



D16.1 Social science measurement framework (draft_1.0)

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1 Summary

This Deliverable presents a social science measurement framework for the REFINE project, including descriptions of technical scenarios that are developed together with the technical experts (from work packages 2 to 15). The measurement framework specifies research approaches that are tailored to the REFINE project to assess the (risk) perceptions, acceptance and information and communication needs of the relevant stakeholder groups, mainly the European societies. In order to assess the highly technology- and context-specific individual perceptions and acceptance, it is necessary to select valid and sensitive social science research methods for an empirical, iterative mixed-methods approach. The definition of quality criteria for valid, objective and reliable research is also paramount.

As acceptance and risk perception measurements always relate to a specific technical product, process or scenario, technical REFINE scenarios are essential to frame the background of public assessment of acceptance and risk perceptions and provide guidance to the social science research participants. In this draft of the Deliverable, their relevance and development process are detailed. The final technical scenarios will describe all relevant steps, resources and products of the REFINE process in a way that is understandable and accessible for laypeople, thereby enabling the participants in the social science studies to make informed decisions and avoid pseudo-opinions.

In addition to the technical scenarios, the measurement framework includes a selected range of appropriate empirical research methods, procedures and analysis techniques. These can be used in WP17 for the empirical assessment of social (risk) perceptions and acceptance and in WP18 for the assessment of information and communication needs. In particular, this framework includes the definition of quality criteria, research objectives, research objects, target groups and the mixed methods research process, including the description of data collection, processing and analysis methods suitable for social research in REFINE.

2 Introduction

2.1 Relevance of a Social Science Measurement Framework

The social science measurement of societal perception and acceptance of the REFINE technology and end-product allows for the identification of socially accepted pathways among different technology roll-out options. The integration of the social dimension in the technology development thus enables the steering of the REFINE development routes in a socially accepted manner with the aim of developing the REFINE process with a high probability for public acceptance. Based on the holistic technology acceptance assessment, guidelines, and recommendations for an effective public communication strategy as well as policy recommendations will be derived.

Research methods are required to produce universally valid statements and theories that extend beyond subjective perceptions (Döring, 2023). Therefore, in order to assess societal perceptions and acceptance in a valid manner, it is necessary to employ a systematic, verifiable, and objective empirical research approach that adheres to scientific quality criteria. This is of particular importance as human factors such as perceptions, experiences, or attitudes are so-called latent variables: they cannot be directly observed and measured. Appropriate social science methods are required to elicit these human experiences and minimise measurement errors (e.g., answering biases, reactivity to data collection). One key step for the valid measurement of these latent human factors are the specification and operationalisation, concepts that will be explained in the following. In particular, for quantitative social research, the precise definition of the theoretical constructs to be measured (concept specification) and the selection of the limited number of relevant concepts that can be measured without burdening the participants are essential. Important resources for this step are

- theoretical underpinnings that allow for a hypotheses-based empirical procedure,
- empirical quantitative results from related studies that allow a comparison of acceptance measures across products and technical innovation, as well as
- qualitative preliminary studies.

In the operationalisation of theoretical constructs, observable and measurable indicators (typically questionnaire items) are defined and the response scales are determined to assign numerical values to each measurement are specified. Although standardised testing procedures (also known as psychometric measurement procedures) are available for certain aspects of the assessment of (risk) perceptions and acceptance in the REFINE project, there are, of course, additional factors specific to the REFINE technology that are not covered by existing acceptance models and psychometric measures. In these cases, specific concepts remain to be specified and operationalised. Furthermore, the selection of target groups and points of measurement is crucial in the empirical research design to ensure the validity and generalisability of the results.

To facilitate “optimal” social science measurements with a standardized, validated measurement rationale, this measurement framework is employed to guide the social science studies. The final measurement framework will define rigorous quality criteria and data cleaning procedures and will outline a comprehensive yet flexible and agile mixed-method research approach, which will be conducted employing a series of empirical studies. This way, the measurement framework provides consistency in social science measurement, thereby promoting comparability of independent studies and providing a meta-perspective to coordinate social research activities.

2.2 Quality Criteria of Social Science Research

In social science research, ensuring the quality and rigour of studies is of paramount importance in order to produce reliable and valid results. Three core criteria are used to evaluate the quality of (quantitative) social science research: validity, objectivity, and reliability (Döring, 2023). Each of these criteria plays a crucial role in the overall assessment and credibility of research findings.

