Towards Net-Zero Emission Rail Transport: Exploring the Acceptability of Green Hydrogen Trains

Mare J. Prins
Campus Fryslan, University of Groningen
Dr. Berfu Ünal
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Abstract

The transport sector significantly contributes to global warming, necessitating the adoption of environmentally friendly transport modes. Transitioning to green hydrogen trains can provide an environmentally friendly solution for the railway industry to further reduce CO^2 emissions. However, introducing green hydrogen trains can only be successful if two fundamental necessities are met: a working infrastructure and consumer acceptance. This paper examined psychological variables that could explain the intention to use green hydrogen trains. Drawing on the Technology Acceptance Framework, we developed a conceptual framework to assess the acceptability of green hydrogen trains. To test this framework, a questionnaire was distributed and completed by 119 participants. Respondents were asked to evaluate items that reflect the 7 variables of the green hydrogen train acceptability framework. The variables reflected (1) subjective knowledge, (2) affect, (3) perceived risks, (4) perceived benefits, (5) attitudes, (6) intention to use, and (7) trust. Results indicated that attitude was not the strongest predictor of intention to use. Instead, affect and trust in technology emerged as the strongest predictors of adopting a green hydrogen train. Practical recommendations can be made, including promoting the benefits of green hydrogen trains more and emphasizing the advanced technology of green hydrogen trains. Moreover, the findings indicate that future research is needed to test additional variables that could predict green hydrogen train acceptability.

Keywords: green hydrogen trains, consumer acceptability, attitude, affect, risk perception, benefit perception, trust, knowledge.

Contents

Unlocking the Potential of Green Hydrogen Trains: Understanding Consumer Acceptability

In the next two decades, temperatures are predicted to rise by more than 1.5 °C (IPCC, 2021). This process, called global warming, can be seen as a severe problem threatening this planet's current and future generations. A major contributor to global warming is the transport sector, which relies heavily on fossil fuels. In 2021, the transport sector was accountable for 21% of the total global energy-related CO^2 emissions (7.7 gigatons of CO^2) (IEA, 2022). Among the various modes of transportation, the rail sector stands out as one of the environmentally friendliest sectors of transportation. As was stated by the International Energy Agency (IEA) in 2019, the rail industry accounts for a mere 2% of the energy consumption within the broader transport sector. While the rail industry has already played a significant role in the reduction of global CO^2 emissions, there is still potential in this industry for future emission reductions.

The IEA projects that by 2030, hydrogen will play a significant role in the energy consumption mix of trains. Hydrogen is a potentially sustainable fuel that can be produced via electrolysis, which involves splitting water into hydrogen and oxygen using an electric current (IEA, 2019; Holladay et al., 2009). When the electricity used in electrolysis stems from renewable sources, the resulting hydrogen is known as green hydrogen and can be considered truly 'clean'. Trains that run on green hydrogen are emitting net-zero emissions (Kapetanović et al., 2022). Therefore, in response to the environmental benefits of using hydrogen fuel and the need to meet emission reduction targets that are imposed on the railway sector (European Commission, 2020), transport company Arriva has issued a tender for four green hydrogen trains that are set to operate in Groningen and Friesland (Provincie Groningen, 2022).

However, introducing green hydrogen trains can only be successful if two fundamental necessities are met: a working infrastructure and consumer acceptance (Schulte, Hard & Van der Vorst, 2004). As social acceptance is crucial for the success of green hydrogen trains, it is important to conduct acceptability studies to accurately assess the likelihood of their success. However, to the best of our knowledge, no articles study the public's perception of green hydrogen trains yet.

To address this research gap, this paper will explore consumer acceptability towards green hydrogen trains. By identifying variables that could predict the intention to use a green hydrogen train, this paper can contribute to the successful implementation and adoption of this emerging technology. The research question that will be addressed in this paper is ‘How does the public perceive green hydrogen trains and which factors can predict consumer acceptability towards green hydrogen trains?’.

To answer this question, we will first discuss the introduction of green hydrogen trains by Arriva in Groningen and Friesland. While we will shortly highlight the environmental benefits of green hydrogen trains, we will also have a look into the safety concerns that might be associated with the transition to green hydrogen trains. Next, we will introduce the Technology Acceptance Framework by Huijts and colleagues (2012) and use it to propose a new conceptual framework that assesses the acceptability of green hydrogen trains. Various variables that can predict the intention to use a green hydrogen train will be discussed. The methods section will follow, whereafter this paper will present the results from the quantitative analysis of the questionnaire that was distributed to people who use the train. In the next section, the discussion, the results will be interpreted and connected to the literature. Lastly, the paper will present limitations and future research directions, followed by some theoretical and practical recommendations.

Theoretical Framework

Arriva’s Transition to Green Hydrogen Trains: Environmental Benefits and Risk Assessment

Arriva is the largest regional railway company in the Netherlands and operates trains in ten Dutch provinces, including Groningen and Friesland (Kapetanović et al., 2022; *Dit is Arriva Nederland*. (n.d.). The Arriva railway lines in these northern provinces are not electrified, which means that, for a long time, the Arriva trains were operating on diesel. However, from February 2023 on, all the Arriva trains in Groningen and Friesland are running on Hydrotreated Vegetable Oil. Driving on this fuel results in 90% less CO^2 emission compared to driving on diesel (*Treinen Arriva in noorden rijden op duurzame brandstof*, n.d.). However, transitioning to green hydrogen trains can reduce CO^2 emissions even more: when green hydrogen is burned in internal combustion engines, it generates no greenhouse gas emissions, although there is a small amount of NOx emissions produced due to the high temperature of the combustion process. When trains are powered by fuel cell technology, which is the dominant hydrogen train technology, there are even more benefits, including high efficiency, noise reduction, and emission-free operation with water vapor and heat as the only by-products (Kapetanović et al., 2022).

The world's first hydrogen train in public rail was introduced in Bremervörde, Germany (EVB Wasserstoffzug, 2022). Since the summer of 2022, five trains that are powered by hydrogen fuel cells are operating on tracks without overhead lines. Fuel cell hydrogen trains do not need overhead lines, as they generate their own electricity from green hydrogen (Akhoundzadeh et al., 2021). Inspired by the case of hydrogen trains in Bremervörde and considering the absence of overhead lines in the regional railway lines of Groningen and Friesland, Arriva launched a tender for four green hydrogen trains that will be received in 2027 (Provincie Groningen, 2022).

However, hydrogen is a gas that has many extreme properties, such as a higher reactivity, a wider flammable range, and a lower ignition energy compared to conventional fuels (Hansen, 2020). Therefore, one might question whether the use of green hydrogen trains can be considered safe. To date, only one academic article has investigated the risk of using hydrogen as a fuel in trains. According to this article, a similar level of safety can be achieved for hydrogen-fuelled trains as for the existing diesel trains when it comes to the outdoor environment (Hansen, 2020). However, more relevant work on hydrogen fuel in general can be found, which concludes that hydrogen is even a safer fuel than petrol (Adamson & Pearson, 2000). Nevertheless, some people still associate hydrogen with danger, which likely derives from the Hindenburg disaster in 1937, which involved a German hydrogen zeppelin that exploded in mid-air (Wurster, Knorr & Prümm, 1999; DiLisi, 2017).

