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Adoption and Diffusion of Nature-Based Solutions by Property Owners in Urban Areas: The Case of Green Roofs in Eindhoven, The Netherlands

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Abstract: This article explores general concepts related to the diffusion of innovations theory (DoI) and its use regarding the adoption of nature-based solutions, specifically green roofs, in urban areas by private house/property owners in the city of Eindhoven (Netherlands). Given the gap in knowledge on the potential for the adoption of green roofs by private house/property owners as well as barriers and enablers to their implementation from the DoI perspective, we used a model for predicting the adoption of innovations (ADOPT). Results show that the predicted peak adoption level is 3% and that the time to peak adoption level is 17 years. However, the level of adoption can be significantly enhanced by increasing profit benefit (i.e., cost savings) in the years that they are used (+19 percent points adoption), reducing risk exposure (+17 percent points adoption), and improving ease and convenience (+15 percent points adoption), while the time to peak adoption level can be reduced by enhancing relevant and existing skills and knowledge (−3 years), simplifying trialability and innovation complexity (−2 years), and increasing observability (−1 year). Hence, key factors affecting the adoption of green roofs by private house/property owners have been identified, contributing to the formulation of urban climate change adoption strategies.

Keywords: adoption; diffusion; nature-based solutions; prediction model; green roofs; urban areas; green infrastructure; climate resilience; stakeholder engagement; participatory approach

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Citation: López-Maciel, M.; Roebeling, P.; Llewellyn, R.; Figueiredo, E.; Matos, F.A.; Mendonça, R.; Bastos, M.I.; Mendes, R.; Postmes, L.; Van Dinter, M. Adoption and Diffusion of Nature-Based Solutions by Property Owners in Urban Areas: The Case of Green Roofs in Eindhoven, The Netherlands. *Resources* **2023**, *12*, 133. https://doi.org/10.3390/resources12110133

Academic Editor: Volker Beckmann

Received: 29 August 2023
Revised: 28 October 2023
Accepted: 2 November 2023
Published: 10 November 2023

1. Introduction

Climate change has impacts all around the world and some urban areas are starting to experience climate-related issues. Filho et al. [1] argued that the geographical conditions and populations of different cities become drivers that have outcomes, such as more common extreme events (urban heat, drought, and floods) and poverty. Consequently, this creates the necessity for local governments and decision makers to improve local resilience through new policies and adaptation initiatives [1].

To adapt to climate change, more cities have been introducing a gradual (re-) integration of nature into their urban areas [2]. For this purpose, the implementation of nature-based solutions (NBSs) that have the potential to provide ecosystem services for climate change adaptation and co-benefits in urban areas seem to be a promising option from a local perspective [3]. NBSs is an umbrella concept including concepts and practices, such as ecosystem-based adaptation, green infrastructure, low-impact development, best management practices, and sustainable urban drainage systems, that can be defined as a series of actions that protect and restore natural or modified ecosystems, providing at the same time social, economic, and biodiversity benefits [4].

One type of NBS for urban areas is green roofs. Green roofs are systems that involve a series of elements to be implemented, such as waterproofing, root repellent systems, drainage systems, filter cloths, and lightweight growing media and plants [5]. Green roofs not only serve as aesthetical infrastructure but also have physiological and functional properties that contribute to mitigating negative effects in urban areas generated by buildings, surface sealing, and heatwaves [6]. Prins [7] pointed out that green roofs are recognized for their ability to mitigate the negative effects of climate change, including peak precipitation and heat waves. Teotónio et al. [8] argued that green roofs have advantages over other types of NBSs in urban areas in places with little available land [8]. From a public perspective, the benefits of green roofs include reducing the urban heat island effect, decreasing air and water pollution, managing storm water, developing new amenity spaces, creating habitats, enhancing biodiversity, and creating local jobs [5,7,9]. From a private perspective, the benefits of green roofs include infrastructure improvement, roof longevity prolongation, reduced energy consumption, noise reduction, real-estate valuation, and aesthetic values [8,10].

Despite this recognition, green roofs are not widely adopted. The adoption and diffusion of green roofs in urban areas are influenced by several factors, including prior conditions to implementation in a specific area, the perceived characteristics of green roofs, and the characteristics—including information exposure—of potential adopters [11]. In this context, the concept of adoption is defined as a multi-stage decision process that considers the amount of information acquired and the active learning experience of potential adopters with different preferences and perceptions of riskiness towards an innovation [12]. Diffusion is defined as the spread of adoption decisions over time and space, which can be represented as a curve with the proportion of potential adopters that have already adopted an innovation as a function of time [13,14].

In many regions around the world, the adoption of green roofs can have financial, structural, knowledge and information, technical, and climatic barriers to their implementation [11]. For instance, installation and maintenance costs could be higher in comparison with traditional roof technologies, such as cool roofs [15–17]. The physical risks associated with the inadequate implementation of green roofs include structural and static challenges and possible damages to buildings or plants, which could lead to leakages or the undesired growth of wild plants [18]. On the other hand, the lack of regulations and incentives for small green roofs may limit their implementation among property owners, making it necessary to provide additional evidence on green roofs that contributes to better-informed assessments and decision-making processes prior to implementation [19,20]. In that regard, Liberalesso et al. [21] pointed out that incentives and related policies have a considerable impact on green infrastructure adoption. However, most incentive policies are found in Europe and North America. From a social perspective, the low diffusion of the green technology culture among potential adopters and the private sector [22], including the ones that can technically apply them (such as architects and the building industry), limits the implementation of green roofs [18]. In that sense, the absence of consistent policy implementation represents a general barrier in different countries around the world, even in countries with a high gross domestic product [23]. Liberalesso et al. [21] explained that city planners often have problems reaching private house/property owners to invest in green infrastructure, especially when private (financial) costs outweigh the benefits, even though the social (economic) benefits may outweigh the costs—such as in the case of green roofs and green walls. For instance, Hendricks and Calkins [24] reported through a survey analysis a low implementation potential for green roofs in the United States of America, specifically for architects and building owner associations in Chicago and Indianapolis. A significant percentage of the participants reported no interest in implementing green roofs in the next five years. The majority of them also stated that they would not support legislation requiring green roofs on commercial buildings, which serves as an example of this type of barrier when implementing them.

To evaluate the potential for the adoption and diffusion of NBSs and, specifically, green roofs, it is necessary to consider case studies that provide evidence for their implementation or the intention to do so [11]. This is important not only for assessing their benefits but also for understanding the barriers and difficulties encountered during their implementation. For this purpose, a general way to assess the adoption and diffusion of NBSs is the use of basic concepts of the diffusion of innovations (DoI) theory [13]. Considering a green roof as an innovation and seeking common relationships, the DoI allows us to determine strengths and opportunity areas during the adoption and diffusion of NBSs such as green roofs [25].

The case study of this article is the city of Eindhoven (Netherlands), which has a population of more than 230,000 inhabitants [26]. The city is facing significant challenges due to climate change and population growth. Climate change has worsened issues such as flooding, air pollution, and urban heat stress, while urbanization has also led to the loss of important green and blue zones, causing negative impacts on the urban environment and quality of life in the city [27]. Furthermore, the city faces several water-related challenges, such as flooding on streets after heavy rainfall due to insufficient drainage capacity, combined sewer outlets (polluting vulnerable surface waters), the malfunctioning of remaining surface waters, and groundwater entering the basements of houses. In addition, a large wastewater treatment plant serving 750,000 inhabitants discharges effluent on a small water surface area, which results in insufficient biological treatment capacity during periods of heavy rainfall [28]. Costa et al. [29] investigated the antecedents of urban flood events in Eindhoven and evaluated the effectiveness of various NBSs, showing that green roofs present a potential alternative to traditional approaches in managing urban floods.

The objective of this article is to assess and analyze the potential adoption and diffusion of green roofs by private house/property owners in the city of Eindhoven (Netherlands). The two main variables analyzed consist of the potential peak adoption level (PAL) and time to peak adoption level (TPAL). For this purpose, an online survey was provided to private house/property owners in the urban area of Eindhoven. The information was analyzed with general descriptive statistics and used in the specialized adoption prediction model ADOPT [30] to assess the potential adoption and diffusion of green roofs by private house/property owners in Eindhoven. The results allow us to understand the factors that most affect the adoption and diffusion of green roofs in the case study area. Hence, this research not only evaluates the potential level of adoption and rate of diffusion of green roofs in the city of Eindhoven but also identifies those factors that mostly constrain or potentiate the adoption and diffusion of green roofs by private house/property owners.

This study goes beyond, López-Maciel et al. [30], who assessed the potential for the adoption of green roofs in Eindhoven in two separate workshops with experts from the Technical University of Eindhoven and the Municipality of Eindhoven by employing a survey setting targeted towards private house/property owners in the urban area of Eindhoven. The main difference between these two approaches is that the survey setting directly involved potential adopters, while the workshop setting involved experts who were considered representatives of potential adopters. Hence, it provides insight into the extent to which expert knowledge and public awareness of green roofs differ and what this implies for the potential adoption and diffusion of green roofs.

