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## **Understanding the Public Acceptance of Hydrogen Technologies in Transport: A Conceptual Framework**

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Public acceptance is recognized as an important factor determining the success of the implementation of hydrogen, next to economic and technical factors [1, 2]. As it is widely recognized that the application of hydrogen as an energy carrier has the highest potential to be implemented on a relatively short term in transport this paper focuses on the acceptance of hydrogen technologies in this application area. In transport, the public is confronted with acceptance of hydrogen in at least two different roles. In the role of consumer, people may decide whether or not to purchase a hydrogen vehicle once they are introduced at the market. In the role of citizen, people may accept or protest against refuelling stations that are planned near their living area. Acceptance in both roles may affect the chicken-and-egg problem: without a widespread network of hydrogen refuelling stations people will not purchase a hydrogen vehicle, while widespread purchase of the hydrogen vehicles is needed in order to make the refuelling stations cost efficient.

It is not entirely clear to what extent hydrogen is accepted in different situations and which psychological factors affect this. Several studies have been conducted on hydrogen acceptance [3] many of which studied consumer acceptance of hydrogen buses. Much less research has been conducted on citizen acceptance, which includes acceptance of hydrogen refuelling stations [4]. The studies are rather descriptive in nature and not well funded in theory [5] In the few studies that are based on theory, only a single theoretical perspective, that is the theory of planned behavior, has been chosen, with the result that other determinants suggested by competing theories are not taken into account. Hence, the insight in which factors affect hydrogen acceptance is still limited. To conclude, what is largely missing is a comprehensive understanding of factors influencing consumer and citizen acceptance of hydrogen technologies in transport.

To the best of the authors' knowledge, also a more general comprehensive causal framework on citizen and consumer acceptance of new technologies that can be applied to this acceptance topic has not been developed yet. In this paper we aim to fill this gap by developing a general framework for citizen and consumer acceptance of new technologies, which is also applicable to hydrogen technology in transport. The presented framework has several functions with respect to hydrogen technology research: it helps to understand the psychological factors that influence the acceptance of the transition to a hydrogen fuelled transportation system and how these are interrelated; it can support decision making by policy makers and practitioners; it can be the starting point for acceptance research for new implementations; and finally, it will help to understand both the value and limitations of currently available hydrogen acceptance studies.

The development of this technology acceptance framework is based on several theories that are well-known in social and environmental psychology. The theories are selected based on

their relevance for new technologies that have environmental or societal benefits, but at the same time carry risks and additional costs compared to common technologies, like the case of hydrogen technologies.

As a start to understanding public acceptance, we recognize that people's acceptance behavior may be motivated by different goals. Lindenberg and Steg [6] explain that goals are influencing decision making: "goals govern or 'frame' what people attend to, what knowledge and attitudes become cognitively most accessible, how people evaluate various aspects of the situation, and what alternatives are being considered." Three goals are distinguished here: the gain goal, the hedonic goal and the normative goal.

The gain goal is typically assumed to be the strongest goal in preference studies: it assumes that people base their decisions on costs-benefit analyses and choose options with the highest gains against the lowest costs. This aligns with the theory of planned behavior [7] which assumes that people's attitudes are based on the evaluations of consequences related to the object or the behavior. This theory postulates that attitudes influence intentions to act, which in turn influences behavior. In addition to attitudes, subjective norm and perceived behavioural control are also assumed to influence intention to behave and behavior. Subjective norm reflects the perceived social pressure to perform or not perform the behavior. Perceived behavioural control reflects the perceived ease or difficulty of performing the behavior. So in the gain goal-frame, people can decide to buy a hydrogen vehicle based on their evaluations of costs, risks and benefits, on what they believe other people think of buying and having the car (reflecting social costs and benefits) and on whether it is perceived to be difficult to purchase, drive and maintain a hydrogen fuelled vehicle. For example, Molin et al. [8] showed that preferences for hydrogen vehicles are influenced by costs (fuel price and vehicle purchase cost) and convenience factors (detour and range).

The hedonic goal-frame suggests that affect has the strongest impact on people's attitudes and behavior; people will base their decision on what feels best. This means that people do not merely aim to optimize the personal outcome of the technology when deciding between behavioural options, but also make decisions based on feelings. Dual-processing theories (e.g. [9]) are theories in the field of psychology that discuss the role of affect. These theories distinguish affects and cognitions assuming that these reflect two separate systems in human thinking and decision making; the impulsive system and the reflective system respectively [9]. While in the reflective system decisions are based on reasoning and logic, in the impulsive system decisions are based on associations and affect. The theory suggests that the two systems have a separate role in attitude formation, but at the same time also influence each other, which means that acceptance will be influenced by people's weighing of perceived costs, risks and benefits, as well as by emotions. Positive and negative emotions have been found to influence technology acceptance (e.g. [10]). For example, the study of Montijn-Dorgelo and Midden [11] measured the influence of associations and affect (both a sign of the impulsive system) and showed that strong associations with danger influenced perceived risks and benefits via the affective pathway.

