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Drivers of Alternative Fuels Acceptance: The Example of Liquefied Natural Gas

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***Abstract*— The Technology Acceptance Model is widely used to assess why persons apply a technology or refuse to apply it. It has already been adopted for various research fields, including alternative fuel technologies. Since Liquefied Natural Gas is a very promising technology to reduce emissions in the transport sector, the aim of the present paper is to extend TAM in order to design a model describing the influencing factors of the behavioral intention to use LNG. The independent variables defined in the model take into consideration the characteristic properties of LNG, e.g. safety issues due to its cold temperature. The resulting research framework helps to anticipate and evaluate actual technology use of LNG.**

Keywords—Acceptance models; theory of planned behavior; Liquefied Natural Gas; alternative fuels acceptance.

I. INTRODUCTION

The transport sector is one of the highest energy consumers and main source of CO2 emissions. To reduce dependencies on oil and achieve climate policy goals as for example foreseen in the European alternative fuels strategy it will be necessary to deploy substantial shares of alternative fuels. Liquefied Natural Gas (LNG) technology is very promising in this context. Due to its high energy density it is especially suitable for waterborne activities and long-haul transport vehicles e.g. trucks or busses. Compared to diesel and conventional marine fuels, LNG leads to reduced air pollution and greenhouse gas emissions as it causes about 20% less CO2, 80-90% less NOx and almost zero PM and SOx [1]. Using bio methane makes it even possible to completely avoid CO2 emissions. There is growing interest in LNG as for heavy duty vehicles there exist only few alternatives for diesel.

LNG is being produced by cooling conventional natural gas down to a temperature of -161.5 °C. This technology is already several decades old and leads to the liquefaction of natural gas. This process causes the volume of natural gas to be reduced 600 times; this means 1 m³ LNG equates to 600 m³ of natural gas. In this form natural gas can be easily distributed by sea or by road. Hence the dependence on pipeline gas can be reduced and a country's energy mix can be diversified [2].

LNG is a clear, colourless, odourless, non-toxic and non-corrosive liquid. Due to the cold temperature, LNG is a cryogenic substance which requires to be handled very carefully. In case LNG is spilled on water, it floats on top and vaporizes rapidly. In the absence of an ignition source, LNG evaporates quickly and disperses, leaving no residue [1]. The flammable limit of LNG in the air is 5-15%, which is exceeded relatively quickly [3].

For implementing LNG and other alternative fuels in general it is necessary to establish required infrastructure and sufficiently provide the commodity. The main prerequisite to ensure feasibility of constructing the required infrastructure is to gain information about the potential demand which could be generated and served. This potential demand is determined by specific influencing factors, some of them being drivers and some of them being barriers for the introduction of alternative fuels. The aim of this paper is to analyze these influencing factors by adapting the widely recognized Technology Acceptance Model from Davis.

The research question that we want to answer is, "which factors have to be included in a model which describes the user acceptance of LNG as an alternative fuel in transportation"? The remainder of the paper is organized as follows: Chapter II gives an overview about standard models of acceptance and behavioral intentions. Furthermore it will represent literature where acceptance models have been developed for the alternative fuels and sustainable energies sector. This comprehensive literature research in chapter II has been carried out to collect evidence for the variables which we integrated into our model. In chapter III we will illustrate the acceptance model which we set up for describing the intentions to use LNG as an alternative fuel. It will also be explained how the variables of the acceptance model are associated with customer's needs toward the introduction of LNG. Since this is a work-in-progress paper, chapter IV gives an outlook on the next research steps.

II. THEORETICAL BACKGROUND

A. Standard Models of Acceptance and Behavioral Intentions

In the last decades, many models have been developed to predict a person's intention to use a specific technology. For this purpose, the factors which influence the decision to apply a technology need to be identified. The socio-psychological *theory of reasoned action* from Fishbein and Ajzen [4] and its extension, the *theory of planned behavior* [5], build the foundation for most of these models. According to Fishbein and Ajzen there is close coherence between attitude and behavior. This implies that behavioral intention, such as the intention to use a technology, is determined by a person's attitude, but also by social norms. Social norms include the (expected) reaction of related persons in answer to the performed behavior.