To assess whether the aforementioned environmental benefits and potential perceptions of risk with green hydrogen trains influence someone's intention to use the green hydrogen trains that Arriva will implement, a theoretical framework will be introduced in the next section.

Technology Acceptance Framework

This paper will use the Technology Acceptance Framework (TAF; (Huijts, Molin & Steg, 2012) as a theoretical foundation and framework to predict green hydrogen train acceptability. To facilitate the understanding of public acceptability towards new sustainable technologies, the TAF incorporates psychological variables and commonly used psychological theories, among which is the Theory of Planned Behaviour (TPB) (Huijts et al., 2012).

If one adapts the TBP to technology acceptance, the TBP states that one can predict an individual's behaviour by looking at their intentions to accept a certain technology (Ajzen, 1991). The

TBP proposes three factors that determine intentions to accept, among which are attitudes. These attitudes in turn can be influenced by perceived costs, risks and benefits, and affective responses (i.e., negative and positive feelings).

Moreover, the TAF also states that the perceived context can influence consumer acceptability. For example, in cases where people have limited knowledge about a technology, their level of acceptance may rely on their trust in the parties responsible for its development and implementation. Most studies have found that trust influences acceptability indirectly through perceived costs, risks, and benefits and that higher levels of trust in the responsible actors generally increase acceptance (Montijn-Dorgelo & Midden, 2008; Midden & Huijts, 2009). Furthermore, the TAF suggests that knowledge regarding a certain technology can influence how people perceive the technology. Knowledge mainly influences individuals' perception of the costs, risks, and benefits of a technology and indirectly the acceptability of that technology.

Thus, the TAF states that consumers can determine their level of acceptance based on five factors: (1) their attitude towards a technology; (2) an overall assessment of costs, risks, and benefits; (3) emotional responses, such as hope, joy, worry, or anger towards the technology; (4) how the technology is implemented; and (5) the knowledge one has about the certain technology.

Evolution and Refinement of the Technology Acceptance Framework for Green Hydrogen Trains

It is important to note that there have been numerous iterations of the TAF over the years. The TAF was first introduced by Fred and Davis in 1989 and was developed to predict consumer acceptability to technologies in general (Marangunić & Granić, 2015). Yet, in order to accommodate various technological innovations and their particular characteristics, their framework has been adapted and modified many times. To illustrate, the aforementioned TAF by Huijts and colleagues (2012) is a framework designed to predict the acceptability of sustainable energy technologies. This study will further enhance and refine the TAF to facilitate the prediction of green hydrogen train acceptability. In specific, this study aims to develop a simplified and more comprehensive model that accounts for the specific factors influencing the intention to use these green hydrogen trains. By doing so, it is hoped that the new framework will contribute to the successful implementation and adoption of this emerging technology.

Inclusion of Key Variables in the Green Hydrogen Train Acceptability Framework

In the next section, a narrative review will be presented that summarises the explanatory variables that are outlined in the TAF and that will be included in the green hydrogen train acceptability framework in light of hydrogen technology. Notably, these variables are attitude, affect, perceived benefits, perceived risks, trust, and knowledge.

Attitude

The attitudes toward hydrogen transportation have been measured by several studies. For instance, a study by LBTS (1997) focused on the introduction of a hydrogen bus in Munich and found that the attitude towards hydrogen is generally positive. Heinz and Erdmann (2008) conducted an international study that investigated the attitude toward hydrogen buses in eight European cities. Results showed that the majority support the substitution of conventional buses for hydrogen buses, with only 1% of the participants objecting to such a substitution. Haraldsson et al. (2006) conducted a survey on the attitude toward hydrogen fuel cell buses in Stockholm. The key findings of the survey revealed a generally positive attitude towards hydrogen fuel cell buses. Research by O'Garra et al. (2007) confirmed that public attitudes towards hydrogen vehicles are predominantly positive and safety concerns do not seem to be an issue for consumers. Overall, attitudes towards hydrogen transportation are positive, leading to more acceptability of hydrogen transport modes.

Affect

The TAF indicates that affect directly influences attitudes and therefore indirectly the intentions, based on the premises of the TPB. One study by Montijn-Dorgelo and Midden (2008) found that negative affective associations with hydrogen result in an inverse relationship between perceived risks and benefits, which suggests that negative feelings decrease acceptability. Moreover, Huijts and colleagues (2014) concluded in their research about hydrogen fuel station acceptance that positive affect is one of the strongest determinants of the intention to support the technology, whereas negative affect was found to be a strong determinant of intention to act against the technology.

Perceived Benefits

As stated by the TAF, an individual's attitude towards hydrogen technology and its acceptability can also be influenced by perceived benefits. Overall, the public perceives hydrogen technologies to be beneficial to the environment. Studies conducted in the Netherlands by Zachariah-Wolff and Hemmes (2006) and Molin (2005) found that individuals perceive hydrogen as an environmentally friendly and renewable fuel, rather than a dangerous one. Similarly, Hickson and colleagues (2007) found that hydrogen's environmentally friendly nature and its potential to decrease dependence on fossil fuels are its primary benefits. Several studies have also found that perceived benefits of hydrogen technology are a significant predictor of acceptability towards hydrogen technology (e.g., Huijts et al., 2019; Chen, Huang & Huang, 2016). For example, Chen and colleagues (2016) discovered that the public's willingness to use hydrogen energy in Taiwan is strongly related to their perception of it being an environmentally friendly energy source.

Perceived Risks

Similar to perceived benefits, perceived risks can influence an individual's intention to accept a sustainable technology indirectly. Several studies have examined whether there is an association between hydrogen and danger. For instance, a study by Dinse (1999), who conducted interviews with people on the street in Berlin, concluded that a few people associate hydrogen with the Hindenburg accident in 1937, which involved a German hydrogen zeppelin that exploded in mid-air (Wurster, Knorr & Prümm, 1999; DiLisi, 2017). Additionally, a study by Zachariah-Wolff and Hemmes (2006), who conducted two surveys among Dutch citizens on hydrogen acceptance, revealed that respondents did make associations between hydrogen and negative incidents, such as (hydrogen) bombs, explosives, and the Hindenburg disaster. Other studies found a strong feeling of safety associated with hydrogen technology (O'Garra et al., 2007; Haraldsson et al., 2006). For example, a study by LBTS (1997) focused on the introduction of a hydrogen bus in Munich and found no confirmation of an association between hydrogen and danger or past accidents like the Hindenburg disaster (LBTS, 1997). Furthermore, Vergragt (2004) carried out qualitative research among bus passengers in Amsterdam and found that the safety of hydrogen buses was regarded as obvious by the participants, as the buses had to meet the current safety standards.

There are also several studies that have explored how perceived risks influence hydrogen technology acceptability. One study found that associations with danger lead to an inverse relationship between perceived benefit and perceived risk, resulting in lower levels of hydrogen acceptance

(Montijn-Dorgelo, 2008). Other studies have also found a negative effect of risk perception on hydrogen acceptability, meaning that as perceived risk increases, acceptability towards hydrogen technologies decreases (Ono & Tsunemi, 2017; Saito, Sasaki & Itaoka, 2015). However, another paper has found that a high level of concern about the safety of hydrogen technology does not influence the support for its development (Chen, Huang & Huang, 2016).