The remainder of this article is structured as follows. In the next section, a conceptual description of the main elements of the diffusion of innovations theory is provided. Then, Section 3 presents the materials and methods, followed by the results and discussion described in, respectively, Section 4 andSection 5. Finally, Section 6 provides the conclusions.

2. The Diffusion of Innovations Theory

The diffusion of innovations (DoI) theory was developed by Everett Rogers in 1962 [13] to explain how an idea or product gains momentum and is adopted over time within a specific population or social system [31]. The DoI is based on two concepts: communication and diffusion [13]. Communication is the process of creating and sharing information among participants to attain a mutual understanding. Diffusion involves perceived risk and uncertainty that can be influenced by the available information. Subsequently, the four main elements of diffusion are associated with (i) innovation, (ii) communication channels, (iii) time, and (iv) the social system [13].

2.1. Innovation

An innovation is an idea, practice, or object perceived as new by a potential adopter (for example, an individual, a specific group, or any other unit of adoption) [13]. Its characteristics will determine the rate of adoption among the members of a social system. It has five attributes:

1. Relative advantage, which measures how much better an innovation is perceived to be compared to the existing idea it is meant to replace. It has a positive relationship with the rate of adoption of the innovation.
2. Compatibility, which measures how well an innovation aligns with the values, experiences, and needs of potential adopters. It has a positive relationship with the rate of adoption of the innovation.
3. Complexity, which measures how difficult an innovation is to understand and use. It has a negative relationship with the rate of adoption of the innovation.
4. Trialability, which measures how easily an innovation can be experimented with on a limited basis. It has a positive relationship with the rate of adoption of the innovation.
5. Observability, which measures how visible the results of the innovation are to others. It has a positive relationship with the rate of adoption of the innovation.

2.2. Communication Channels

Communication channels are the different means by which one individual gets messages from others [13]. These channels can be categorized as either interpersonal (which includes the functions of knowledge, persuasion, and decision) or mass media. Also, these communication channels can be originated from either local or cosmopolite sources.

2.3. Time

Time is an independent variable that is involved directly in the diffusion of innovations in three areas [13]:

1. Innovation decision processes involve several stages, including the previous conditions of potential adopters, knowledge and persuasion regarding the innovation, the decision of adoption or rejection, implementation, and confirmation. The persuasion stage depends on the characteristics of the innovation, including relative advantages, compatibility, complexity, trialability, and observability.
2. Innovativeness refers to the tendency of potential adopters to be early or late in adopting new ideas compared to the rest of their social system. Earlier adopters tend to have higher socioeconomic status, more education, greater empathy, less dogmatism, a more favorable attitude towards change and science, and more social participation and interconnectedness.
3. The adoption rate is the relative speed of innovation adoption within a social system and is determined by five variables: the perceived attributes of the innovation, type of innovation decision, communication channels, the nature of the social system, and the innovation promotion efforts and stakeholders involved.

2.4. Social System

The social system is described as the interrelationships of units looking to solve a common problem to reach a collective goal [13]. A critical element of a social system is its structure, which gives stability and regularity to individual behavior within its members. Facilitating or not the diffusion of innovations, it is essential to mention the three types of innovative decisions: optional, collective, and authoritarian. A fourth one can be included by combining two or more of these types of decisions during contingencies carried on after a prior innovation decision. Rogers explained that the adoption and diffusion process considers what he calls diffusion and communication networks, i.e., the interconnection of individuals who are linked by patterned flows of information. Communication networks give stability and predictability to human behavior during the adoption and diffusion process of an innovation [13].

3. Materials and Methods

To assess and analyze the potential adoption and diffusion of green roofs by private house/property owners in the city of Eindhoven (The Netherlands), use was made of the Adoption and Diffusion Outcome Prediction Tool (ADOPT, [32]) based on responses obtained through an online survey. The original questions found in ADOPT were adapted to the case of green roofs (see Section 3.2). As the study was conducted during the COVID-19 pandemic, ADOPT questions were transformed into an online questionnaire format that was promoted (newsletter) and made available (Microsoft Forms) by the municipality of Eindhoven through their monthly newsletter (accessible to all Eindhoven residents). In the introduction to the questionnaire, the context (NBSs and green roofs for urban climate change adaptation), aims (to assess possibilities for the construction of green roofs in Eindhoven), and target audience (private house/property owners from all neighborhoods of the city) were clearly defined to reduce self-selection bias. It is important to note that the survey did not involve the processing of personal information from the respondents. Instead, the analysis focused on examining general group trends regarding the perception of green roof adoption. This specification was explicitly communicated in the introduction to the survey, ensuring transparency and clarity for participants before they proceeded to fill it out.

3.1. The Adoption and Diffusion Outcome Prediction Tool (ADOPT)

ADOPT is a web-based model developed by the Commonwealth Scientific and Industrial Research Organisation (CISRO) along with other Australian laboratories and academic institutions [30,32,33]. Although ADOPT was originally designed for the agricultural sector [34], the principles underpinning ADOPT are non-agricultural specific [32] and, hence, ADOPT has also recently been applied to assess, for example, the factors influencing the adoption of solar photovoltaic systems [35]. The underpinning principles are conceived taking into account a wide range of innovations and building on the diffusion of innovations (DoI) theory (see Section 2). In the ADOPT framework, these influential factors are organized into four distinct categories, often referred to as quadrants, which provide a comprehensive perspective on the adoption process:

1. Relative advantage for the population (quadrant Q1);
2. Learnability characteristics of the innovation (quadrant Q2);
3. Learnability of the population (quadrant Q3);
4. Relative advantage of the innovation (quadrant Q4).

By organizing the general variables into these four categories, ADOPT provides a systematic approach to understanding and analyzing the complex dynamics of innovation adoption. It allows for a comprehensive assessment of the various factors that influence adoption, enabling practitioners and researchers to develop targeted strategies and interventions to promote the successful adoption of innovations. ADOPT uses different interaction variables, including the adopter's networks, profit orientation, environmental orientation, risk attitude and enterprise scale, the innovation's financial costs and benefits, environmental impacts, risks and complexity, and the possibility to trial the innovation on a small scale and readily observe apparent effects [33].

ADOPT is composed of 22 quantitative variables divided over these four main quadrants. It can be observed in Figure 1 that the 22 questions were correlated, creating different intermediate variables with the objective of reaching two central values in the prediction scenario: the peak adoption level (PAL), defined as the maximum reachable level of adoption, and the time to peak adoption level (TPAL), defined as the time needed to reach the maximum level of adoption. Also, it can be noted that Q1 and Q4 are directly related to the PAL and, when most of them are combined into the intermediate variable Relative Advantage, these cited quadrants also affect the TPAL. Quadrants Q2 and Q3 are only related to the TPAL. The answers to these questions were obtained through a survey of 22 questions, though could also have been obtained in a stakeholder workshop setting (see e.g., [25,32]). In turn, the answers' mean values to these questions were introduced into ADOPT, as calibrated and validated by Kuehne et al. [33], to obtain the PAL and TPAL.