One main coefficient regarding the intention to use is technology acceptance. The concept of technology acceptance was introduced by Davis in 1989 [6]. His *technology acceptance model* (TAM) originally focused on assessing the acceptance of IT, but by now it has already been employed on various other types of technologies, also on alternative energy systems and power sources. TAM is based on the Theory of Planned Behavior and is one of the most influential and most widely used extensions of Ajzen and Fishbein's work. Since the attitude toward using a technology is influencing the behavioral intention to use and finally the actual system use, Davis specifies this *attitude toward using* by introducing two external variables. These new variables are *perceived usefulness* and *perceived ease of use*.

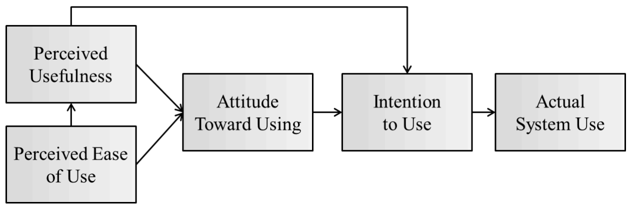

Fig. 1. Technology Acceptance Model [3].

Davis defines perceived usefulness as "the degree to which a person believes that using a particular system would enhance his or her job performance", so a useful technology is perceived to be capable of being used advantageously. Perceived ease of use is described as "the degree to which a person believes that using a particular system would be free of effort". Davis claims that all else being equal, a technology will be more likely to be accepted by users if its application is considered to be useful and easy to use [6].

A lot of work has been published to refine TAM and expand the applications fields of this model. Recent developments include additional factors such as social, psychological and cognitive components to enhance predictive accuracy of technology usage. In 2000, Vankatesh republished the basic model together with Davis himself, which is referred to as TAM2 [7]. They amplified TAM in terms of social influence (subjective norms, voluntariness, image) and cognitive instrumental processes (job relevance, output quality, result demonstrability, perceived ease of use).

Due to the high variety of competing acceptance models, Vankatesh et al. sought to integrate eight of the most important existing models in 2003 by proposing the *unified theory of acceptance and use of technology* (UTAUT). Previous acceptance research is thereby advanced by unifying several models and by introducing moderators to account for dynamic influences. These consist in organizational context, user experience and demographic characteristics. UTAUT explained as much as 70 percent of the variance in intention to use, which is more than the previous models did [8].

B. *Acceptance Models in the Energy Sector*

As mentioned before, the original objective of TAM was to assess the acceptance of computers and IT in general, but it has already been used to set up models for alternative energy technology acceptance and power systems acceptance as well. Table 1 gives an overview of selected acceptance studies related to the field of alternative fuels and energy.

TABLE I. ENERGY RELATED ACCEPTANCE STUDIES

Reference	Research subject	Region	#
Wang (2016)	Electric vehicles (hybrid)	China	[9]
Sang & Bekhet (2014)	Electric vehicles	Malaysia	[10]
Zhang et al. (2011)	Electric vehicles	China/ USA	[11]
Huijts et al. (2014)	Hydrogen fuel stations	NL	[12]
Schulte et al. (2004)	Hydrogen vehicles	UK	[13]
Yeh (2007)	Natural gas vehicles	USA	[14]
Yang et al. (2016)	Carbon capture and storage technologies	China	[15]
Guo et al. (2015)	Wind power	China	[16]
Huijts et al. (2012)	Sustainable energy technologies	NL	[17]

As can be seen in Table 1, there are already several acceptance models which have been developed for different types of alternative fuels, mainly for electric vehicles and for hydrogen. We enlarged the topic of our literature research and did not only include alternative fuel technologies, but also other sustainable energy technologies like CCS (Carbon capture and storage technologies) and wind power. The regarded studies originate from different countries and continents. Remarkably, a substantial number of publications derive from China. This might be because China is a major energy-consuming country and is under great pressure to improve its energy efficiency and reduce carbon emissions [9].

It is worth pointing out that no study about acceptance and behavioral intention to use LNG has been found within the review.

The three papers dealing with the acceptance of electric vehicles (EV) include very similar variables to describe the behavioral intentions, although the aggregation levels differ clearly. Out of these, Zhang et al. [11] set up the most detailed model with nine independent variables referring to the demographic characteristics of the respondents (including gender, age, education level, income, family size, number of vehicles in a family and others) and ten further independent variables describing the respondents' perception of EV technology. These variables are: vehicle performance, government policy, environmental requirement, the opinion of peers, vehicle price, tax reduction, fuel price, fuel availability, maintenance cost and vehicle safety.