Trust

According to the TAF, trust is another pivotal factor in predicting the acceptability of hydrogen technology. Multiple studies have found that trust in hydrogen technology and trust in actors who are responsible for the technology have a strong influence on acceptability. For example, a study by Achterberg and colleagues (2010) found that individuals who exhibit high levels of trust in technology are more likely and willing to support hydrogen technology. Similarly, O'Garra et al. (2008) found that resistance towards hydrogen fuel stations is higher among people who have little trust in regulation. As the TAF suggests, trust was found to influence acceptability mainly through perceived risks and benefits of technologies, but it can also influence someone's affective response towards a technology (Siegrist & Cvetkovich, 2000). For example, one study observed that lower trust in the actors involved in the technology results in an inverse relationship between perceived risks and benefits, meaning that lower trust in the actors leads to higher perceived risks and lower perceived benefits, ultimately leading to lower acceptability of the relevant technology (Montijn-Dorgelo & Midden, 2008).

Knowledge

As indicated in the TAF, knowledge can influence people's perception of the costs, risks, and benefits of a technology, which can indirectly affect its acceptability. This has to do with the 'familiarity hypothesis' from Kahan et al. (2009), which states that people tend to have a more positive opinion about a technology once they have gained a better understanding of it. In the field of hydrogen technology, studies have found a generally positive relationship between knowledge and the evaluation of various hydrogen technologies. For example, a study commissioned by BMW revealed that people with more knowledge about hydrogen tend to have a more positive attitude towards it, while those with less knowledge perceive the risk of hydrogen fuel to be higher (Dinse, 2000). This was also found by Molin (2005) and Achterberg and colleagues (2010), who suggested that higher factual knowledge of hydrogen would increase hydrogen acceptance. When it comes to hydrogen fuelling stations, knowledge about hydrogen and hydrogen technology has also been found to be an important factor in influencing the acceptability of hydrogen fuelling stations (Ono & Tsunemi, 2017; Huijts et al., 2014). However, a study conducted in Norway found that greater knowledge about hydrogen vehicles and refuelling stations may imply lower support for them, suggesting a negative effect of knowledge on hydrogen acceptability (Tarigan et al., 2012). It is also important to note that several studies have found a lack of extensive knowledge regarding hydrogen knowledge (Zachariah-Wolff and Hemmes, 2006; Haraldsson et al., 2006; Vergragt, 2004). For example, a study by Dinse (1999), which involved interviewing people on the street in Berlin, concluded that there is little knowledge about hydrogen technologies.

Different types of knowledge can influence hydrogen acceptability, including objective knowledge, which is assessed through a knowledge test, and subjective knowledge, as rated by participants (House et al., 2004). As subjective knowledge appears to have a stronger influence on hydrogen technology acceptance than objective knowledge (Scovell, 2022; Huijts & van Wee, 2015), this study will use subjective knowledge to assess the effect of knowledge on the intention to use a green hydrogen train.

The Green Hydrogen Train Acceptability Framework

In the green hydrogen train acceptability framework (see Figure 1), we reason that the intention to use green hydrogen trains will be directly predicted by attitudes toward hydrogen transportation, which is in line with the TPB. Next, we expect attitudes to be directly predicted by three factors: affect, perceived risks, and perceived benefits. Notably, we want to test whether this process leading to a higher intention to use green hydrogen trains will be fuelled by trust and/or knowledge. We measured both trust in technology and trust in Arriva, which is in line with previous research that shows that these two factors are both crucial for predicting consumer acceptability towards green hydrogen trains (Huijts et al., 2014; Molin, 2005; Achterberg et al, 2010).

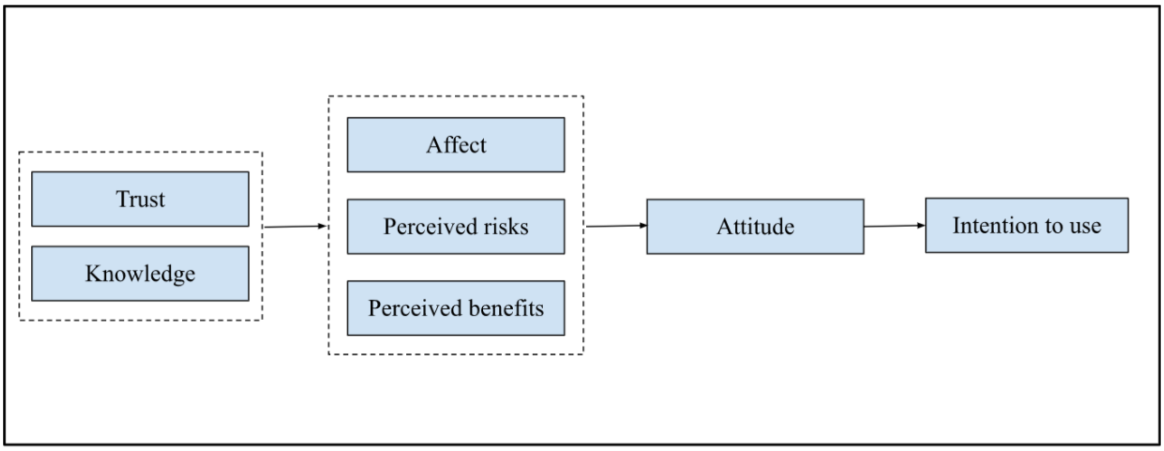

Figure 1. A Schematic Representation of the Green Hydrogen Train Acceptability Framework

Methods

Research Design

For this paper, a quantitative study design was used. First, a literature review was conducted. Existing literature on the topics of hydrogen fuel and consumer acceptability was analysed. Second, a survey was distributed to people who use the train. A software program called SPSS was used to analyse the survey data and to understand what variables predict green hydrogen train acceptability. To ensure minimal harm to the participants, informed consent was obtained, participant anonymity was maintained, and data confidentiality was upheld throughout the research process.

Procedure and Participants

Data was collected from Dutch citizens living mainly in the province of Friesland and Groningen. To recruit participants, a link was distributed on different social media platforms, including LinkedIn, WhatsApp, and Instagram. To ensure a representative study sample, snowball sampling was used, meaning that some respondents were asked to help further distribute the survey link to acquaintances. The link directed participants to the online study environment in Qualtrics. Participants first read the informed consent form and study information (see Appendix A). By clicking the 'yes, I consent' button, they were directed to the survey. Participants first filled in the questionnaire asking about their responses on the 7 variables that could potentially predict green hydrogen train acceptability. Subsequently, they were asked to fill in some demographic information. Lastly, the respondents were thanked for their participation. The questionnaire took approximately 5 minutes to complete. The data were collected in 12 days.

In total, 119 questionnaires were completed. The mean age of respondents was 34.34 years (*SD* = 17.15) and the age ranged from 18 to 69 years. The sample population included 58% females, 40.3% males, 0.8% non-binary/third gender, and 0.8% who preferred not to disclose their gender preference. About 48% of the respondents lived in Groningen, 31% lived in Friesland, and the remaining 21% resided in another province. Among the individuals residing in a different province, 8 individuals indicated their residence in Drenthe, 2 in Gelderland, 2 in Noord-Holland, 4 in Overijssel, 5 in Utrecht, and 2 in Zuid-Holland. About 30.2% of the respondents were frequent train users, meaning they use the train either every day or a couple of times per week. The other respondents (69.8%) were less frequent train users, meaning they used the train only a couple of times per month or year. 63.9% of the respondents indicated that they used the train by choice, while the other 36.1% had no alternative way to travel than by train. In the sample population, 48.7% owned a car and 51.3% did not own a car.