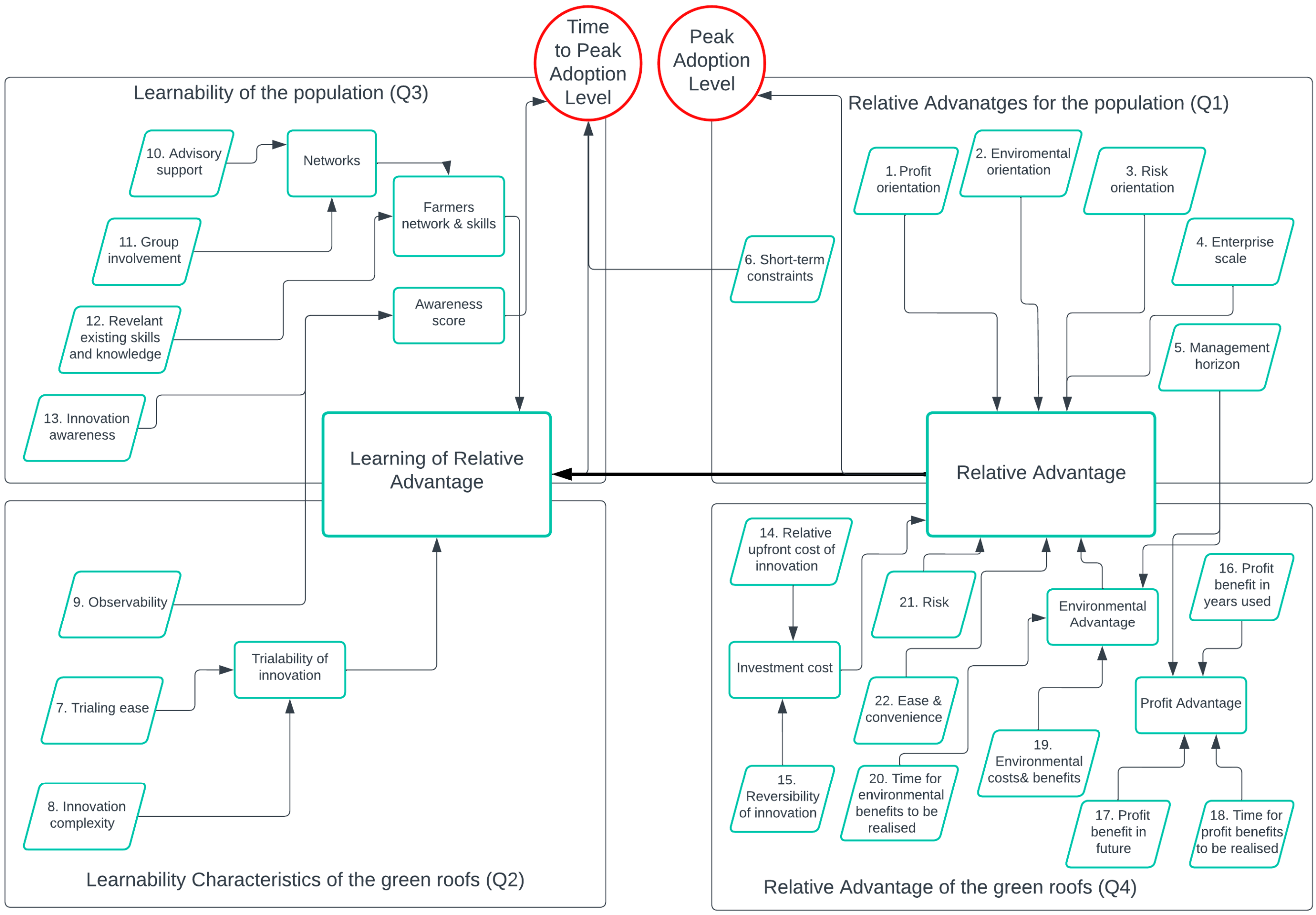

Figure 1. The four quadrants and their relationships related to the 22 questions of ADOPT (adapted from Kuehne et al. [33]).

3.2. Questionnaire "Green Roofs in Endhoven-Exploring the Potential for Adoption"

The questionnaire was derived from the 22 questions in ADOPT, mentioned in the previous section. Although ADOPT was initially developed in the context of innovations within the agricultural sector, ADOPT is a generic model with broad applicability to different types of innovations (see e.g., [30]). Several modifications were essential to ensure the relevance and comprehensibility of the questionnaire for house/property owners, which constituted the target population of this study:

- Literature review: The authors conducted a comprehensive literature review to gain insights into the specific characteristics and factors relevant to the adoption of green roofs by house/property owners.
- Questionnaire refinement: Various iterations of the questionnaire were developed and tested within an academic setting at the University of Aveiro in Portugal. These internal workshops allowed the authors to refine the questions and ensure that they were easily understandable and applicable to potential adopters.
- Pilot study: In 2018, a preliminary version of the questionnaire was used in a workshop setting at the Eindhoven University of Technology and with the Municipality of Eindhoven (see [30]). This pilot study provided valuable feedback and insights into the practical usability and effectiveness of the survey.
- Final survey development: The final version of the survey questionnaire emerged as a result of this refinement process, incorporating the feedback and lessons learned from the pilot study as well as based on detailed feedback from the Municipality of Eindhoven. This version was then prepared for implementation on a larger scale (see Appendix A).

The data were collected via online responses (using Microsoft Forms) to the questionnaire, which was divided into five sections:

1. Introductory questions;
2. Relative advantage for the population (quadrant Q1);
3. Learnability characteristics of green roofs (quadrant Q2);
4. Population-specific influences on the ability to learn about green roofs (quadrant Q3);
5. Relative advantage of green roofs (quadrant Q4).

The final questionnaire consisted of 30 questions, divided between four introductory questions, the four quadrants (Q) containing the 22 variables from ADOPT, and four optional open questions in case the respondents wanted to express their reasoning for their answers in each quadrant (see Appendix A for the full questionnaire). For the case study in Eindhoven, the survey was presented with the option to answer in English or Dutch. The average time for responding to the survey was 15 min. The questionnaire was announced in a monthly newsletter by the municipality of Eindhoven and made available online (using Microsoft Forms) for one month. The data were analyzed using descriptive statistics, including mean, standard deviation, and minimum and maximum values.

3.3. Sensitivity Analysis

A sensitivity analysis was performed to assess to what extent the peak adoption level (PAL) and time to peak adoption level (TPAL) were sensitive to changes in the scores for each of the 22 ADOPT questions. To this end, scores to the respective questions were, one by one, increased and decreased along the corresponding scoring scale, and subsequent changes in PAL and TPAL were recorded. The sensitivity analysis showed the effect on PAL and TPAL of this increase and decrease in the response for each variable if all other variables remained unchanged [33].

4. Results

The questionnaire was open to all private house/property owners in Eindhoven in March 2021. In total, 1023 anonymous responses were received, of which 666 were men, 343 were women, and 14 were other/prefer not to say. This section provides the descriptive statistics (Section 4.1), the survey analysis using ADOPT (Section 4.2), the sensitivity analysis for the peak adoption level (Section 4.3), and, finally, the sensitivity analysis for the time to peak adoption level (Section 4.4).

4.1. Descriptive Statistics

To determine if the sample of 1023 answers was significant, a sample size calculator was used [36], setting it with a confidence level of 95%, a margin error of 5%, a population size of 116,056 private houses/properties [26], and a population proportion of 44%

(51,098 private house/property owners; [26]) for the city of Eindhoven in the year 2021 [26]. The result was a minimal sample size of 378. Hence, the number of obtained responses (1023) was statistically significant for the city of Eindhoven at a 95% confidence level [36].

Table 1 provides an overview of the response values, including the mean, standard deviation (std. dev.), minimum (min.) and maximum (max.) values, respectively. The values for the responses are given in ranks scoring from 1 to 5 or 6 or 8, depending on the question (see Appendix A).

Table 1. Descriptive statistics for variables by quadrant (Q; N = 1023).

Variable	Mean	Std. Dev.	Min.	Max.
Introductory questions				
Age (years)	58	14	21	75
Income (€/month)	3278	1511	1000	6000
Relative advantage for the population (Q1)				
1. Profit orientation (low “1” to high “5”)	2.3	1.3	1	5
2. Environmental orientation (low “1” to high “5”)	4.4	0.9	1	5
3. Risk orientation (low “1” to high “5”)	3.3	1.2	1	5
4. Enterprise scale (low “1” to high “5”)	2.4	1.2	1	5
5. Management horizon (low “1” to high “5”)	2.0	*	1	5
6. Short-term constraints (low “1” to high “5”)	5.0	*	1	5
Learnability characteristics of green roofs (Q2)				
7. Trialling ease (low “1” to high “5”)	3.5	1.4	1	5
8. Green roof complexity (high “1” to low “5”)	3.4	1.5	1	5
9. Observability (low “1” to high “5”)	2.9	1.3	1	5
Learnability of the population (Q3)				
10. Advisory support (low “1” to high “5”)	3.0	1.3	1	5
11. Group involvement (low “1” to high “5”)	1.5	0.8	1	5
12. Relevant skills and knowledge (high “1” to low “5”)	3.1	1.3	1	5
13. Green roof awareness (low “1” to high “5”)	1.0	2.4	1	5
Relative advantage of green roofs (Q4)				
14. Relative upfront cost of practice (high “1” to low “5”)	2.5	1.0	1	5
15. Reversibility of green roofs (low “1” to high “5”)	3.2	1.0	1	5
16. Profit benefit in years they are used (high “1” to low “3” costs, neutral “4”, and low “5” to high “8” benefits)	3.2	1.5	1	5
17. Profit benefit in future (high “1” to low “3” costs, neutral “4”, and low “5” to high “8” benefits)	4.2	1.2	1	8
18. Time for profit benefit to be realized (high “1” to low “5” and neutral “6”)	3.9	1.8	1	6
19. Environmental impact (high “1” to low “3” costs, neutral “4”, and low “5” to high “8” benefits)	5.5	1.4	1	8
20. Time for environmental impacts to be realized (high “1” to low “5” and neutral “6”)	3.7	1.5	1	6
21. Risk (high “1” to low “3” increase, neutral “4”, and low “5” to high “8” reduction)	3.3	1.6	1	8
22. Ease and convenience (high “1” to low “3” reduction, neutral “4”, and low “5” to high “8” increase)	3.5	1.6	1	8

Note: * Due to the formulation of these questions, the answers were simplified to two options (“yes” or “no”), which excluded them from a standard deviation analysis.