- **Validity** refers to the extent to which a research study accurately reflects or measures the concept or phenomena that it intended to measure. It is of the utmost importance to utilise valid test instruments in order to guarantee that the conclusions drawn from the results are accurate.
- **Reliability** refers to the consistency and stability of the results, or to the degree to which a measurement is biased by measurement errors. A reliable study produces similar results under consistent conditions, thereby demonstrating that the test measures the characteristic precisely.
- **Objectivity** is achieved when the results of measurement are independent and unbiased from the researcher, thus the research is free from personal or subjective influence. Objectivity is a crucial aspect of social science research, as it enables the production of unbiased and impartial results (Döring, 2023).

For the evaluation of the quality of quantitative psychological tests, the aforementioned core quality criteria are further differentiated (Moosbrugger & Kelava, 2008).

In order to assess the validity of a test, several types of validity must be considered.

- **Content validity** describes the representativeness of the testing/measurement in relation to the measured characteristic and can be evaluated by experts.
- **Face validity** similarly assesses whether it is apparent to a layperson which characteristic the test measures.
- **Construct validity** examines whether the methods used truly measure the theoretical constructs they are intended to measure. For instance, a survey designed to measure depression should accurately capture the symptoms and experiences associated with depression.

- **Criterion validity** is high when the measured test results predict characteristics that should be related to the measured characteristic.

Regarding reliability, the following measures are important for the social research in REFINE:

- The **internal consistency** of a (quantitative) test comprising several items is evaluated using reliability coefficients such as Cronbach's Alpha.
- The **inter-rater reliability** captures the degree of agreement among different researchers (Neuendorf, 2010), that analyse and evaluate the data. High inter-rater reliability suggests that the measurement is consistent regardless of who is conducting the assessment. Inter-rater reliability is mainly used in qualitative analyses.

Three types of objectivity are distinguished:

- To maintain **objectivity of implementation and analysis**, it is essential to employ standardised procedures and tests. The use of and adherence to standardised tests, procedures and analysis rules ensures that personal biases do not influence the outcomes.
- The **objectivity of interpretation** is maintained through the classification of test results against norm values, for example, the evaluation of statistical significance and effect sizes through well-established thresholds (Field, 2013).

In addition to the core quality criteria, validity, objectivity and reliability, there are further considerations to be made with regard to the quality of social science tests.

The **standardisation** of a test provides a reference system that aids in comparing and interpreting results. Standardisation techniques used to contextualise a test result include the comparison with the standard deviation and established thresholds regarding significance and effect size.

Furthermore, the **test economy**, the effort (in time or costs) to gain the desired knowledge should be appropriately small.

A test must also be **reasonable**, meaning that it should not unduly burden the participants with the testing. This must be judged relative to the utility of the test, which represents the practical relevance and the beneficial relevance of the consequences of testing.

The test fairness must be ensured to prevent systematic discrimination against people based on their ethnic, socio-cultural or gender-specific groups.

The **non-fakeability** of typical survey testing is often challenging, as social desirability bias may be present whereby the participant disguises their actual opinion in order to answer more socially desirable. To avoid social desirability bias and other response biases (systematic distortions in the way participants answer, e.g. tendency for extreme answering, tendency to agree), the testing situation and the test instrument are of utmost importance and can either invite or discourage response biases. The use of online surveys in which participants answer anonymously and are instructed about their anonymity and the importance of answering honestly are important steps to reduce biases from the testing situation. Key to avoiding response biases is the response format and item wording. The use of neutral, comprehensible, non-ambiguous wording, randomisation of question orders, an even number of answering points without a "neutral" midpoint and the use of reverse-worded items has been demonstrated to reduce response biases (Wetzel et al., 2016). Moreover, the utilisation of alternative survey methodologies, such as conjoint experiments, circumvents the prevalent response biases



associated with rating scales through the use of comparisons and discrete choices as alternative techniques (Bansak et al., 2021).

All these methodological standards and procedures (appropriate test design and selection; standardised testing where applicable; appropriate cleaning of data; inclusion of representative participants; etc.), are employed during the social science measurements of the REFINE project. Section 7.2.3 describes the data cleaning process in detail.

2.3 Ethics in Social Science Studies

In the field of social science, the object of investigation is the individual, and thus, research integrity and ethics are of paramount importance. Objectivity of research as one important ethical principle is achieved through the implementation of methodically rigorous, intersubjectively comprehensible scientific practices in accordance with defined quality criteria — as defined above. Additionally, research ethics must be upheld to protect research participants in their dignity and well-being. This ethical treatment of research subjects is grounded in three principles (Döring, 2023),

- voluntariness and informed consent,
- protection against impairment and damage, and
- the anonymisation and confidentiality of data.