Materials and Measures

In the questionnaire, respondents evaluated 32 items that reflected the 7 variables of the green hydrogen train acceptability framework. The variables reflected (1) subjective knowledge, (2) affect, (3) perceived risks, (4) perceived benefits, (5) attitudes, (6) intention to use, and (7) trust in technology and Arriva. The variables were presented in the questionnaire in the aforementioned order, to ensure that feelings of trust in technology and Arriva did not influence the answers to the other variables. The statements were either modified from the literature or created for this survey (see Table 1 below for an overview of the items and their origins).

Subjective Knowledge

We measured subjective knowledge by using three statements to which the respondents rated their knowledge level on a scale from 1 (not knowledgeable) to 4 (very knowledgeable). The higher the mean, the higher the subjective knowledge level of respondents was (*M* = 1.70, *SD* = 0.52). The Cronbach’s alpha of the scale was .78.

Affect

The feelings of the respondents towards green hydrogen trains were measured by asking the respondent to what extent certain emotions were invoked in them when they thought of the operation of green hydrogen trains in Groningen and Friesland. The affect items were measured on three dimensions, representing positive, negative, and neutral emotions. The emotions that are relevant to the implementation of green hydrogen trains were rated on a 4-point Likert scale (1 = not feeling it at all, 4 = feeling it strongly). The five negative emotions were worry, anger, powerlessness, fear, and stress; the six positive statements were hope, excitement, pride, satisfaction, joy, and calmness; and the two neutral emotions were indifference and disinterest. In the literature, both positive and negative affect have been found to significantly influence the acceptability of a certain technology (e.g., Huijts et al., 2014; Huijts & van Wee, 2015). However, the effect of neutral affect on a technology has not been studied intensively yet. In this current study, neutral affect was included as a subcategory of affect to gain insight into whether there are people who are indifferent to the implementation of green hydrogen trains. The mean score for positive affect was 2.66 (*SD* = 0.69), for negative affect 1.16 (*SD* = 0.27), and neutral affect 1.60 (*SD* = 0.77). A closer look revealed that feelings of hope were associated the strongest with the operation of green hydrogen trains (*M* = 3.03, *SD* = .906). Other emotions that were rated high were satisfaction (*M* = 2.75, *SD* = .856), joy (*M* = 2.69, *SD* = .881), calmness (*M* = 2.62, *SD* = .991), pride (*M* = 2.54, *SD* = 1.080), excitement (*M* = 2.35, *SD* = 1.022). Lower ratings were given for indifference (*M* = 1.61, *SD* = .894), disinterest (*M* = 1.58, *SD* = .818), worry (*M* = 1.37, *SD* = .649), stress (*M* = 1.16, *SD* = .411), fear (*M* = 1.11, *SD* = .339), powerlessness (*M* = 1.08, *SD* = .381), and anger (*M* = 1.06, *SD* = .270). Higher means indicated higher associations of a certain emotion with the operation of green hydrogen trains. Reliability analysis revealed a Cronbach's alpha of .62.

Perceived Risks

We measured perceived risks by asking respondents to indicate to what extent they associated a negative term with green hydrogen trains. Respondents rated their association on a 4-point Likert scale ranging from 1, not at all, to 4, strongly. The negative terms "unsafe", "dangerous" , and 'explosive" were used. Reliability analysis showed that the terms formed a reliability scale, evidenced by a Cronbach's alpha of .84 (*M* = 1.41, *SD* = 0.55).

Perceived Benefits

The perceived benefits to the environment were measured by asking the participants to what extent they agreed or disagreed with seven statements related to the environmental friendliness of green hydrogen trains. Participants rated their agreement on a 5-point Likert scale ranging from 1, strongly disagree, to 5, strongly agree. The mean score of the perceived benefits variable was 3.86 (*SD* = 0.50). The higher the mean, the more the participants perceived green hydrogen trains to have environmental benefits. The Cronbach's alpha of the scale was .77.

Attitude

To measure attitude, three statements were presented to the respondent. Respondents could respond to these statements on a 5-point Likert scale ranging from 1, strongly disagree, to 5, strongly agree (M = 3.82, SD = 0.68). The statements formed a reliable scale (α = .80).

Intention to Use

We measured the intention to use a green hydrogen train by asking participants if they were willing and going to use a green hydrogen train once it is operating. Respondents could rate their willingness on a 5-point Likert scale ranging from 1, strongly disagree, to 5, strongly agree. The third item of the 'intention to use' variable, 'I would look for alternative means of travelling when a green hydrogen train is operating', was phrased negatively, and therefore the score of this item was reversed in SPSS. The statements formed a reliable scale (α =.68). The higher the mean, the more willing participants were to use a green hydrogen train (M = 4.46, SD = 0.54).

Trust

We measured trust in two subcategories: trust in Arriva, as a service provider, and trust in technology. Participants indicated their trust levels in these two categories by using a 4-point Likert scale ranging from 1 (no trust at all) to 4 (a lot of trust). Additionally, respondents were given the option to have no opinion regarding these questions. The mean score for trust in Arriva was 3.40 (*SD* = 0.54), and for trust in technology 3.20 (*SD* = 0.56). Higher means indicated higher trust. The 4-item trust in Arriva subscale had a good internal consistency (α = .83). The subcategory 'trust in technology', which consisted of 2 items, was also found to be reliable (α = .70).

Table 1. Items per Subscale with Source.

Subscale	Item	Source
Subjective Knowledge (3-point scale ranging from (1) not knowledgeable at all - (3) very knowledgeable)	How much do you know about the benefits of hydrogen as a fuel?	Modified from Huijts & van Wee (2015)
	How much do you know about the risks of hydrogen as a fuel?	Modified from Huijts & van Wee (2015)
	How much do you know about the technology of green hydrogen trains?	Modified from Huijts & van Wee (2015)
Affect (4-point scale ranging from (1) not at all - (4) strongly)	To what extent are the following emotions invoked when you think of the operation of green hydrogen trains in Groningen and Friesland: 1. Worry 2. Hope 3. Excitement 4. Anger 5. Powerlessness 6. Indifference 7. Fear 8. Satisfaction 9. Joy 10. Stress 11. Calmness 12. Pride 13. Disinterest	Huijts and colleagues (2007)
Perceived Risks	To what extent do you associate the term ‘unsafe’ with green hydrogen trains?	Modified from Molin (2005)