The introductory questions show that the average age of the respondents was 58 and the average income was 3278 €/month. The standard deviations were relatively low, about 25% and 45%, respectively.

For the first quadrant (Relative advantage for the population; Q1), it was shown that profit maximization was not a strong motivation for the majority of respondents (Profit orientation = 2), protecting the environment was a strong motivation for the majority of respondents (Environmental orientation = 4), and respondents were neutral with respect to risk (Risk orientation = 3). In addition, it was shown that a minority of the respondents had a long-term management horizon for their property (Management horizon = 2) and that almost none of the respondents faced severe short-term financial constraints (Short-term constraints = 5). Finally, the respondents indicated that a minor part of their property was suitable for the implementation of green roofs (Enterprise scale = 2). The standard deviation for the first quadrant was low (Question 2) to medium (Questions 1, 3, and 4), indicating that the obtained responses regarding the relative advantage for the population were close to the mean. Note that in this quadrant, variables 5 and 6 did not show a value for the standard deviation as in ADOPT these questions are designed to gather collective responses, without considering individual variations. Note that in ADOPT, questions related to variables 5 and 6 are framed as "What proportion of the target population . . ." and are to be answered by relevant experts in a workshop setting. As we worked in a questionnaire setting and based on a request from the Municipality of Eindhoven to simplify these questions, we transformed these questions such that respondents could respond individually and simply. In turn, individual responses in combination with the total number of responses were used to obtain population-level proportions. Hence, between 0% and 20% of 'No' responses corresponded to "Almost none have . . ." (=1), between 21% and 40% of 'No' responses corresponded to "A minority have . . ." (=2), between 41% and 60 of 'No' responses corresponded to "About half have . . ." (=3), between 61% and 80 of 'No' responses corresponded to "A majority have . . ." (=4), and, finally, between 81% and 100% of 'No' responses corresponded to "Almost all have . . ." (=5).

For the second quadrant (Learnability characteristics of green roofs; Q2), half of the respondents had the perception that green roofs can be moderately difficult to test on a small scale at a low cost, allowing for some potential learning about their likely benefits (Trialling ease = 3). Also, half of the respondents considered that it was moderately difficult to evaluate the effects of the adoption of green roofs due to their complexity (Green roof complexity = 3). In the same sense, half of the respondents believed that green roofs can be moderately observable to potential adopters. For this quadrant, the general standard deviation was medium, indicating that responses for the learnability characteristics of green roofs were moderately dispersed regarding the mean.

For the third quadrant (Learnability of the population; Q3), half of the respondents stated that they would sometimes use advisors capable of providing advice relevant to green roofs (Advisory support = 3). On the other hand, most of the respondents had never participated in groups that discussed topics related to nature-based solutions, including green roofs (Group involvement = 1). Regarding the need to develop substantial new skills and knowledge to use green roofs, half of the respondents did not know if they needed additional skills to use them (Relevant skills and knowledge = 3). Lastly, the majority of the respondents were not aware of previous trialing or testing of green roofs in the city of Eindhoven (Green roof awareness = 1). The standard deviation for the third quadrant was low (Question 12) to medium (Questions 10 and 11), which indicates that the obtained responses regarding the learnability of the population were relatively close to the mean.

The last quadrant (Relative advantage of green roofs; Q4) showed that half of the respondents considered that the initial investment relative to the potential annual benefit of the implementation of the green roofs was moderate (Relative upfront cost of practice = 3). In the same sense, the respondents considered it to be moderately difficult to reverse the use of green roofs (Reversibility of green roofs = 3). On the other hand, most of the respondents considered that green roofs are likely to generate small annual costs in the years they are implemented (Profit benefit in years they are used = 3). Alternatively, most of the respondents considered that green roofs would provide neither a loss nor a profit in the future value of their properties (Profit benefit in future = 4). Nevertheless, respondents expected it would take 1 to 2 years for the effects on the value of their property to be realized (Time for profit benefit to be realized = 4). Most respondents believed the use of green roofs had moderate environmental benefits (Environmental impact = 6), taking a time of 1 to 2 years to realize those benefits (Time for env. impacts to be realized = 4). The perception of most of the respondents was that green roofs would affect in a small way the net exposure of property to risk (Risk = 3). The standard deviation for this quadrant was medium (Questions 14 to 22), showing that the answers were not as close to the mean in comparison with the previous quadrants.

4.2. Survey Analisis Using ADOPT

In this section, the survey responses are used in ADOPT, using the rounded mean values from the survey (see Tables 1 and 2). The objective was to process the information from the perception of the property owners to obtain a calculated prediction scenario giving the PAL and the TPAL of green roofs for the city of Eindhoven.

Table 2. ADOPT input score and meaning.

Question	Response
Relative advantage for the population (Q1)	
1. Profit orientation	2. Probably, profit maximization IS NOT a strong motivation
2. Environmental orientation	4. Probably, protecting the natural environment IS a strong motivation
3. Risk orientation	3. Neither agree nor disagree that risk minimization is a strong motivation for me
4. Enterprise scale	2. A minor part of the house/property is suitable for the implementation of green roofs
5. Management horizon	2: A minority have a long-term management horizon
6. Short-term constraints	5: Almost none currently have severe short-term financial constraints
Learnability characteristics of green roofs (Q2)	
7: Trialable	3. Moderately difficult to trial/test on a small scale
8: Innovation complexity	3: Moderately difficult to evaluate effects of use due to complexity
9: Observability	3. Moderately observable to potential adopters
Learnability of the population (Q3)	
10: Advisory support	3. Sometimes
11: Group involvement	1. Never
12: Relevant skills and knowledge	3. I do not know if I would need some additional skills
13: Innovation awareness	1. No, I am not aware of previous trialing/testing in my city/neighborhood
Relative advantage of green roofs (Q4)	
14: Relative upfront cost of innovation	3. Moderate initial investment relative to the potential annual benefit
15: Reversibility of innovation	3. Moderately difficult to reverse
16: Profit benefit in years they are used	3. Small annual costs in the years that they are implemented/used
17: Future profit benefit	4. Neither loss nor profit in the future
18: Time for profit benefit to be realized	4: 1–2 years
19: Environmental costs and benefits	6: Moderate environmental benefits
20: Time to environmental benefit	4: 1–2 years
21: Risk exposure	3: Small increase in risk
22: Ease and convenience	4: No decrease in ease and convenience

The predicted peak adoption level (PAL) of green roofs is 3% (see Figure 2). The adoption level after 5 years is 1.1% and after 10 years it is 2.7%. The predicted time to peak adoption level (TPAL) is 17 years, while in 13 years, 95% of the maximum adoption level is expected.

The results obtained through ADOPT show a low peak adoption level (PAL) of green roofs for the property owners surveyed in Eindhoven (3%). In order to comprehend the low PAL, it is essential to observe the ADOPT quadrants and variables that have relevance in the PAL (namely, Q1 and Q4; see Figure 1). The 'Relative advantage for the population' quadrant (Q1) established whether the orientation of the population (e.g., motivated towards environmental benefits more so than towards profit benefits) would lead to some of the characteristics of green roofs (such as environmental benefits) being more highly weighted when determining the overall net relative advantage for adopters [33]. It is important to consider that the overall motivations and orientations of a population characterized in this quadrant are usually difficult to change at the level of project interventions [33], but it can be expected that broader shifts occur over time (e.g., stronger environmental orientation among urban populations). On the other hand, the 'Relative advantage of the innovation' quadrant (Q4) was related to the direct advantages of green roofs derived from their own qualities. Scores were below average for 4 and average for 3 out of the 9 questions in this quadrant, again explaining the low level of adoption.

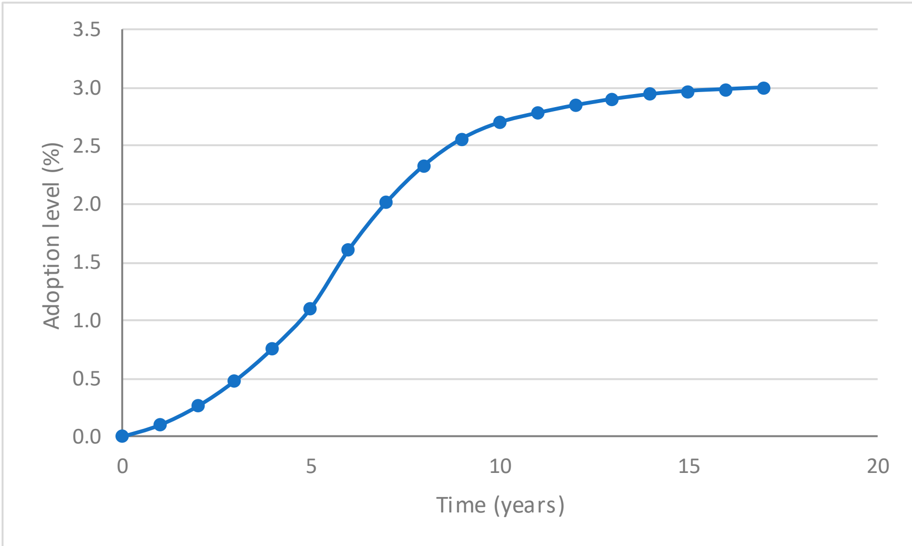

Figure 2. Adoption level curve based on the ADOPT results for the implementation of green roofs in Eindhoven.

