findings in the UK [65], where individuals with greater environmental values and expressing greater concerns about energy supply security and climate change, are found to be less likely to favor NPT; though as a democracy, when the discourse was re-framed to allow argumentation for and against the technology, then energy supply security and climate change concerns became positive predictors of NPT acceptance.

Since the environment is part of the biosphere, while climate change is an expressed imbalance in the natural flow/order of the biosphere, our above result suggests that: taken together, youths' perceived negative influence of climate change on the biosphere exceed the observed positive influence from their environmental values and energy security needs, thereby contributing to their overall less

favorable perceptions (pessimistic expectations) about NPT in the UAE. Moreover, accounting for all relevant factors including youths' interests in the biosphere, and their media diet, our findings revealed that NPT awareness does not significantly influence UAE youths' expectations about the technology. This latter result contrasts the finding within the context of NAFTA, where ref. [59] reported rising NPT awareness among youths in the USA, Canada and Mexico to significantly increase their optimistic expectations toward the technology.

Our current analysis also showed that youths' enjoyment of science as an affective factor improves both, NPT awareness and expectations in the UAE. This latter finding aligns with [63], which reports affective feelings toward NPT to play a key role in NPT acceptance by the general public in Switzerland. A report further reiterated more recently by [34], which found affective feelings about NPT to contribute to voters' fading support for nuclear divestment in Switzerland. In our current analysis, youths' affective enjoyment of science seems to contribute to their better understanding of NPT, and the challenges attached to the operation of nuclear reactors, including the management of the resulting radio-active nuclear waste. This overall understanding by the youths that enjoy science appears to be triggering more optimistic perceptions about the future of the technology in the UAE.

Our findings further indicated a 2.9% and 9.6% improvement in both NPT awareness and expectations, from each increased level of youths' frequency of ecological website visits in the UAE. This result is unlike that in the North American context, where ref. [59] found ecological website visits to reduce youths' awareness about NPT, while however contributing to more optimistic expectations about the future of the technology among American, Canadian, and Mexican youths. Our finding seems to suggest that in their current (2015) state of use, ecological websites sufficiently raise UAE youths' environmental awareness and improve their environmental values, which studies have shown contributed to more public support for NPT in china [61] and the UK [65]. Our results on the remaining knowledge control factors including youths' visits of news blogs, web browsing for broad science content, and book reading on broad science, align with those found in the North American context [59]. Namely, they all seem to be reducing youths' NPT awareness while improving their expectations about the technology, especially the last two sources with broad science content.

The results of our included socio-demographic factors suggest that age differences among UAE youths do not significantly determine observed differences in youths' NPT awareness, but does so for their expectations about the technology in the country. Indeed, age appears to have a negative impact on youths' optimism, suggesting that aging contributes to less optimistic expectations about NPT in the UAE. This result is in line with the findings reported by the meta-analysis [5], which showed older Swiss respondents to be less receptive of NPT than their younger counterparts. This result contrasts however with that reported within the context of NAFTA, where ref. [59] found that aging improves both NPT awareness and expectations among youths in the USA, Canada and Mexico.

On the influence of gender on youths' attitude toward NPT in the UAE, the present study found that males are relatively more aware, but less optimistic about NPT, in comparison with their female counterparts. This result corroborates [60] and aligns fully with the findings in the context of NAFTA [59], although the estimated effects within NAFTA appear stronger than those found in the UAE. Our latter results however contrast partially with [5], where relatively greater acceptance and approval of NPT was reported among males, compared to females. Our results of youths grade levels' influence on their NPT awareness and expectations suggest no significant variations in awareness between grades 8 to 12 in the UAE, although significant positive but non-linear effects on their optimistic expectations about NPT appeared to prevail from their increased grade level in school. This latter finding corroborates [59], within the context of NAFTA, and also [5], where education was reported to positively influence public acceptance of NPT. Also corroborating these latter two studies is the positive and significant effect observed for the index of economic, social, and cultural status on youths' NPT awareness and expectations in the current analysis, which aligns with the reported income effects in the UAE adult transient population [60].