(4-point scale ranging from (1) not at all - (4) strongly)	To what extent do you associate the term 'dangerous' with green hydrogen trains?	Modified from Molin (2005)
	To what extent do you associate the term 'explosive' with green hydrogen trains?	Modified from Molin (2005)
Perceived Benefits (5-point scale ranging from (1) strongly disagree - (5) strongly agree)	To what extent do you think that green hydrogen trains would be more environmentally friendly than conventional trains?	Modified from Ledger, Cunningham, & Regan (2018)
	To what extent do you think that green hydrogen trains can help mitigate global warming?	Modified from Ono & Tsunemi (2017)
	To what extent do you think that green hydrogen trains would reduce greenhouse gas emissions?	Modified from Ono & Tsunemi (2017)
	To what extent do you think that green hydrogen trains can help resolve air pollution problems?	Modified from Ono & Tsunemi (2017)
	To what extent do you think that green hydrogen trains can contribute to the renewable energy transition?	Created for questionnaire
	To what extent do you think that green hydrogen trains can contribute to the phase-out of natural gas?	Created for questionnaire
	To what extent do you think that green hydrogen trains can reduce noise pollution?	Created for questionnaire

Attitude (5-point scale ranging from (1) strongly disagree - (5) strongly agree)	To what extent do you think that investments in green hydrogen trains are good?	Modified from Molin (2005)
	To what extent do you think that green hydrogen trains are good?	Modified from Molin (2005)
	To what extent do you think that we need to convert to green hydrogen trains as quickly as possible?	Modified from Molin (2005)
Intention to Use (5-point scale ranging from (1) strongly disagree - (5) strongly agree)	I am willing to use a green hydrogen train	Created for questionnaire
	I am going to use a green hydrogen train when it is operating	Created for questionnaire
	I would look for alternative means of travelling when a green hydrogen train is operating.	Created for questionnaire
Trust in Technology (4-point scale ranging from (1) no trust at all – (4) a lot of trust). Option 'no opinion' is provided.	To what extent do you trust that the technology of green hydrogen trains is safe?	Created for questionnaire
	To what extent do you trust that the technology of green hydrogen trains is fully developed?	Created for questionnaire
Trust in Arriva (4-point scale ranging from (1) no trust at all – (4) a lot	To what extent do you trust that Arriva is competent enough to introduce green hydrogen trains in Groningen and Friesland in a responsible manner?	Modified from Huijts & van Wee (2015) and Montijn-Dorgelo & Midden (2008)

of trust). Option 'no opinion' is provided.	To what extent do you trust that Arriva has the knowledge and experience for making sure that a safe green hydrogen train will operate on the train track?	Modified from Huijts & van Wee (2015) and Montijn-Dorgelo & Midden (2008)
	To what extent do you trust that Arriva has the intention to make sure that a safe green hydrogen train will operate on the train track?	Modified from Huijts & van Wee (2015) and Montijn-Dorgelo & Midden (2008)
	To what extent do you trust that Arriva pays attention and performs safety checks to make sure the operation of green hydrogen trains stays safe?	Modified from Huijts & van Wee (2015) and Montijn-Dorgelo & Midden (2008)
Demographics	What is your gender identification? (Male, female, non-binary/third gender, preferred not to say)	Created for questionnaire
	What is your age?	Created for questionnaire
	How often do you take the train?	Created for questionnaire
	In which province do you live?	Created for questionnaire
	Please choose the answer that fits you best: • I use the train by choice. • I have no alternative way than to travel by train.	Created for questionnaire

Data Analyses

To test the green hydrogen train acceptability framework, three types of analyses were carried out consecutively. First, for each of the 7 variables that potentially predict the acceptability of green hydrogen trains, we determined the means, standard deviations, frequencies, and Cronbach's alphas. The means were computed for each variable as the average of all the items within the variable. The Cronbach’s alphas were calculated to test the internal consistency, a measure to determine the reliability of the scales used in the survey. Second, Spearman’s correlations between all the variables were calculated. This non-parametric measure was chosen as it does not assume any specific distribution of the data. Third, three stepwise regression analyses were performed to test the expected relationships between the variables and the intention to use a green hydrogen train. In the series of regression analyses, our initial examination focused on identifying whether the variable preceding the dependent variable in the chain exhibited a direct correlation with the dependent variable (referred to as step 1). Then, in step 2, we tested whether the incorporation of all the remaining variables lower down in the green hydrogen train acceptability framework would improve the explained variance in the dependent variable (i.e., intention to use). This procedure was adopted from studies by de Groot and colleagues (2007) and Ünal and colleagues (2018), as they have shown that this form of regression analysis is suitable for testing whether variables further down the chain have a direct effect on the dependent variable.

Results

Exploratory Analysis: Frequencies and Correlations of Variables

Prior to performing the regression analyses, we investigated the frequencies of given answers and examined the correlations between all the variables. All the variables correlated in the expected direction (see Table 2). For each variable, a summary of the frequencies for items and scale correlations will be given.

Attitude

The findings of the survey revealed a generally positive attitude towards green hydrogen trains, implying that the majority (77.3%) of the respondents believed that green hydrogen trains are good. However, converting to green hydrogen trains as quickly as possible is less strongly supported, with 52.9% of the respondents indicating that we should urgently shift towards green hydrogen trains.

Moreover, a positive significant correlation can be identified between intention to use a green hydrogen train and attitude ($\rho = .26$, $p < .01$). This suggests that respondents with more positive attitudes towards green hydrogen trains were more likely to have higher intentions to use a green hydrogen train.

Affect

Findings revealed that there is a positive significant correlation between intention and positive affect ($\rho = .28$, $p < .010$), implying that higher levels of positive affect were associated with higher intentions to use a green hydrogen train. There was no association between the intention to use green hydrogen trains and negative affect or neutral affect. Furthermore, we can infer from the results that respondents who experienced positive feelings more strongly had more favourable attitudes towards green hydrogen trains. Neutral affect showed a significant negative correlation with attitude, implying that feelings of indifference regarding the operation of green hydrogen trains led to less favourable attitudes. Moreover, respondents had more positive feelings towards green hydrogen trains when they perceived them to have more beneficial effects. Likewise, respondents experienced more negative feelings when they perceived green hydrogen trains to have more risks.

The emotion that was most strongly associated with the implementation of green hydrogen trains was hope, as 35.3% of the respondents said to associate this emotion strongly with the operation of green hydrogen trains. Out of the emotions that were not associated with the operation of green hydrogen trains at all, anger scored highest, with 95% of respondents indicating that they did not associate this emotion with green hydrogen trains at all.

Perceived Benefits

Intention to use a green hydrogen train and perceived benefits were not significantly related ($\rho = .07$, p = n.s.).

Moreover, the questionnaire results found that the green hydrogen train's contribution to the renewable energy transition and its potential to reduce greenhouse gas emissions were its primary benefits. Interestingly, the respondents did not necessarily think that green hydrogen trains can reduce noise pollution, as 63.9% of the respondents reported having no opinion about this question.

Perceived Risks

From the potential risks that were presented to the respondents, 'explosive' was the risk that was most associated with green hydrogen trains. However, the extent to which this was associated with green hydrogen trains was still rather low: only 2.5% of respondents said they strongly associated explosiveness with green hydrogen trains, while 34.5% and 6.7% said they associated it only a little bit or moderately with green hydrogen trains, respectively.

Moreover, a negative correlation can be detected between the intention to adopt a green hydrogen train and perceived risks (ρ = -.21, $p < .05$), indicating that higher levels of perceived risks were associated with lower intention. This suggests that the more risks people associated with green hydrogen trains, the lower the acceptability rate of green hydrogen trains was.