4.3. Sensitivity Analysis to Peak Adoption Level

To determine how each of the cited variables affected the peak adoption level (PAL) of green roofs in Eindhoven, a sensitivity analysis was performed (see Section 3.3). Table 3 shows the sensitivity analysis for the 22 ADOPT variables, noting that Q1 (variables 2 to 5) and Q4 (variables 14 to 17 and 19 to 22) are the only ones that affect the PAL.

For Q1, it can be observed that changes were minimal, changing the level of adoption by up to only 1 percentage point. For Q4, it can be observed that changes were considerable, changing the level of adoption by up to about 20 percentage points. Focusing on quadrant Q4, which proved to be of most influence for the PAL of green roofs, it can be observed that the variables 'Profit benefit in the years that green roofs are used', 'Risk exposure', 'Ease and convenience', 'Future profit benefit', and 'Environmental costs and benefits' were the most relevant aspects to enhance the PAL (up to +22, +20, +18, +12, and +10 percentage points adoption, respectively). As stated, these variables are related to the modification of the green roof design and characteristics. Hence, to improve the PAL of green roofs, the promoters of green roofs could find a way to redesign green roofs accordingly.

The first variable, 'Profit benefit in years that they are used', is of the highest importance when trying to increase the PAL (up to +22 percentage points adoption) and is associated with the question, "To what extent do you think is the green roof likely to affect the operation and maintenance costs of your house/property during the years it is implemented/used?". This question was focused on expected financial direct profits or annual savings due to green roof installation. Hence, it referred to avoided costs or cost savings associated with the implementation of green roofs, e.g., through energy savings related to cooling and/or heating of the house/property. The average impression of the respondents was that instead of profits, small annual costs were expected during the years green roofs are implemented, considerably reducing the potential adoption of green roofs.

Table 3. Sensitivity analysis for peak adoption level of green roofs in Eindhoven, showcasing only those variables for which an effect was observed (scores obtained from the survey are bold and underlined).

Variable	**Peak Adoption (%)**							
	Answer 1	**Answer 2**	**Answer 3**	**Answer 4**	**Answer 5**	**Answer 6**	**Answer 7**	**Answer 8**
Relative advantage for the population (Q1)								
2: Environmental orientation	2	2	3	**<u>3</u>**	4	N/A	N/A	N/A
3: Risk orientation	4	3	**<u>3</u>**	3	3	N/A	N/A	N/A
4: Enterprise scale	3	**<u>3</u>**	4	4	4	N/A	N/A	N/A
5: Management horizon	3	**<u>3</u>**	3	4	4	N/A	N/A	N/A
Relative advantage of green roofs (Q4)								
14: Relative upfront cost of innovation	2	3	**<u>3</u>**	4	5	N/A	N/A	N/A
15: Reversibility of innovation	3	3	**<u>3</u>**	4	4	N/A	N/A	N/A
16: Profit benefit in years they are used	2	2	**<u>3</u>**	5	7	10	15	22
17: Future profit benefit	2	2	3	**<u>3</u>**	5	6	9	12
19: Environmental costs and benefits	1	1	1	2	2	**<u>3</u>**	6	10
20: Time to environmental benefit	2	2	3	**<u>3</u>**	4	4	N/A	N/A
21: Risk exposure	2	3	**<u>3</u>**	5	7	10	14	20
22: Ease and convenience	1	2	2	**<u>3</u>**	5	8	12	18

The second variable, 'Risk exposure' (up to +20 percentage points adoption), is associated with the question, "To what extent would the use of the green roof affect the net exposure of the house/property to risk?". The intention was to identify whether green roofs reduced, or not, the possibility of a negative impact on a house/property (e.g., infiltration, fire, or wind damage). The average response was that the house/property owners expected a slightly increased risk exposure to their property when adopting green roofs, reducing the PAL considerably.

The third variable, 'Ease and convenience' of green roofs (up to +18 percentage points adoption) is associated with the question, "To what extent would the use of the green roof affect the ease and convenience of the maintenance of your house/property during the years that it is used?". The intention was to measure changes to the ease, convenience, and management demands on the house/property that may result from implementing a green roof. The average response was neutral, meaning the respondents' perception was that the management of their property would remain almost the same; hence, not favoring an intention to adopt green roofs.

The fourth variable, 'Future profit benefit' of green roofs (up to +12 percentage points adoption) is associated with the question, "To what extent are the green roofs likely to have additional effects on the future value of your house/property?". This question focused on the structural, long-term impacts of green roofs on the value of a house/property. Again, the average response was neutral, meaning that the respondents' perception was that they expected the value of their property to remain the same; hence, also not favoring an intention to adopt green roofs. It is important to note that the respondents' responses did not reflect the accurate projections of the value of their house/property in the future after implementing green roofs, but their perception about it, which can be a limiting factor when considering the implementation of green roofs.

Finally, the variable 'Environmental costs and benefits' (up to +10 percentage points adoption) is associated with the question, "To what extent do you think the use of the green roofs have net environmental benefits or costs?". This question focused not only on environmental costs and benefits but also on allied non-profit concerns such as health and wellbeing. The respondents perceived moderate environmental benefits for the adoption of green roofs. However, for this variable to be significant for increasing the PAL, at least large or very large environmental benefits would have to be recognized when implementing green roofs (see responses 7 and 8 in Table 4).

Table 4. Sensitivity analysis for time to near peak adoption level of green roofs in Eindhoven, showcasing only those variables for which an effect was observed (scores obtained from the survey are bold and underlined).

Variable	Time to Near Peak Adoption (Years)							
	Answer 1	**Answer 2**	**Answer 3**	**Answer 4**	**Answer 5**	**Answer 6**	**Answer 7**	**Answer 8**
Relative advantage for the population (Q1)								
6: Short-term constraints	17	16	15	14	**<u>13</u>**	N/A	N/A	N/A
Learnability characteristics of green roofs (Q2)								
7: Trialable	16	14	**<u>13</u>**	12	11	N/A	N/A	N/A
8: Innovation complexity	16	14	**<u>13</u>**	12	11	N/A	N/A	N/A
9: Observability	14	14	**<u>13</u>**	13	12	N/A	N/A	N/A
Learnability of the population (Q3)								
10: Advisory support	14	14	**<u>13</u>**	13	12	N/A	N/A	N/A
11: Group involvement	**<u>13</u>**	13	13	13	12	N/A	N/A	N/A
12: Relevant skills and knowledge	17	15	**<u>13</u>**	12	10	N/A	N/A	N/A
13: Innovation awareness	**<u>13</u>**	13	13	12	12	N/A	N/A	N/A
Relative advantage of green roofs (Q4)								
14: Relative upfront cost of innovation	15	14	**<u>13</u>**	13	13	N/A	N/A	N/A
19: Environmental costs and benefits	14	14	13	13	13	**<u>13</u>**	13	13

4.4. Sensitivity Analysis for Time to Peak Adoption Level

Similarly, to determine how each of the cited variables affected the time to peak adoption level (TPAL) of green roofs in Eindhoven, a sensitivity analysis was performed (see Section 3.3). Table 4 shows the sensitivity analysis for the 22 ADOPT variables, noting that Q1 (variable 6), Q2 (variables 7 to 9), Q3 (variables 10 to 13), and Q4 (variables 14 and 19) were the ones that affected the TPAL.

Considering that the adoption of green roofs is a learning process, Q3 ('Learnability of the population') focused on the involvement of property owners in a relevant way to learn about green roofs, the capacity to have advisory support for decision making, current skills and previous knowledge regarding green roofs, and how aware property owners are regarding green roof uses and functionality. Complementarily, Q2, ('Learnability characteristics of the innovation') represented the characteristics of the innovation that influence the learning process, including how easy it is to test and implement green roofs or how complex changes in the property can be when implementing them.

It can be observed from Table 4 that the variables in Q2 and Q3 ('Relevant (existing) skills and knowledge', 'Trialability', 'Innovation complexity', 'Observability', 'Advisory support', 'Group involvement', and 'Innovation awareness') reduced the TPAL to 10 years. In that sense, the difference estimated in comparison with the actual response of 13 years for TPAL (95%) would be a reduction of up to 3 years if one of the variables was changed in their average response.