On immigration status, our study revealed that both first generation and second generation youth expatriates are relatively more aware and more optimistic about NPT than their native counterparts in the UAE. Given that the UAE does not have a formal permanent immigration policy like its North American, and European counterparts, but rely instead on employment-based temporary expatriation, the context are somewhat different. The UAE context was termed as “transient residency” in [60], where the authors reported transient adult residents of the UAE to perceive stronger benefits over risks from nuclear energy production, causing them to have less objections to new nuclear plants constructions in the country. Nonetheless, comparing our current findings to those reported in the North American context [59], it can be noted that in both settings, first generation youth expatriates (UAE) and immigrants (NAFTA) show more awareness and optimism toward NPT than their native counterparts. However, with second generation expatriates (UAE) and immigrants (NAFTA), the story is different. While in the UAE context, second generation youth expatriates still show relative more awareness and optimistic expectations about NPT, in the NAFTA second generation immigrants now appear relatively less aware of and less optimistic about NPT than their native counterparts.

Together, these latter findings seem to suggest an assimilation effect in youths’ NPT attitudes between natives and non-natives depending on whether the national immigration context is described by temporary expatriation (transiency) or permanent immigration. Nevertheless, our findings on the UAE youth expatriates align with those reported in the country’s transient adult population [60]. The literature also suggests the existence of a country of origin effect of immigration’s influence on NPT attitudes. Indeed, Keller et al. [64] reported greater NPT acceptance in German-speaking-communities, compared to french-speaking-communities in Switzerland, while examining community acceptance of old nuclear plants’ substitutions with new generation counterparts. The study also reported respondents in the German speaking community to have relatively more optimistic associations with nuclear energy, while those in the french speaking community appeared to have more pessimistic associations, including negative health and environmental consequences.

Our current analysis also highlighted heterogeneous NPT awareness and expectations among UAE youths across the seven Emirates. Indeed, the youths residing in Abu Dhabi and Dubai appeared relatively more aware and more optimistic about NPT, than their counterparts in the other five Emirates. This finding aligns with the cross-country regional bloc level heterogeneity in youths’ NPT awareness and expectations reported by [59], between Canada, USA, and Mexico. It also corroborates the spatial heterogeneity and proximity to site effects, reported in the literature on public acceptance of NPT, by [37] in Thailand, Hung & Wang [24] in Taiwan, Huh et al. [36] in South Korea, and [60] in the UAE transient adult population.

Since the initial nuclear reactors considered for operation at the UAE’s “Barakah” plant are of the Advanced Pressurized Water types (APR 1400), our finding that increased youths’ interests in the biosphere leads to more NPT awareness, but conjointly less optimistic expectations about the technology may perhaps suggest that future expansions of the national nuclear capacity could benefit from improved youths’ NPT perceptions by considering the Small Modular Reactors (SMRs) types. Indeed, the SMRs types have been proposed as possible alternatives addressing the socioeconomic problems (i.e., high costs, risk of catastrophic incidents, difficult radioactive waste management), which confront the nuclear power industry today [94–96].

Moreover, the consolidation of decades of research has contributed to fresh water resources being recognized as “the bloodstream of the biosphere” [97]. Because potable water production in the UAE is entirely done through seawater desalination [68], the added benefits of leveraging the Energy-Water nexus through open innovation entrepreneurial dynamics [98] and technological convergence [99] could prove invaluable. As both indispensable inputs in modern economies, energy and water resources have been lately driven by the need for economic efficiency, environmental sustainability, and supply security [100], therefore the types of open innovation driven technological convergence observed in the mobile telecommunication industry [101], the textile machinery industry [102], and the

nutraceutical (nutrition and pharmaceutical) industry [103,104], offer significant precedents that could inspire the needed synergy between the energy and water sectors in the UAE.