Participation in the empirical studies must be voluntary, and participants must consent to their involvement. They will be informed in a clear and understandable manner about the purpose of the research, the expected duration and procedure, their right to refuse or discontinue participation, data protection and data use for scientific purposes, and will be provided with contact details for further inquiries. Participants must consent to the conditions before they can participate. Furthermore, social research in REFINE will be conducted in accordance with the principles of "no risk research," which is generally exempt from institutional review board approval in accordance with the guidelines of the German Psychological Society (2018). Nevertheless, survey concepts, instruments, and data management strategies employed in REFINE will be subjected to review by the Ethics Committee of the Faculty of Arts and Humanities at RWTH Aachen University to ensure their suitability for empirical use.

The data will be collected, processed, and stored in accordance with the General Data Protection Regulation (GDPR) and the REFINE data management plan, following informed consent. In online questionnaires, data is collected anonymously. Audio and video recordings of qualitative research approaches, which may be used to re-identify participants, will be stored confidentially according to the REFINE data management plan, with access only to the researchers. In the data preparation phase, anonymised data are created for use in further research. Only anonymous excerpts will be used in publications and teaching.

Furthermore, social research in REFINE aims to be inclusive, including participants from all groups of society in surveys aimed at the general public. To collect representative samples from the general public beyond the social networks of the researchers and student samples, independent market research companies will be tasked with the recruitment of participants. Quotas are employed to ensure the inclusion of individuals from diverse demographic groups (e.g., across groups of age, gender, education level) in order to achieve samples that are representative of the general public with respect to these criteria.

3 Technical Scenarios

3.1 Relevance of Technical Scenarios in Social Research and Technology Development

Technical scenarios represent a fundamental instrument in the REFINE project, serving two primary objectives. Primarily, they delineate and circumscribe the framework conditions of the project. This function is of paramount importance for surmounting communication barriers among different partners

in the multi- and interdisciplinary setting. By establishing transparent parameters, technical scenarios assist in ensuring that all stakeholders possess a common understanding of the project's scope and objectives. Technical scenarios can provide a unified basis for discussion, preventing misunderstandings that might arise from different disciplinary perspectives.

Secondly, technical scenarios are employed in social science studies to inform participants about the technology and products under consideration. This enables participants to make informed decisions regarding the adoption or rejection of the REFINE technology and end products. A key issue addressed by technical scenarios is the prevention of pseudo-opinions (Daamen et al., 2006; de Best-Walshofer et al., 2009). It is possible that participants may form opinions about technologies they are unfamiliar with, which may result in evaluations based on incomplete or incorrect information. By providing detailed and accurate information, technical scenarios ensure that participants can evaluate the technology based on its actual characteristics rather than relying on potentially error-prone mental models (mental representations of an object or process, the properties associated with it, and the functionality of the object or process).

In order for technical scenarios to be effective, they must provide sufficient detail to enable participants to understand the characteristics of a case, to compare it with others and to evaluate it comprehensively. This detailed information makes the obtained results valid and thus usable and relevant.

Moving from expert-oriented, detailed technical scenarios to those suitable for non-experts (laypeople) requires information tailored to the target group, regarding content, familiar usage contexts, and comprehensible wording. It should be noted that the term "layperson" implies a lack of technical knowledge. However, laypeople are "social experts" in that they evaluate innovations in terms of their personal benefits and barriers, as well as societal consequences. This enables them to serve as a valuable information source for technical designers who may not have the same perspective. In order to allow the public to realistically evaluate the novel technology, any information given as a scenario must be adapted to the comprehension abilities of the target group under investigation. For instance, a scenario designed for the general public might utilise straightforward language, visual aids and analogies to familiar technologies to facilitate the accessibility of complex technical details.

Clearly defined cases within technical scenarios allow for the evaluation of specific objects of investigation. By varying these objects, researchers can compare participants' perceptions and acceptance levels. For instance, scenarios that vary regarding specific process characteristics might be used to compare these options, helping to identify which is more acceptable to the public.

Finally, technical scenarios in social research must be distinguished from other scenario-based methods. In contrast to broader scenario planning or forecasting techniques, technical scenarios are designed to provide detailed, accurate, and context-specific information to inform decision-making processes. This distinction is crucial to ensure that the scenarios are used appropriately and effectively in research settings.

3.2 Development of Technical Scenarios

It is essential that the technical scenarios encompass all pertinent parameters of the REFINE technology, which are crucial for the assessment and evaluation of the technology by the public. These include the required production infrastructure, production processes (including resources, environmental impact, by-products, etc.), and the characteristics and potential uses of solar butanol as the end-product. Furthermore, the technical scenarios encompass various technological and process options that fall within the constraints defined for the REFINE project. These include different applications for the butanol end-product and different process options.