The most relevant variable for the TPAL sensitivity analysis was 'Relevant and existing skills and knowledge', with the capacity to decrease the TPAL to 10 years (95%), associated with the question, "Would you need to develop substantial new skills and knowledge to use green roofs?”. The question’s premise was related to the fact that in some cases, house/property owners would require substantial new skills and knowledge before the potential benefits of green roofs could be realized. The average response was that the house/property owners were unsure if they would need additional skills, considerably jeopardizing the TPAL.

Next, ‘Trialability’ and ‘Innovation complexity’ were both able to reduce the TPAL to 11 years (95%). ‘Trialability’ is associated with the question, “How easily can a green roof be trialled/tested on a small part of your house/property before a decision is made to apply it on a larger scale?”, which aimed to identify if property owners could test a green roof on a small scale at a low cost to allow for some learning about their potential benefits. ‘Innovation complexity’ is associated with the question, “How difficult is it to evaluate the effects of the adoption of the green roof on your house/property?”, which related to property owners’ ability to measure/evaluate the potential short- and long-term impacts, costs, and benefits of green roofs. For both questions, respondents answered that it is moderately challenging to test green roofs on a small scale and evaluate their effects due to their complexity—also jeopardizing the TPAL.

The last set of variables, ‘Observability’, ‘Advisory support’, ‘Group involvement’, and ‘Innovation awareness’, had the ability to reduce the TPAL to 12 years (95%). ‘Observability’ is associated with the question, “To what extent would your green roof be observable to other potential adopters in the neighbourhood?”, which aimed to assess whether or not green roofs were easily visible to other potential adopters of green roofs. For instance, green roofs on low-rise residential housing would be easily observed, while green roofs on high-rise or factory buildings would not be easily observed. The average response was that green roofs were considered moderately observable to other potential adopters of green roofs. ‘Advisory support’ is associated with the question, “Would you use advisors capable of providing advice relevant to green roofs?”, and aimed to assess to what extent house/property owners would use advisors or extension services to obtain information (requirements, pros and cons) relevant to the establishment and maintenance of green roofs. Respondents indicated that they sometimes used advisors who could give them relevant advice regarding green roofs. ‘Group involvement’ is associated with the question, “Do you participate in any groups that discuss topics related to nature-based solutions (including green roofs)?”, which referred to the existence of potentially relevant groups that discuss and raise awareness about nature-based solutions in general and green roofs in particular. Respondents indicated they never engaged in groups that discussed nature-based solutions or green roofs. Finally, ‘Innovation awareness’ is associated with the question, “Are you aware of the use or previous trialling/testing of green roofs in your city/neighbourhood?”, and aimed to assess whether people in the neighborhood were likely to recognize that green roofs, and information about them, previously existed in their urban area. Respondents indicated that they were not aware of previous trialing or testing of green roofs in Eindhoven or their neighborhood. These variables had a limited impact on the TPAL.

5. Discussion

The concept of NBSs includes a wide range of technologies and implementations. This characteristic makes it difficult to assess their impact in a general way. However, there are general lessons we can learn in the adoption process of NBSs through different examples and individual case studies. Following the DoI conceptual framework [13], we can infer that NBSs are innovations with the objective of tackling environmental and socio-economic challenges; those innovations can be adopted by a target population if the conditions are adequate. In that sense, the adoption characteristics considered in ADOPT, such as learnability characteristics of the population, relative advantage for the population, learnability characteristics of the innovation, and relative advantage of the innovation [32], can be applied in a general context to different types of NBSs. However, due to their particular characteristics, the assessment has to be performed for each innovation separately. For instance, Teotonio et al. [8] explained that specific NBSs, such as green pavements and rain gardens, have particular goals with evident private (financial) benefits.

In contrast, green roofs could have smaller private (financial) benefits in comparison, but they could provide other types of ecosystem services and social (economic) benefits. Therefore, differentiation in the analysis is necessary to characterize adequately the benefits and limitations of each NBS. Hence, the case study of green roof adoption in the city of Eindhoven provides a methodology that could be replicated for other types of NBS.

Although there have been previous studies on the adoption of green roofs in the Netherlands [7], the USA [37], and Germany [19], this research presents one of the pioneering attempts to not only evaluate the potential level of adoption and rate of diffusion of green roofs but also identify those factors that mostly constrain or potentiate the adoption and diffusion of green roofs, thereby building on the diffusion of innovation (DoI) framework. It is important to note that green roof adoption was posed in a general context to house/property owners, without differentiation based on the various types of green roofs (such as intensive or extensive) that could potentially be installed. This study aimed to capture the actual knowledge of the respondents and their perceptions of green roofs as a whole, setting the stage for subsequent questions related to the learnability characteristics of green roofs (Q2) and the learnability of the population (Q3) (see Appendix A). However, it should be noted that specific types of green roofs might yield different preferences in responses. This aspect should be considered in future studies.

Given that the city of Eindhoven is dealing with changing climatic conditions that have resulted in negative impacts on the city, an interest in the adoption of NBSs to adapt to these impacts was expected. However, the results of our analysis revealed that the predicted level of adoption and rate of diffusion of green roofs by private house/property owners in the city of Eindhoven are low (PAL of 3% with a TPAL of 17 years). This could be explained by the limited knowledge about and experience with NBSs at the time of the survey (March 2021) and, hence, the expected climate change mitigation benefits NBSs could have to house/property owners. Also note that if the level of adoption is low, adoption will be slow as a consequence—largely because there is very little or no perceived relative advantage for most of the potential adopters (see Figure 2). It is harder to learn about an innovation with a low average relative advantage, even if you are one of the individuals in the population who will benefit. Hence, peak adoption (among those few where it has a positive relative advantage) is slow to reach.

Compared to López-Maciel et al. [30], who assessed the potential for the adoption of green roofs in Eindhoven in two separate workshops with experts from the Technical University of Eindhoven (TU/E) and the Municipality of Eindhoven (Mu/E), our estimated peak adoption level was significantly lower (12% for TU/E; 68% for Mu/E), while the time to peak adoption level was fairly similar (16 years for TU/E; 19 years for Mu/E). The main difference between these two approaches is that the survey setting directly involved potential adopters, while the workshop setting involved experts who were considered representatives of potential adopters. In the workshops, experts were considerably more positive about the variables 'Profit benefit in years they are used', 'Future profit benefit', and 'Risk exposure' than the private house/property owners, explaining the difference in the peak adoption level. Hence, experts seem to overestimate the benefits and underestimate the risks of green roofs and/or private house/property owners seem to be insufficiently informed about the benefits and risks of green roofs. This mismatch between expert knowledge and public awareness of green roofs can help us to understand the difference in the perception of adoption from social (municipal) and private (house/property owner) perspectives.

Liberalesso et al. [21] pointed out a number of factors, such as lack of research or information about socio-environmental benefits, low environmental awareness, lack of standards, high installation costs, and lack of professional and effective public policies, that lead to a low implementation of green infrastructure in cities. For instance, Kuper [38] performed a survey analysis to assess the awareness of green roofs at Temple University in Suburban Ambler, Pennsylvania (US). They concluded that some of the conditions from the classical DoI theory were not satisfied among the respondents in order to adopt green roofs (simple to understand, have relative economic and ecological advantages, be observed elsewhere, be compatible with existing materials and methods, and be easy to try), and 52% of the respondents did not know about green roofs. Teotónio et al. [8] concluded that, in general, property owners are less keen to adopt green roofs compared to other traditional (engineering) solutions, which could be related to the differences between the social (economic) and private (financial) costs and benefits of green roofs. Madhdiyar [39] argued that the social–economic viability of green roofs is considerably higher than the private–financial viability of green roofs, especially when green roofs are implemented at a large scale. This corresponds with the results of our analysis, which indicate that the variable 'Profit benefit in years that they are used' is of the highest importance when trying to increase the adoption of green roofs.

Some variables were highlighted as able to increase the level and rate of adoption of green roofs by private house/property owners in Eindhoven, such as increased profitability (+19 percentage points adoption), reduced risk exposure (+17 percentage points adoption), and improved ease and convenience (+15 percentage points adoption), as well as enhanced skills and knowledge (−3 years), simplified trialability and innovation complexity (−2 years), and increased observability (−1 year). It is important to note that these variables are not necessarily isolated from each other. The sensitivity analysis provides insight into how the level of adoption may change when a single variable is altered while keeping the remaining variables constant. However, it is important to acknowledge that in real-world scenarios, multiple variables can undergo simultaneous changes, further influencing the level of adoption. These interconnected modifications can have a compounded effect on the adoption process, i.e., the improvement of certain green roof characteristics as well as the learnability of green roofs in the target population could have some benefits that may work synergistically, increasing the adoption rate in more than one variable, affecting positively both the PAL and the TPAL. Also, from a physical perspective, a combination of two different nature-based solutions, for instance, green roofs and green facades, can lower installation and maintenance costs in some cases [17]. Taking this option into account could make the adoption of green roofs more appealing.