In Wang et al. [9], several of the aforementioned variables are summarized as "perceived behavioral control". Consequently, perceived behavioral control includes questions of price, maintenance and availability of (hybrid) electric vehicles. Additional variables in [9] are attitude toward adoption, subjective norm (i.e. what do other people think when I adopt EV technology) and personal moral norms. Beyond that Wang et al. define environmental concern as superordinate independent variable which influences all other independent variables in the model. Some further questions serve for the purpose of creating demographic profiles of the respondents.

Sang and Bekhet set up a model with seven factors influencing the intention to use EV, these are infrastructure readiness, government intervention, environmental concern, performance attributes, social influence, financial benefits and finally again demographic attributes [10].

Huijts et al. developed a very detailed framework of technology acceptance which they first deployed in view of energy technologies in general [17], and later applied with regard to hydrogen fuel stations [12]. In their model they propose sixteen factors which influence one another and which finally have an impact on the intention to accept. In contrast to the above described EV models, the designated names of the factors do not specifically relate to alternative fuels application (as for example fuel price or vehicle safety) but are rather general and indeterminate such that they can be applied to nearly any technology (as for example perceived costs, perceived risks, perceived benefits,…). The intended contents are nonetheless comparable. The same applies to Schulte et al. [13]: Their model includes the very basic components of values, needs, wants and perception to describe the acceptance for hydrogen vehicles. Social backgrounds and experiences are affecting these components, whereas the first ones are difficult to influence and the second ones are possible to influence [13].

Yeh's analysis on the adoption of natural gas vehicles [14] is rather uncoupled from the main acceptance theories that have been described in section II.A. The aim of the study is rather to create a conceptual framework of policy instruments promoting the adoption of advanced transportation technologies such as natural gas vehicles. The three main components can be described as technology, context (social, cultural, economic as well as spatial) and impacts (economic, health, environmental, energy, land use).

The five elementary independent variables of the model of CCS acceptance [15] can also be applied to alternative fuels: public cognition, perceived risk, perceived benefit, environmentalism and public trust. Finally, the study about wind power [16] is very much based on the simplicity and straightforwardness of the standard models from Fishbein/Ajzen and Davis. Guo et al. point out that there are three factors influencing the local acceptance of wind power, namely perceived interest (including both, economic benefit and environmental cost), public attitudes toward environmental issues and general attitudes toward wind energy.

III. ACCEPTANCE OF LIQUEFIED NATURAL GAS

A. Model framework

As the preceding elaborations have shown, a wide range of proposals for extending the standard models of technology acceptance with regard to alternative fuels already exists, with many of them being quite complex and including a high number of variables and interdependences. The original models only consist of a few variables, and our model to describe LNG acceptance should similarly focus on this simplicity and concentrate on the most essential influencing factors. Figure 2 illustrates the proposed model for the acceptance of LNG as an alternative transport fuel.

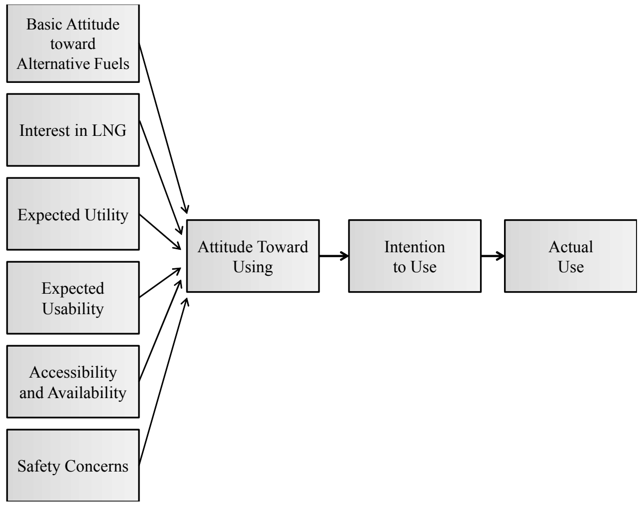

Fig. 2. Conceptual model of the determinants affecting LNG acceptance.