This integrative solution to the issue of energy and water security in the country now appears plausible through NPT. Indeed, nuclear desalinization of seawater has been proposed as a sustainable alternative to the UAE currently used fossil fuel powered desalination systems [105,106]; offering a viable option for the co-production of electricity and fresh water because of the significant heat produced by the nuclear fission, which can be used for steam and on-site electricity productions for thermal and membrane desalination plants [107,108]. This option was indeed proven feasible for the UAE by [109], which indicated the operation of low pressured small nuclear steam-only plant coupled with seawater thermal desalination, to significantly improve safety and economy without compromising much on performance.

To further minimize the loss in electricity production from freshwater co-production in the case of large nuclear reactors such as the UAE APR 1400, Lee et al. [110] proposed the use of “supercritical CO<sub>2</sub>” Brayton cycle technology. Although as identified by [94], “one size does not necessarily fit all”. That is, all the commonly identified issues with NPT today cannot be solved simultaneously. As such, choices will have to be made that reflect a compromise between the various trade-offs and the preferences of the local community for NPT and freshwater in the UAE [60]. Studies relying however on the quadruple helix model of technological innovation and diffusion [111–113] suggest that optimal choices reflecting the collective preferences of the various stakeholders in the local community, are indeed possible.

## 6. Conclusions

This study has relied on a bivariate ordered probit modeling of youths’ environmental attitudes data from the United Arab Emirates, to analyze the impact that youths’ interests in the biosphere have on their attitudes toward NPT in the country. The study is a follow up to [59], which relied on the same data source to look at NPT awareness and expectations within NAFTA; It also complements [60], which addressed NPT acceptance in the UAE’s transient adult population. Since the UAE has finally started in August 2020 operating its first nuclear power plant, which has been in construction since 2012; our present analysis aimed at providing a cross-sectional snapshot of UAE youths’ NPT awareness and expectations, for further evidence-based nuclear power policy formulation, to sustain the nascent nuclear industry in the long-run. Following the formal analysis to address our raised research question, we have found sufficient evidence to suggest that interest in the biosphere significantly raises awareness, while conjointly contributing to less optimistic expectations about NPT in the UAE youth population.

Given the centralized energy planning system in the country, which is more comparable to that of China than the North American or the European settings, where NPT decisions are the outcomes of decentralized social discourses and deliberations, the assessment of youths NPT awareness and expectations in the current analysis is more concerned with the long term continuity of nuclear electrical power production in the country than its actual acceptability. For the continuity and long-term sustainability, today’s adult stakeholders of the UAE nuclear industry ought to ensure that enough UAE youths are in the pipeline with the adequate skills, expertise and enthusiasm for nuclear technology. This will inevitably depend on how UAE youths imagine NPT and its future, which is also key to understanding how and why they invest in the technology financially, personally, professionally and otherwise.

By improving perceptions and optimistic expectations in the youth population and the general public more broadly overtime, a successful framing of the nuclear energy discourse [114,115], which showcases its complementarity with fresh water production, while appealing to youths’ interests in the biosphere, and accounting for the regional heterogeneity in NPT awareness and expectations across the seven emirates, could further contribute to the long term sustainability of the UAE’s nascent nuclear program.