Based on examples from other case studies, Oberti et al. [15] concluded that in the case of Italy, a larger involvement of the public administration and researchers in the diffusion of green roof benefits is needed to spread a technological culture of green roofs among all stakeholders. It that sense, an important way to have a wider diffusion of green roofs across different regions of the world is to improve the communication of its benefits, in particular, to professionals working in the field (designers, building companies, etc.) [20,40].

The motivation to develop proper incentives for green infrastructure adoption depends on the intrinsic environmental, socio-political, and economic characteristics of each country or city [21]. For the Netherlands, incentives for adopting green roofs exist. Prins [7] exposed that the municipalities of The Hague, Rotterdam, and Amsterdam offer subsidies from the national budget 'Impulsregeling Klimaatadaptatie', which aims to accelerate adaptation measures in provinces, water authorities, and municipalities. However, each local authority has its terms and conditions, making it challenging to have uniformity on the target groups, subsidy levels, conditions to adhere to, and timing of the subsidies. One of the drawbacks that was mentioned by the frontrunners in his study was the high initial cost, which depends on location, labor costs, green roof type, and material, acting as a barrier to green roof adoption. Our results identified barriers that were also observed in other cities in the Netherlands, including the perception of high initial costs for green roof installation and characteristics of the population, such as fear of the unknown, when adopting [7].

In the city of Eindhoven, it was observed that there were no financial constraints among the majority of respondents, which could be an opportunity with the right promotion for the adoption of green roofs. Berto et al. [16] explained that a potential action includes the implementation of economic incentives to promote the diffusion of green roofs, such as tax incentives [17]. One country that is already applying these is Malaysia; however, the results show that the incentives are not enough to generate a significant impact [22]. In that sense, some case studies show that political interventions produce desirable results by promoting the adoption, such as in cities like Stuttgart with its greener urban development [18], which highlights the importance of decision makers in the integration of different proposals for the implementation of NBSs.

In relation to the classic diffusion theory perspective, the dissemination of information regarding green roofs as an innovation is a critical factor for its diffusion, proving advantages to the target population, marketing, education efforts, and policies related to ecological design [37]. This is also confirmed by our results, although they refer to a small group of potential adopters. In that sense, Hendricks and Calkins [24] concluded that many potential adopters have misconceptions regarding the costs and benefits of green roofs and do not largely value the environmental benefits. This is in line with the perceptions obtained from a similar study in the Netherlands [7]. However, early adopters have a deeper knowledge of the technology and value its benefits. Then, education and information dissemination to improve the image of green roofs is necessary. A case study in Knoxville, Tennessee (US) concluded that a combination of financial incentives and promotional campaigns is more effective when adopting green roofs, and the efficiency of the green technology is the most important factor in the adoption rate [41]. In general terms, co-planning and co-management become very important to consider the success of NBSs in the long term [42].

In the context of Eindhoven, incorporating information, policies, and incentives associated with green roofs can play a significant role in promoting their adoption by private house/property owners. By integrating such measures into the overall strategy, the PAL of green roofs can be enhanced, leading to a greater number of installations within a shorter timeframe, thereby reducing the time to reach the TPAL. This approach acknowledges the potential influence of comprehensive and targeted promotional efforts on expediting the widespread adoption of green roofs in Eindhoven. By effectively communicating the benefits, addressing any barriers, and providing favorable incentives, the city can increase and accelerate the uptake of green roofs, ultimately contributing to the sustainability and resilience of the urban environment.

6. Conclusions

This study analyzed the level and time to the peak adoption of green roofs by house/property owners in the city of Eindhoven in the Netherlands. For this purpose, the participation of house/property owners was achieved through an online survey obtaining their perception regarding the potential adoption of green roofs on their properties. Responses from over 1000 respondents were analyzed using ADOPT and calibrated and validated with ADOPT to obtain insight into the extent to which certain factors determine the level and time to peak adoption of green roofs in Eindhoven. This study went beyond previous studies by not only identifying constraining factors but also assessing to what extent these factors influence the adoption and diffusion of green roofs. Moreover, where, in previous studies, a workshop approach with relevant experts was adopted, in this study, a survey approach among potential adopters was used, giving insight into the actual knowledge, information, and perception of potential adopters.

The results show a low level (3% peak adoption) and slow rate (17 years to peak adoption) of the adoption of green roofs by private house/property owners. The adoption of green roofs can, however, be substantially enhanced by several factors, notably, by increasing profit benefits, reducing risk exposure, and improving ease and convenience. Moreover, the time required to reach peak adoption can be shortened by enhancing relevant skills and knowledge, simplifying trialability and innovation complexity, and increasing observability.

These insights have significant implications for policymakers, urban planners, and stakeholders involved in promoting sustainable urban development. By leveraging the identified factors, they can develop tailored strategies and initiatives that effectively address barriers to adoption and maximize the potential of green roof technology in mitigating environmental challenges and improving urban resilience. This information could help decision makers to make decisions focusing on the opportunity areas of the quadrants shown in ADOPT, increase potential adoption, or organize related strategies orientated to the adoption of green roofs.

A limitation of the present analysis and possible new research paths include not only how these variables combined can increase the level of adoption and rate of diffusion of green roofs but also in what sequence these variables should be rolled out. In that sense, a scenario approach could be developed in which the increase of certain variables, such as awareness, group involvement, advisory support, or relevant skills, could affect the adoption level. Also, an analysis per neighborhood could provide information regarding which neighborhoods and house/property owners are more likely to implement green roofs—allowing for the definition of even more targeted green roof adoption strategies. Another aspect to take into consideration for future studies is the intention and possibility of tenants as potential green roof adopters—instead of just house/property owners.

It is important to recall that the results given by ADOPT are numeric outputs that give a prediction scenario and, in that sense, the interpretation of the information should be taken with caution. Also, the results represent a snapshot in time (representative of the time the survey was held) and, hence, predictions are likely to change as conditions, characteristics, information, and knowledge change over time.

Author Contributions: Conceptualization, M.L.-M. and P.R.; methodology, P.R., M.L.-M., R.L. and E.F.; investigation, M.L.-M., P.R., L.P., M.V.D., F.A.M., R.M. (Rita Mendonça), R.M. (Rúben Mendes) and M.I.B.; formal analysis, M.L.-M., P.R., R.L., L.P. and M.V.D.; writing—original draft preparation, M.L.-M.; writing—review and editing, M.L.-M., P.R., E.F., R.L., F.A.M., R.M. (Rita Mendonça), R.M. (Rúben Mendes) and M.I.B. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the UNaLab project (grant agreement no. 730052, topic: SCC-2-2016-2017: Smart Cities and Communities Nature-based solutions). We also acknowledge financial support to CESAM by FCT/MCTES (UIDP/50017/2020+UIDB/50017/2020+LA/P/0094/2020) through national funds.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study according to the UA Regulation for the Protection of Data.

Data Availability Statement: Data will be made available upon request to the first author.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Variable description by quadrant (Q) of the ADOPT-NBS survey distributed to property owners in the city of Eindhoven, the Netherlands, including introductory and complementary questions.

Variable	Question	Answers
Introductory questions		
Postal code	Please select your postal code	Various options
Gender	What is your gender?	Woman, man, other, prefer not to say
Age	Please select your age range	21–70, prefer not to say
Income	What is your average monthly income? (after-tax)	Various options from 0 € to >4300 €, prefer not to say
Relative advantage for the population (Q1)		
1. Profit orientation	Is profit maximization a strong motivation for you? This question asks about the importance of profit/utility maximization for the property owner and should be answered independent of the innovation.	1. No, profit maximization IS NOT a strong motivation for me 2. Probably, profit maximization IS NOT a strong motivation for me 3. Neither agree nor disagree, that profit maximization is a strong motivation for me 4. Probably, profit maximization IS a strong motivation for me 5. Yes, profit maximization IS a strong motivation for me