Trust

A positive correlation between intention to use and trust in technology can be observed (ρ = .40, $p < .010$). This indicates that higher degrees of trust in technology were associated with higher intentions, suggesting that participants who trusted technology more were more likely to have stronger intentions toward accepting a green hydrogen train. Besides, a positive correlation between intention and trust in Arriva has been identified (ρ = .33, $p < .010$), implying that higher levels of trust in Arriva were related to stronger intentions to use a green hydrogen train. Moreover, more trust in Arriva in safeguarding the safe operation of green hydrogen trains resulted in stronger positive feelings (ρ = .38, $p < .010$), and weaker negative and neutral feelings (negative affect: ρ = -.20, $p < .05$; neutral affect: ρ = -.25, $p < .010$). Trust in technology, on the other hand, only correlated significantly with positive affect (ρ = .26, $p < .010$).

Looking at the frequency of answers given to the trust in technology items, it becomes clear that most of the people had a lot of trust in the statement that the technology behind green hydrogen trains is safe (46.2% had a lot of trust). Whether the technology behind green hydrogen trains is fully developed was less trusted, with only 12% of the respondents expressing a lot of trust in this statement. When it comes to trust in Arriva, participants trusted Arriva the most in having the intention to make sure that a safe green hydrogen train will operate on the train track (58% of the respondents had a lot of trust).

Respondents trusted Arriva the least in having the knowledge and experience for making sure that a safe green hydrogen train will operate on the train track (only 34% of the participants had a lot of trust).

Subjective Knowledge

Self-reported knowledge of green hydrogen fuel and trains was low. Of all the participants, 16% did not know about the benefits of hydrogen as a fuel, while 68.1% possessed basic knowledge, and 16% had a profound understanding. Regarding the risks of hydrogen as a fuel, 46.2% of the respondents admitted to having no knowledge, 42.9% had limited knowledge, and 10.9% had a good understanding. When asked how much they knew about the technology of green hydrogen trains, 62.2% of the participants indicated to have no knowledge, 31.9% only had a limited understanding, and 5.9% possessed a significant level of knowledge.

There is a positive correlation between intention to use and subjective knowledge ($\rho = .24$, $p < .010$), implying that higher levels of subjective knowledge were linked to stronger intentions to use a green hydrogen train. In other words, respondents with more subjective knowledge about green hydrogen fuel and green hydrogen trains tended to have higher intentions to use a green hydrogen train.

Intention to Use

The individual correlations of each variable with intention to use have already been discussed above. However, it is good to note that the strongest correlation is observed between intention to use and trust in technology ($\rho = .40$, $p < .010$). This indicates that changes in feelings of trust towards hydrogen technology were strongly associated with changes in intention to use.

Moreover, results indicated that there is a strong inclination to use green hydrogen trains. Notably, when participants were asked whether they would be willing to use a green hydrogen train, 44.5% said that they would be willing to use a green hydrogen train and 52.9% strongly expressed their willingness to utilize a green hydrogen train. Similarly, regarding their intention to use a green hydrogen train once it is operational, 46.2% agreed to use it and 46.2% strongly indicated that they were going to use a green hydrogen train. Only one participant (0.8%) expressed a definitive decision not to utilize a green hydrogen train. When asked if they would seek alternative means of transportation when a green hydrogen train is operating, 3.3% of participants stated they would explore other options, 8.4% remained neutral, and a significant majority of 88.3% indicated that they would not seek alternative means of transport, implying their preference to use a green hydrogen train. Respondents who did not own a car were marginally more willing to use a green hydrogen train than respondents who did own a car. Similarly, people who indicated that they had no other choice than to travel by train had higher intentions to use a green hydrogen train than respondents who said that they travelled by train by choice. Moreover, respondents who regularly used the train, meaning they used the train either daily or several times a week, showed a stronger intention to use a green hydrogen train than people who less frequently took the train.

Table 2. Spearman's Correlations Between Variables.

Variables	1	2	3	4	5	6	7	8	9	10
1. Intention to use	1.00									
2. Attitude	.327**	1.00								
3. Positive affect	.302**	.578**	1.00							
4. Negative affect	-.085	-.140	.138	1.00						
5. Neutral affect	.086	-.328**	-.338**	-.030	1.00					
6. Perceived benefits	.120	.580**	.527**	-.007	-.274**	1.00				
7. Perceived risks	-.274**	-.214*	-.051	.496**	-.098	.016	1.00			
8. Subjective knowledge	.236**	.091	.213*	.112	-.146	.056	.080	1.00		
9. Trust in technology	.420**	.420**	.262**	-.158	-.103	.182	-.263**	.249*	1.00	
10. Trust in Arriva	.340**	.362**	.375**	-.198*	-.254**	.186	-.321**	.145	.354**	1.00

Note: Significance levels: *$p < .05$. **$p < .01$. ***$p < .001$.

Regression Analyses

Next, we tested our conceptual framework via a series of stepwise regression analyses. For the first regression analysis, the variable 'intention to use' was used as the dependent variable (see Table 3). In the first step, the variable 'attitude' was chosen as the independent variable. In this step, attitude explained 5.7% of the variance in intention to use. More favourable attitudes were related to a stronger intention to use a green hydrogen train (β = .258, p = .010). After having entered all the remaining variables in the regression model in the second step, the explained variance increased to 23.3%. At this step, neutral affect and trust in technology appeared to be the strongest significant predictor of intention to use (neutral affect: β = .241, p < .001; trust in technology: (β = .224, p < .001). Attitude, perceived benefits, perceived risks, subjective knowledge, negative affect, positive affect, and trust in Arriva did not contribute significantly to the model in the second step.

Subsequently, we further examined the relations in the green hydrogen train acceptability framework by employing attitude as the dependent variable in the regression analysis. The variables 'perceived benefits', 'perceived risks', and 'affect' were taken as the independent variables in the first step. In this initial step, perceived benefits, perceived risks, and affect explained 45% of the variance in attitude. Positive affect and perceived benefits significantly predicted attitudes towards green hydrogen trains, with positive affect being the strongest predictor (positive affect: β = .356, p < .001; perceived benefits: β = .352, p < .001). Thus, greater recognition of the advantages of green hydrogen trains and a heightened association of positive emotions with the trains resulted in more favourable attitudes. Negative affect, neutral affect, and perceived risks did not contribute to the model in a significant way. After including the other variables in the analysis in step 2, explained variance increased slightly to 46%. At this step, perceived benefits and positive affect still significantly predicted attitude, but perceived benefits turned out to be the strongest predictor at this step (perceived benefits: β = .350, p < .001; positive affect: β = .324, p < .001). Of the newly added variables, non significantly contributed to the model.

Lastly, in the third regression analysis, we tested the model by using affect, perceived benefits, and perceived risks separately as the dependent variables in the regression model. Subjective knowledge, trust in technology, and trust in Arriva were used as the independent variables. There was no significant relationship found between perceived benefits and the independent variables. However, there is a significant positive contribution of trust in Arriva to the explanation of positive affect (β = .318, p < .001), which implies that higher trust in Arriva resulted in higher positive affect towards green hydrogen trains. Moreover, subjective knowledge contributed to the explanation of negative affect (β = .289, p < .001), indicating that people who perceived themselves to have more knowledge about green hydrogen fuel and trains tended to experience higher levels of negative affect towards green hydrogen trains. Another relationship can be identified between trust in Arriva and neutral affect (β = -.255, p < .05), which suggests that respondents who had more trust in Arriva felt stronger neutral emotions, meaning they were indifferent to the implementation of green hydrogen trains. Finally, the two subcategories of trust contributed significantly to the explanation of variance in perceived risks (trust in technology: β = -.249, p < .05; trust in Arriva: β = -.233, p < .05). When respondents had lower trust in technology and Arriva, they had a higher perception of risks associated with green hydrogen trains.