Many of the above described models include a component such as "environmental concern" in order to describe the target group's general awareness for environmental issues. Similarly, the proposed model for LNG contains the independent variable "basic attitude towards alternative fuels" in order to assess the general perception of environmentally friendly fueling technologies.

Next, there is another elementary variable, "interest in LNG". This describes the basic perception of LNG, for example if it is seen as a promising fuel or not.

"Expected utility" can be compared with the variable "perceived usefulness" from Davis' standard model. Accordingly, it describes the degree to which LNG technology is assumed to be advantageous or helpful to fulfill one's aims.

Since the existence of required infrastructure and equipment is a crucial matter influencing the choice of alternative fuels, "accessibility and availability" has been established as independent variable. The presence of LNG filling stations is especially in landlocked countries like Austria very limited.

Due to the cold temperature, people sometimes raise safety issues in context with LNG. For this reason, "safety concerns" is implemented as an individual factor in the model, although it can be seen as part of the usability of LNG technology. By considering it as an individual component in the model, it can be testes which influence safety really has.

The variable "expected usability" explains to which degree LNG technology is capable for being used conveniently, we introduced it analogically to Davis' "perceived ease of use".

All the aforementioned independent variables of our model are suggested to directly influence the dependent variable, namely "attitude toward using LNG".

B. Acceptance and Customer Needs

In our previous work we analyzed customer needs towards LNG [18], [19]. This means that we tried to answer the question which requirements must be fulfilled in order to establish LNG as a viable fueling option for potential users. It can be differentiated between the most basic needs and higher level needs. Most basic ones are that LNG application is economically viable and that infrastructure exists such as a sufficient network of refueling stations. If these two most basic needs are fulfilled, potential customers require harmonized legislation which regulate the use of LNG vehicles (e.g. approvals, insurance questions,…). It is evident that customers will also demand proven and mature technology to be available at the market. Furthermore, customers will require that the operation and maintenance of the vehicles is safe and easy to understand because there are for instance issues like the treatment of boil-off gas in context with LNG. Finally customer needs include that there are positive environmental effects by using LNG technology [18].

Since the factors influencing the acceptance of LNG are highly linked to these customer needs, Table II shows which factors are associated with which customer needs.

TABLE II. ACCEPTANCE FACTORS IN RELATION TO DEFINED CUSTOMER NEEDS

Variables of acceptance / **Customer needs**	Basic attitude toward alternative fuels	Interest in LNG	Expected utility	Expected usability	Accessibility and availability	Safety concerns
Economic viability	X	X	X			
Infrastructure available	X	X			X	
Legisletion is harmonized	X	X		X		
Mature and proven technology	X	X			X	X
Unproblemativ operation of vehicles	X	X		X		X
Positive environmental effects	X	X	X			

Table II indicates the relevance of the suggested influencing factors in the LNG acceptance model due to the fact that each variable from the model is related to at least two of the defined customer needs. It can be stated that the basic variables "attitude toward alternative fuels" and "interest in LNG" are associated with all types of customer needs because the fulfilment or the absence of every single customer need influences the perceived attitude and interest for alternative fuels in general and LNG in particular.

IV. IMPLICATIONS AND OUTLOOK

The underlying objective of the developed model is to gain insight into the driving factors that influence the acceptance of LNG as an alternative transport fuel. Since the existence of these driving factors can be examined, the model also helps to anticipate actual technology use. Finally LNG technology can be evaluated if there is knowledge about the characteristics of the components. One finding could for example be that potential users fear safety issues in context with LNG and therefore it can be concluded that efforts have to be put on this topic.

The next step of our work will be to test the proposed model within potential users of LNG and stakeholders along the whole LNG value chain such as energy providers, equipment manufacturers or LNG supplying and distributing companies. The aim is to verify if the suggested factors actually influence LNG demand. The region covered by the survey will include the European Rhine-Main-Danube axis, where there are distinctive sectoral differences: The Rhine region, especially the Netherlands, is an exceptionally pioneering region with regard to LNG while the Danube area is currently in a development stage. It should be underlined that the target groups for this survey are companies while the respondents in most acceptance studies reviewed in the literature research (Table 1) were private persons. This makes it difficult to achieve a large sample size.

A questionnaire will be designed with three items for each introduced components of the model. For scaling the responses, a seven-point Likert scale will be employed to specify the respondents' level of agreement or disagreement. The results are expected for autumn 2016.

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