Table A1. *Cont.*

Variable	Question	Answers
2. Environmental orientation	Is protecting the natural environment a strong motivation for you? This question asks about the importance of environmental motivations (defined broadly) for the property owner and should be answered independently of the innovation.	1. No, protecting the natural environment IS NOT a strong motivation for me 2. Probably, protecting the natural environment IS NOT a strong motivation for me 3. Neither agree nor disagree, that protecting the natural environment is a strong motivation for me 4. Probably, protecting the natural environment IS a strong motivation for me 5. Yes, protecting the natural environment IS a strong motivation for me
3. Risk orientation	Is risk minimization a strong motivation for you? This question asks about the importance of minimizing risk for the property owner.	1. No, risk minimization IS NOT a strong motivation for me (risk taker) 2. Probably, risk minimization IS NOT a strong motivation for me 3. Neither agree nor disagree, that risk minimization a strong motivation for me 4. Probably, risk minimization IS a strong motivation for me 5. Yes, risk minimization IS a strong motivation for me (risk averse)
4. Enterprise scale	What proportion of your house/property is suitable for the implementation of green roofs? This question helps to identify to what extent green roofs can be implemented on the property. For example, if green roofs could be implemented on only few areas of the property, then the answer should be "a minor part of the property".	1. Almost none of the house/property 2. A minor part of the house/property 3. About half of the house/property 4. A majority of the house/property 5. Almost all of the house/property
5. Management horizon	Do you have a long-term (more than 10 years) management horizon for your house/property? This question helps to identify the planning horizon of the property owner. For example, if the planning horizon is 1 year, then the answer should be "No, I have a short-term (less than 10 years) management horizon for my property ".	1. No, I DO NOT have a long-term management horizon for my house/property (i.e., less than 10 years) 2. Yes, I DO have a long-term management horizon for my house/property (i.e., more than 10 years)
6. Short-term constraints	Do you face severe temporary financial constraints? This question helps to identify whether there are temporary financial constraints to the implementation of green roofs. In this context, severe could be defined as the limited capacity to meet basic needs.	1. No, I DO NOT face severe temporary financial constraints 2. Yes, I DO face severe temporary financial constraints
If desired, you can provide a brief description of the reasoning for your answers regarding questions 1 to 6		
Learnability characteristics of the green roofs (Q2)		
7. Trialling ease	How easily can a green roof be trialled/tested on a small part of your house/property, before a decision is made to apply it on a larger scale? This question identifies whether the green roof can be tested on a small scale with low cost to allow some learning about its likely benefits.	1. Not trialable/testable at all on a small scale 2. Very difficult to trial/test on a small scale 3. Moderately difficult to trial/test on a small scale 4. Easy to trial/test on a small scale 5. Very easily trialable/testable on a small scale

Table A1. *Cont.*

Variable	Question	Answers
8. Practice complexity	How difficult is it to evaluate the effects of the adoption of the green roof on your house/property? For example, changing materials in a property is a simple change that is not usually difficult to assess. Changes in wellbeing can be more complex to evaluate	1. Very difficult to evaluate effects of use due to complexity 2. Difficult to evaluate effects of use due to complexity 3. Moderately difficult to evaluate effects of use due to complexity 4. Slightly difficult to evaluate effects of use due to complexity 5. Not at all difficult to evaluate effects of use due to complexity
9. Observability	To what extent would your green roof be observable to other potential adopters in the neighbourhood? Green roofs on low-rise residential housing are easily observed. Green roofs on high-rise or factory buildings may not be easily observed	1. Not observable at all to potential adopters 2. Difficult to observe to potential adopters 3. Moderately observable to potential adopters 4. Easily observable to potential adopters 5. Very easily observable to potential adopters
If desired, you can provide a brief description of the reasoning for your answers regarding questions 7 to 9		
Learnability of the population (Q3)		
10. Advisory support	Would you use advisors capable to provide advice relevant to green roofs? This question uncovers to what extent property owners use advisors for obtaining information (pros and cons) that could be relevant to the establishment and maintenance of green roofs.	1. Never 2. Hardly ever 3. Sometimes 4. Almost always 5. Always
11. Group involvement	Do you participate in any groups that discuss topics related to nature-based solutions (including green roofs)? This question refers to groups that are potentially relevant to raise the awareness of nature-based solutions in general and green roofs in particular.	1. Never 2. Hardly ever 3. Sometimes 4. Almost always 5. Always
12. Relevant skills & knowledge	Would you need to develop substantial new skills and knowledge to use green roofs? In some cases, property owners would require substantial new skills and knowledge before the full value of green roofs can be realized.	1. No, I WOULD NOT need additional skills 2. Probably, I WOULD NOT need additional skills 3. I do not know, if I would need some additional skills 4. Probably, I WOULD need additional skills 5. Yes, I WOULD need additional skills
13. Practice awareness	Are you aware of the use or previous trialling/testing of green roofs in your city/neighbourhood? This question is about whether people in the neighbourhood are likely to recognize if green roofs or information about them, previously exists in their urban area.	1. No, I am not aware of previous trialling/testing in my city/neighbourhood 2. I am a little aware of previous trialling/testing in my city/neighbourhood 3. I am moderately aware of previous trialling/testing in my city/neighbourhood. 4. I am aware of previous trialling/testing in my city/neighbourhood
If desired, you can provide a brief description of the reasoning for your answers regarding questions 10 to 13		

Table A1. *Cont.*

Variable	Question	Answers
Relative advantage of the green roofs (Q4)		
14. Relative upfront cost of practice	What do you think is the size of the initial investment relative to the potential annual benefit from the implementation of the green roof? In this context, if subsidies or incentives are provided, they should be incorporated into your estimate as part of the initial investment.	1. Very large initial investment relative to the potential annual benefit 2. Large initial investment relative to the potential annual benefit 3. Moderate initial investment relative to the potential annual benefit 4. Minor initial investment relative to the potential annual benefit 5. No initial investment required
15. Reversibility of the practice	To what extent do you think can the use of the green roof be reversed? This question assesses how difficult is to reverse/remove the implementation of a green roof on the property once it has been built.	1. Not reversible at all 2. Difficult to reverse 3. Moderately difficult to reverse 4. Easy to reverse 5. Very easy to reverse
16. Profit benefit in years it is used	To what extent do you think is the green roof likely to affect the operation and maintenance costs of your house/property during the years it is implemented/used? This question is focused on your expected financial profit (i.e., expected annual savings) or loss (i.e., expected annual expenses), not on any other non-financial benefits.	1. Large annual costs in years that it is implemented/used 2. Moderate annual costs in years that it is implemented/used 3. Small annual costs in the years that it is implemented/used 4. No annual costs or benefits in the years that it is implemented/used 5. Small annual benefits in the years that it is implemented/used 6. Moderate annual benefits in the years that it is implemented/used 7. Large annual benefits in the years that it is implemented/used 8. Very large annual benefits in the years that it is implemented/used
17, Profit benefit in future	To what extent are the green roofs likely to have additional effects on the future value of your house/property? This question is related to the profit obtained or loss suffered in property value, due to the implementation of the green roof.	1. Large loss in house/property value in the future 2. Moderate loss in house/property value in the future 3. Small loss in house/property value in the future 4. Neither loss nor profit in the future 5. Small profit in house/property value in the future 6. Moderate profit in house/property value in the future 7. Large profit in house/property value in the future 8. Very large profit in house/property value in the future
18. Time profit benefit to be realized	How long after the green roof is implemented do you think it would take for the effects on the value of your house/property to be realized? This question aims to capture the expected time delay before the future profit or loss suffered in property value, measured by the previous question, is obtained.	1. More than 10 years. 2. 6 to 10 years 3. 3 to 5 years 4. 1 to 2 years 5. Immediately 6. Not applicable

Table A1. *Cont.*

Variable	Question	Answers
19. Environmental impact	To what extent do you think the use of the green roof have net environmental benefits or costs? This question is not only focused on environmental costs and benefits but could also include allied non-profit concerns (such as health and wellbeing).	1. Large environmental costs 2. Moderate environmental costs 3. Small environmental costs 4. No net environmental effects 5. Small environmental benefits 6. Moderate environmental benefits 7. Large environmental benefits 8. Very large environmental benefit
20. Time env. impacts to be realized	How long after the green roof is first implemented do you think it would take for the expected environmental benefits or costs to be realized? This question aims to capture the expected time delay before the future environmental costs and benefits, measured by the previous question, are obtained.	1. More than 10 years 2. 6 to 10 years 3. 3 to 5 years 4. 1 to 2 years 5. Immediately 6. Not applicable
21. Risk	To what extent would the use of the green roof affect the net exposure of the house/property to risk? This question identifies whether green roofs reduce, or not, the possibility to have a negative/positive impact on the management expenses of the property.	1. Large increase in risk 2. Moderate increase in risk 3. Small increase in risk 4. No increase in risk 5. Small reduction in risk 6. Moderate reduction in risk 7. Large reduction in risk 8. Very large reduction in risk
22. Ease and convenience	To what extent would the use of the green roof affect the ease and convenience of the maintenance of your house/property, during the years that it is used? This question measures changes to the ease, convenience and management demands on the property that may result from implementing a green roof.	1. Large decrease in ease and convenience 2. Moderate decrease in ease and convenience 3. Small decrease in ease and convenience 4. No decrease in ease and convenience 5. Small increase in ease and convenience 6. Moderate increase in ease and convenience 7. Large increase in ease and convenience 8. Very large increase in ease and convenience
If desired, you can provide a brief description of the reasoning for your answers regarding questions 14 to 22		

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