Table 3. Regressions for Green Hydrogen Train Acceptability Framework.

Variables	β	Conf.Interval	t	Adjusted r^2	F	df	p
DV: intention to use							
Step 1:			12.178	.057	6.995	1.98	.010
Attitude	.258**	(.051 to .359)					
Step 2:			3.351	.233	4.344	9.90	< .001
Attitude	.145	(-.082 to .313)					
Positive affect	.185	(-.045 to .334)					
Negative affect	.038	(-.342 to .491)					
Neutral affect	.241*	(.032 to .308)					
Perceived benefits	-.097	(-.351 to .141)					
Perceived risks	-.069	(.277 to .142)					
Subjective knowledge	.170	(-.024 to .381)					
Trust in technology	.224*	(.021 to .411)					
Trust in Arriva	.173	(-.037 to .386)					
DV: attitude							
Step 1:				.451	17.280	5.94	< .001
Positive affect	.356***	(.170 to .528)	3.867				
Negative affect	-.069	(-.599 to .255)	-.800				
Neutral affect	-.111	(-.241 to .043)	-1.387				
Perceived benefits	.352***	(.238 to .717)	3.961				
Perceived risks	-.151	(-.393 to .023)	-1.769				
Step 2:				.459	11.508	8.91	< .001
Positive affect	.324**	(.129 to .506)	3.346				
Negative affect	-.050	(-.562 to .315)	-.559				
Neutral affect	-.108	(-.240 to .048)	-1.320				
Perceived benefits	.350**	(.235 to .714)	3.937				
Perceived risks	-.095	(-.336 to .103)	-1.055				
Subjective knowledge	-.059	(-.292 to .135)	-.730				
Trust in technology	.147	(-.024 to .381)	1.750				
Trust in Arriva	.054	(-.154 to .291)	.612				
DV: Positive affect							
Step 1:				.123	5.635	3.96	.001
Subjective knowledge	.164	(-.0.37 to .480)	1.703				
Trust in technology	.031	(-.216 to .293)	.300				
Trust in Arriva	.318**	(.150 to .674)	3.123				
DV: Negative affect							
Step 1:				.087	4.158	3.96	.008
Subjective knowledge	.289**	(.050 to .258)	2.939				
Trust in technology	-.146	(-.173 to .031)	-1.379				
Trust in Arriva	-.146	(-.180 to .031)	-1.405				
DV: Neutral affect							
Step 1:				.056	2.946	3.96	.037
Subjective knowledge	-.151	(-.520 to .072)	-1.503				
Trust in technology	.057	(-.213 to .369)	.531				
Trust in Arriva	-.255*	(-.665 to -.065)	-2.418				

DV: Perceived benefits							
Step 1:				-.009	.695	3.96	.558
Subjective knowledge	-.015	(-.215 to .186)	-.141				
Trust in technology	.045	(-.158 to .237)	.401				
Trust in Arriva	.124	(-.087 to .320)	1.140				
DV: Perceived risks							
Step 1:				.130	5.917	3.96	< .001
Subjective knowledge	.125	(-.071 to .339)	1.296				
Trust in technology	-.249*	(-.448 to -.043)	-2.407				
Trust in Arriva	-.233*	(-.449 to -.033)	-2.299				

Note: DV = dependent variable
Significance levels: *$p < .05$. **$p < .01$. ***$p < .001$.

Discussion

This paper examined psychological variables that could explain the intention to use green hydrogen trains. To test which variables could help to explain green hydrogen train acceptability, a framework was developed. This green hydrogen train acceptability framework was based on the TAF from Huijts and colleagues (2012). As a starting point for the framework, we proposed that, in line with the TPB, attitude would directly predict the intention to use a green hydrogen train. From the regression analysis, we can infer that attitude was indeed significantly related to the intention to use green hydrogen trains, confirming our expectations. However, after entering all the variables in the regression analysis, attitude no longer was the strongest predictor of intention. Therefore, while our findings support the direct relationship between attitude and intentions as posited in TPB (Ajzen, 1991), they also indicate that attitudes might not be the main predictor of intentions. In line with this argument, the TAF also suggests another way through which one can predict the intention to accept a certain technology. Huijts and colleagues (2012) propose that, according to the Norm Activation Model (Schwartz, 1977), personal norms, which are related to feelings of moral obligation to act in a certain way, can also influence the intention to accept. Future research could examine whether personal norms have a stronger influence on the intention to use a green hydrogen train than attitude has.

Neutral affect and trust in technology turned out to contribute the strongest to the prediction of intention to use a green hydrogen train. That neutral affect is the strongest predictor of intention to use a green hydrogen train is surprising. As there is a lack of academic papers that have investigated how neutral affect specifically influences the acceptability of certain technologies, it is difficult to provide a precise explanation of this phenomenon. Nonetheless, we can make assumptions regarding the reasons why neutral affect emerges as the strongest predictor of green hydrogen trains. Namely, if someone does not have a strong interest or concern about the operation of green hydrogen trains, it is logical to assume that they may not prioritise or pay much attention to the type of train they are riding. This lack of interest may lead to an increased intention to use a green hydrogen train, as the person is interested in just using a train.

Moreover, we reasoned that attitude is influenced by affect, perceived benefits, and perceived risks. This regression model was statistically significant, and all the just-mentioned variables explained a high proportion of variance in attitude. However, we assumed that negative affect, neutral affect, and perceived risks would have direct relationships with attitude, but these relationships were not found to be statistically significant. Therefore, only positive affect and perceived benefits can be regarded as significant direct predictors of attitude.

It was also postulated that subjective knowledge, trust in technology, and trust in Arriva predicted intention to use via affect, perceived benefits, perceived risks, and attitude. Subjective knowledge, trust in technology, and trust in Arriva were not associated with perceived benefits, as this regression model was not statistically significant. On the other hand, trust in technology and trust in Arriva did significantly predict risk beliefs, where more trust in technology and Arriva led to fewer perceived risks. The fact that the two subcategories of trust did not have an effect on perceived benefits but did relate to perceived risks contradicts previous research by Midden and Huijts (2009), who found that trust directly influences perceived benefits but not risks. They argue that this can be explained by the fact that trust is measured with a positive connotation, as distrust was not explicitly measured. As our current study also did not explicitly measure distrust, we would have expected the same results as Midden and Huijts (2009). What could then be the reason why the two subcategories of trust influence perceived risks but not perceived benefits? Prior research has found that when people know little about technological risks and benefits, as is the case with the green hydrogen technology, acceptance mostly depends on trust in the actors that are responsible for the technology and trust in the technology itself (Siegrist & Cvetkovich, 2000; Midden & Huijts, 2009). Instead of making rational judgements based on knowledge, trust in the responsible actors and technology is employed to base one's opinion on. As was mentioned earlier, this study found that 16% of the participants had no knowledge about the benefits of hydrogen as a fuel while 46,2% of the respondents admitted to not knowing about the risks of hydrogen as a fuel. Therefore, since respondents had significantly less knowledge about the risks of hydrogen, they might have especially relied on the opinions of the responsible authority when making risk assessments. As the people rated their own knowledge to be relatively high for the perceived benefits, participants could have used their own knowledge when making judgements about the benefits of hydrogen instead of relying on their feelings of trust. Consequently, this might explain why the two trust categories did not influence the perceived benefits in our framework but did influence perceived risks.