The normative goal-frame suggests that people base their choice on what is the most appropriate thing to do; on what they think "ought to be done". This goal-frame is relevant for technologies that have an environmental or societal beneficial component. An example of

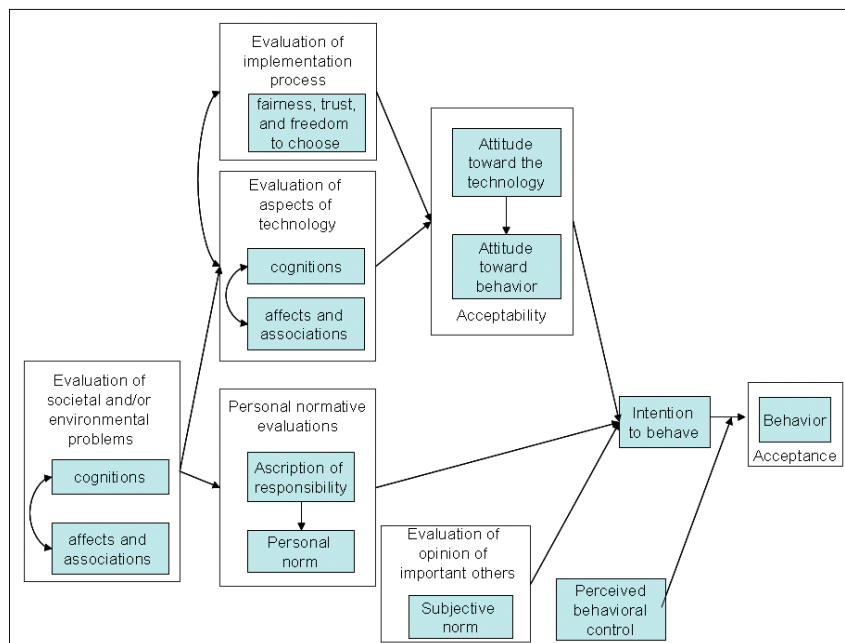
acting on a normative goal-frame is that if people think that it is our personal obligation to attend to the environment, they will purchase clean vehicles like hydrogen vehicles and support refuelling stations for clean fuels. Personal norms reflect feelings of moral obligation to engage in a particular action. The Value-belief-norm theory (VBN, [12]) describes how personal norms arise. First, values will influence how one perceives consequences of behavior and awareness of problems (like climate change). Related to the energy system, this will be both environmental problems and problems with energy security. Once aware of the problems and consequences, people decide whether they are personally responsible for these problems and whether they can do something about it. When people think they are responsible they might develop personal norms that influence their behavior. For example: when people consider the importance of reducing CO<sub>2</sub>-emissions in order to limit climate change, people might decide to accept hydrogen as a fuel, even though the personal benefits of the switch of fuel might be small or even negative (e.g. when the costs are higher). The effect of normative considerations on the acceptance of hydrogen technologies has not been tested yet.

Next to these goal-frames, studies have shown that also the way the implementation of a technology is perceived and how the actors involved are perceived, influences the perceived costs, risks and benefits, and the attitude towards the technology. Three important factors in this respect are fairness, voluntariness/freedom to choose, and trust. Fairness can be distinguished into two types: procedural and distributional fairness. Procedural fairness concerns whether people find the way in which decisions were made fair. For example, decisions can be found unfair and can diminish acceptance when they were made by policy makers while citizens were not involved. Distributional fairness concerns the perceived fairness of the distribution of personal and societal costs and benefits (e.g. [13]). For example, people living close to a refuelling station might feel that a location choice is unfair to them, because they are faced with the safety risks, while others only get the benefits of the refuelling station. Both types of fairness are likely to play a stronger role when others rather than you have taken the decision for the implementation of the technology. Perceived voluntariness is found to influence the trade-off between perceived risk and perceived benefit for activities and technologies [14] and is likely to play a role in acceptance of hydrogen technologies. Trust in actors involved with the technology and actors providing information about the technology are found to influence acceptability of technologies that have risks associated with them, especially when risks are involved of which people know little about (e.g. [15, 16]). Trust has been found to influence acceptability of hydrogen technologies in transport [11].

Finally, knowledge and familiarity are found to influence the acceptance of hydrogen. Knowledge concerns many things, like knowledge of an environmental problem (e.g. climate change and its connection to the relation between energy use, fossil fuels, and CO<sub>2</sub>-emissions) or knowledge about the way technology is currently applied. Familiarity refers to personal experience, like having been inside a hydrogen vehicle, or using a hydrogen refuelling station. Knowledge and familiarity potentially influence all previously discussed factors, depending on the type of knowledge and experience.

To conclude, we suggest that citizen and consumer acceptance are influenced by a wide range of variables, as depicted in picture one. Knowledge and familiarity are not depicted in

the model, because they influence all variables, but can also act as a moderator which means that they influence the strength of the relation between the variables. The causal order is based on the causal order suggested in the original theories and measured in empirical studies. This conceptual model needs to be tested for several technology acceptance issues and specifically the relative importance of each factor for hydrogen technology acceptance needs to be tested. As made clear before, the framework includes a number of factors that have never been tested for hydrogen technology acceptance, like evaluation of environmental problems, ascription of responsibility and personal norm.



**Figure: The technology acceptance framework (TAF).**

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