**Funding:** This research received no external funding.

**Conflicts of Interest:** The author declares no conflict of interest.

## Appendix A

**Table A1.** Descriptive Statistics of the Explanatory Variables used in the Regression Model ( $n = 6919$ ).

Quantitative Variables	(Means and Standard Deviations)	Mean	s.d.
IntBiosph	Level of interest in the biosphere 1-Don't know what it is, 2-not interested, 3-Hardly interested, 4-Interested, 5-highly interested.	3.36	1.07
IntScPrevDis	Level of Interest in how science can help prevent disease; 1-Don't know what it is, 2-not interested, 3-Hardly interested, 4-Interested, 5-highly interested.	3.99	1.08
JOYSCIE	PISA index of student's Enjoyment of science	0.59	1.06
<b>How often student do the following:</b>			
1-never or Hardly, 2-sometimes, 3-regularly, 4-very often.			
EcoWebVisit	↔ Visit Ecological Websites:	3.02	0.97
BlogsVisit	↔ Follow news via blogs:	2.83	1.00
BroadScBooks	↔ Read books on broad science:	2.93	0.95
BroadScWeb	↔ Visit websites on broad science:	2.65	0.96
AGE	The student's age.	15.80	0.29
ESCS	Standardized Index of economic, social and cultural status.	0.63	0.66
WFSTUWT	Student final weight in the Data	3.31	2.40
Qualitative Variables	(absolute and percent relative frequencies)	Abs. Freq.	Rel. Freq.
Gender	Gender:		
	1-Female	3790	54.78
	2-Male	3129	45.22
IMMIG	Student Immigration status:		
	1-Native	2641	38.17
	2-Second-generation	1596	23.07
	3-First-generation	2682	38.76
GradeLev	Student grade level in school;		
	7th grade	25	0.36
	8th grade	89	1.29
	9th grade	692	10.00
	10th grade	3856	55.73
	11th grade	2163	31.26
	12th grade	94	1.36
Regionc	Unique Identifiers for each of the 7 Emirates in the UAE:		
	1-Abu Dhabi	1636	23.65
	2-Dubai	3320	47.98
	3-Sharjah	505	7.30
	4-Ajman	423	6.11
	5-Umm Al Quwain	159	2.30
	6-Ras Al Kaimah	460	6.65
	7-Fujairah	416	6.01

**Source:** Authors' construction using the UAE extract of the published data [56].

**Table A2.** MLE Results for Youths NPT Awareness and Expectations in the UAE.

N 6919	Awareness Coef.	(s.e.)	Expectations Coef.	(s.e.)
Cutoff 2	$\mu_2 = 1.032^{***}$	(0.011)	$\delta_2 = 0.875^{***}$	(0.009)
Cutoff 3	$\mu_3 = 2.042^{***}$	(0.014)		
(Intercept)	0.584 ***	(0.456)	1.194 *	(0.480)
IntBiosph	0.135 ***	(0.008)	−0.024 **	(0.008)
<b>Affective controls</b>				
IntScPrevDis	0.062 ***	(0.007)	−0.002	(0.008)
JOYSCIE	0.159 ***	(0.008)	0.023 **	(0.008)
<b>Demographic &amp; economic controls</b>				
AGE	0.009	(0.027)	−0.100 ***	(0.029)
GenderM	0.087 ***	(0.015)	−0.052 ***	(0.016)
ESCS	0.136 ***	(0.011)	0.100 ***	(0.011)
(IMMIG)2	0.216 ***	(0.019)	0.261 ***	(0.020)
(IMMIG)3	0.396 ***	(0.018)	0.393 ***	(0.019)
GradeLev8	−0.186	(0.150)	0.347 *	(0.158)
GradeLev9	−0.195	(0.138)	0.277	(0.146)
GradeLev10	−0.137	(0.137)	0.287 *	(0.144)
GradeLev11	0.072	(0.137)	0.391 **	(0.145)
GradeLev12	0.155	(0.149)	0.331 *	(0.157)
<b>Knowledge controls</b>				
EcoWebVisit	0.029 **	(0.011)	0.096 ***	(0.011)
BlogsVisit	−0.049 ***	(0.010)	0.016	(0.011)
BroadScBooks	−0.051 ***	(0.011)	0.036 **	(0.011)
BroadScWeb	−0.046 ***	(0.011)	0.024 *	(0.011)
<b>Regional control dummies</b>				
Dubai	0.093 ***	(0.018)	0.093 ***	(0.019)
Sharjah	−0.100 ***	(0.021)	0.052 *	(0.022)
Ajman	−0.113 **	(0.035)	0.014	(0.037)
Umm Al Quwain	−0.379 ***	(0.084)	−0.075	(0.087)
Ras Al Khaimah	−0.220 ***	(0.032)	−0.227 ***	(0.034)
Fujairah	−0.124 **	(0.041)	−0.113 **	(0.043)
Awareness (SENA)			−0.005	(0.008)
Log-likelihood	−28,698.1		−24,408.3	
BIC	57,626.1		49,046.4	
AIC	57,448.3		48,868.5	

\*\*\*  $p < 0.001$ , \*\*  $p < 0.01$ , \*  $p < 0.05$ .

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