The development of accurate and detailed technical scenarios involves collaboration with the technical partners, who are responsible for contributing their insights, ideas, and expertise. These inputs must

then be collected, organised, and reformulated to align with different information levels (i.e., those of experts and the general public).

To elicit the knowledge and concepts of the REFINE technology from the technical partners in an efficient and productive manner, an iterative process is planned. Based on the information provided by the project proposal, initial descriptions of the technical details and process steps have been drafted. The first interviews with the UiO partners are scheduled (at time of submission of this Deliverable), during which the initial information will be refined. The revised information will then be further confirmed, enhanced, and sharpened using input from the other technical partners in their respective areas of expertise. As is the case with a truly agile process, any adjustments or specifications made to the technical development during the course of the project can be incorporated into the technical scenarios, as the societal input can be used to steer the technical development.

When the detailed technical scenarios are drawn up from the technical perspective, the information must be rephrased to be used in social science studies to inform non-experts. The aim is to decrease complexity and increase comprehensibility and accessibility. To ensure the accuracy and quality of these instructional technical descriptions, these will be tested in empirical pre-tests with non-technical experts regarding their comprehensibility, and the results will be sent back to the technical experts to review the technical accuracy.

3.3 Description of the REFINE Scenarios

In the final version of this Deliverable, the developed technical scenarios will be presented in detail.

4 Objectives of Social Science Measurement in REFINE

4.1 Integration of Social Perspectives into the Holistic Technology Development

In the case of novel products and emerging technologies such as the REFINE approach, it is of the utmost importance to consider and incorporate social perception and acceptance from the outset of the technical development process. By including acceptance factors at an early stage of the technical development process, along with technical, economic, and ecological aspects, socially accepted pathways can be identified among different technology deployment options. This approach allows for the addressing of both valid and unfounded concerns, as well as the identification and utilisation of elements that enhance acceptance, thus guiding the REFINE development in a socially accepted manner. It is therefore important to note that the social science research process delivers open results; it cannot procure acceptance but delivers important information on social perceptions that can inform the technical development and roll-out process, inform decision makers and politics, and can be the basis for communication and information strategies.

There are various cases in which the roll-out of novel technologies failed due to a lack of public (local) acceptance and perceived risks. A case that is closely related is the failed introduction of E10, an ethanol-petrol blend in Germany, which was rejected by the majority of motorists despite its potential to reduce fossil fuel consumption (Tosun, 2018). In contrast, the REFINE project aims to develop the first 4G biorefinery, which is a socially and market-placed 3G biorefinery. To this end, in REFINE the socio-political aspects are integrated with technological and industrial requirements in order to accelerate the integration and market deployment of the emerging technology. The non-technical aspects are referred to as an “information hub”, as depicted in the project overview in Figure 1.

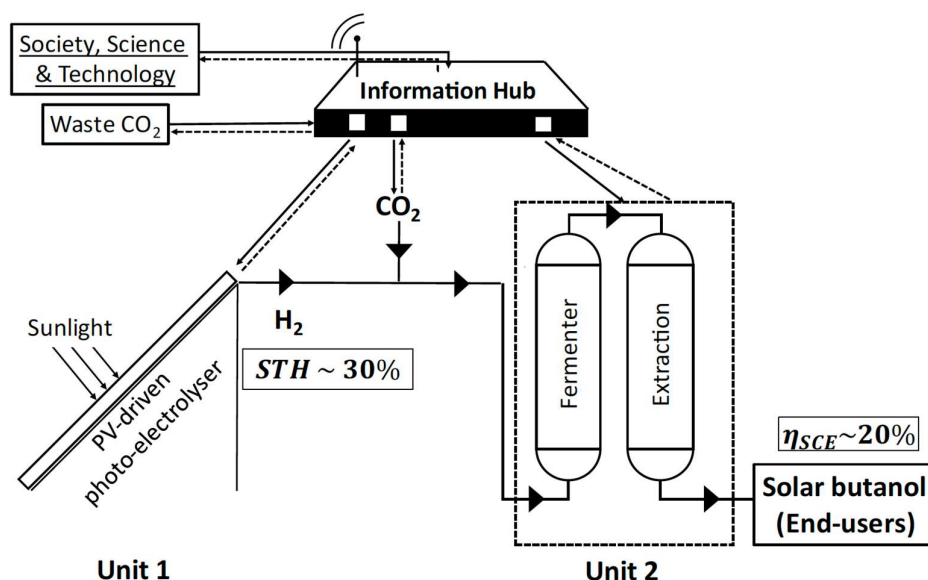


Figure 1: Schematic description of the REFINE approach.