Limitations and Future Directions

A limitation of this study is the limited time in which data could be collected, which resulted in a lower sample size than was anticipated. Initially, we planned to also distribute the questionnaire on the train, however, due to collaborating with a busy third party (Arriva) and time constraints, this was not achieved. Moreover, as the sample in this study is representative only of the Dutch population, the results may not generalize to other countries. Notwithstanding the relatively limited and ungeneralizable sample, this work still offered valuable insight into the predictors of green hydrogen train acceptability in Groningen and Friesland. Moreover, because respondents knew very little about the novel technology yet, they could have had a hard time assessing the risks and benefits of the technology. This could have influenced our data and, for example, have led to a higher mean of neutral affect. Future research could consider providing respondents with information about green hydrogen trains prior to their answering the questions.

The current study also provides a good starting point for future research on other factors that can predict the acceptability of green hydrogen trains. For example, a few variables in the TAF composed by Huijts et al. (2012) have not been studied in the current paper, being procedural fairness, distributive fairness, perceived costs, outcome efficacy, problem perception, social norm, perceived behavioural control, personal norm, and experience. Additional focus is specifically required on these variables. Additionally, future research could assess whether consumer acceptability of green hydrogen trains will change after implementation. Some studies have suggested that public acceptability of low-carbon technologies increases after implementation (e.g., Devine-Wright, 2005; Bailey et al., 2011). However, this positive shift over time has not yet been thoroughly researched or understood. The implementation of green hydrogen trains in Groningen and Friesland provides the perfect opportunity to investigate the process behind this possible increase in acceptability, and the current study could serve as a baseline assessment.

Theoretical and Practical Implications

As far as the theoretical implications are concerned, this paper has illuminated that there was not enough evidence to suggest certain direct relationships between variables that were outlined in the TAF. For example, a revision of a framework that predicts green hydrogen train acceptability could consider eliminating a direct relation of subjective knowledge and trust with perceived benefits.

Based on the results, specific practical recommendations on how to enhance the success of implementing green hydrogen trains can also be made for Arriva. First, although not being the strongest predictor when coupled with other variables, attitudes still directly predicted intention to use a green hydrogen train. As our study found that attitude is significantly predicted by positive affect and perceived benefits, Arriva must maintain a positive image of green hydrogen trains by emphasising the benefits that green hydrogen trains have. Second, as participants indicated that they are not aware of the fact that green hydrogen trains can reduce noise pollution, Arriva could especially focus on promoting this advantage more. Moreover, positive affect can be fostered by encouraging emotional connections through positive narratives and stories of successful transitions towards green hydrogen trains in other places, for example in the German town of Bremervörde. As particularly hope was associated with the implementation of green hydrogen trains in Groningen and Friesland, Arriva could highlight the role of green hydrogen trains in addressing the challenges of climate change, and convey the message that these hydrogen trains represent hope in achieving a more sustainable future. Moreover, as trust in technology was also found to be a strong predictor of intention to use a green hydrogen train, Arriva could also try to raise awareness of the fact that hydrogen train technology has advanced past the research and development stage and is already in use in, for example, Bremervörde. To increase trust in Arriva itself, Arriva could demonstrate expertise in the safe operation of green hydrogen trains. Additionally, when actions are taken that foster trust in Arriva, positive emotions can be increased and negative emotions can be decreased, ultimately increasing the acceptability of green hydrogen trains. A key recommendation to Arriva is to increase knowledge of green hydrogen fuel and green hydrogen train technology. Public knowledge can be strengthened by providing accessible and trustworthy information through a variety of platforms, including educational campaigns, workshops, and Internet resources. Perceived risks do not seem to play a big role in the intention to adopt a green hydrogen train, as most respondents indicated that they do not perceive there to be risks associated with green hydrogen trains and perceived risks were not significantly predicting intention to use. This means that Arriva could better emphasize the perceived benefits of using hydrogen trains rather than emphasizing aspects related to lower risks of using hydrogen trains.

Conclusion

The aim of the present paper was to determine how the public perceived green hydrogen trains and which variables can predict consumer acceptability towards green hydrogen trains. Findings of a survey-based quantitative investigation of the intention to use a green hydrogen train were presented. Results indicated that the public generally supported a transition to green hydrogen trains. Intentions to use green hydrogen trains were high, and attitudes towards green hydrogen trains were mainly favourable. Furthermore, the public perceived there to be many benefits of green hydrogen trains and only a few people made an association between hydrogen and danger. However, the majority of the participants did not rate themselves to have knowledge about green hydrogen fuel and green hydrogen technology. Moreover, in the green hydrogen train acceptability framework, all the variables were found to contribute to explaining the intention to use a green hydrogen train. Notably, intention to use is, directly or indirectly, significantly predicted by the variables attitude, affect, perceived benefits, perceived risks, trust, and subjective knowledge. When all variables were entered into the regression analysis, neutral affect and perceived benefits were found to be the strongest predictors of intention to use, even stronger than attitude. This suggests that especially feelings of indifference and awareness of benefits were paramount to the understanding of the public’s intention to use a green hydrogen train. Moreover, attitude was most strongly predicted by positive affect and perceived benefits. The current study found no effect of subjective knowledge and trust on perceived benefits. Theoretical and practical recommendations have been presented, including the advice to emphasise the benefits of green hydrogen trains that respondents are unaware of. Future research can, among others, shed light on the influence of other variables on the intention to adopt a green hydrogen train and the process behind a possible increase of acceptability after green hydrogen train implementation. In conclusion, this paper has highlighted the significant potential of green hydrogen trains as an environmentally friendly substitute for the current regional trains in Groningen and Friesland. The overall positive public perception of a transition to green hydrogen trains offers an optimistic outlook for a future in which the railway industry will see fewer CO^2 emissions and enhanced sustainability.

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Appendix A. Informed Consent

Welcome to this survey!

The University of Groningen, and specifically Campus Fryslân, is collecting data on consumer acceptability towards green hydrogen trains. This research is done in collaboration with transport company Arriva, who has issued a tender for four green hydrogen trains that are set to operate in Groningen and Friesland. This survey takes around 5 minutes to complete. You will be asked questions about your perception of green hydrogen trains.

Your participation in this survey is completely voluntary. You, as a participant, have the right to refuse or withdraw participation and consent to use the answers at any point of the research without any consequences or providing reasons. The data collection in this survey is anonymous, which means that data that are published, for example in university reports, cannot be used to identify you. Anonymised data may be shared with other researchers for scientific purposes.

By clicking the “Yes, I consent” button below, you indicate that: “I read and understood the information above, I voluntarily participate in this study, and I give the consent to the use of my survey responses as data”.