4.2 Research Objectives

The social research conducted in WP17 (empirical assessment of social perceptions and acceptance) aims to gain insight into the public's (risk) perception, social acceptance of diverse stakeholder groups, and to derive communication and information concepts from empirical analysis. This research is informed by and based on fundamental theories and related work regarding social perceptions and acceptance of similar (energy) technologies. However, given that the social perceptions and acceptance of such novel technologies are highly context-specific, original empirical research on the REFINE technology is of the utmost importance. The research is closely linked and interrelated to the technological development, as it utilises the technical scenarios and the iterative process in which

results are frequently presented to the project consortium. Thereby, social research is informed by the technological development to fit the REFINE approach while the public feedback collected is fed back into the technical development.

In detail, the objectives of the social research regarding the REFINE approach are as follows:

- (1) To explore and identify relevant factors for (risk) perception and acceptance.
- (2) To elicit prevailing mental models, normative beliefs, and argumentation lines.
- (3) To quantify (risk) perceptions and acceptance levels.
- (4) To model influencing factors on societal acceptance.
- (5) To compare different development/roll-out options regarding societal perceptions and acceptance and assess stated preferences.
- (6) To make public requirements visible in terms of perceived benefits, costs and risks in reference to the technological characteristics.
- (7) To derive risk or adopter profiles for the examination of specific acceptance patterns.
- (8) To examine cultural-specific acceptance patterns.
- (9) And to assess information and communication needs and profiles.

In order to pursue these objectives, it is necessary to adapt the research design to the specific requirements of the REFINE project. This entails identifying the *objects of measurement*, the *target groups*, and the *methods* to be employed for *data collection*, *preparation*, and *analysis*. It is not the intention of this research framework to present a detailed plan for each individual study. Rather, it is intended to provide a framework and structure for a systematic, iterative research approach, in which one building block complements the other and the joint results capture the overall research objectives under defined quality criteria.

5 Research Objects

The research object, or the subject matter to be studied, is the starting point for the conceptualisation and design of a study. In the context of the REFINE social research, our overall aim is to gain insight into the societal perception and acceptance of the REFINE approach. Consequently, our target concepts are societal (risk) perception and acceptance, which we aim to understand and predict using a combination of quantitative and qualitative methods. In quantitative research, acceptance is our so-called *dependent variable*, which we aim to explain by *independent variables*. For a simple example, previous research indicates that the perception of benefit and the perception of barriers (independent variables) influence acceptance (dependent variable).

5.1 Target Concepts and Underlying Theories

Acceptance: The specification and definition of research variables represents a crucial stage in the overall research process, as well as in the individual study phase. The definition of acceptance as *the approval of the development, implementation, and/or use of technologies* (Dethloff, 2004) is frequently employed, but it is too general to reflect the specific nuances of this concept. This may result in misinterpretation of the empirical findings. The concept of acceptance can be defined in two ways. It can be understood as a passive approval or rejection on an attitudinal level. Alternatively, it can include an active component manifesting in behaviours such as purchasing or protesting. In order to enable the measurement of the behavioural component of acceptance with regard to technologies that are not yet marketable, it is feasible to specify acceptance as the behavioural intention for acceptance behaviour (e.g., intention to use, purchase, protest) (e.g., Davis, 1985; Huijts et al., 2012). In accordance with the “Theory of Reasoned Action” (Ajzen & Fishbein, 1980), it is posited that behavioural intention is a determining factor in actual behaviour, contingent on the circumstances.

The acceptance of energy technologies can be further categorised into three main types: socio-political, community, and market acceptance (Wüstenhagen et al., 2007).

- **Socio-political acceptance** is defined as the general approval of a technology or product by the public as well as key stakeholders and policy-makers. This encompasses mainly the attitudinal dimension.
- **Community acceptance** is related to the local approval of specific projects and siting decisions by residents and local stakeholders.
- **Market acceptance** refers to the willingness of consumers and investors to adopt and use a product.

In many cases, there is a favourable socio-political reception to the technology, yet actual purchasing behaviour fails to meet expectations. For instance, the case of E10 (Tosun, 2018) demonstrates this discrepancy. In other cases, the level of community acceptance regarding the local implementation of infrastructure is less than anticipated, particularly when socio-political acceptance is the primary consideration. This is evidenced by the occurrence of protests against wind farms (Kontogianni et al., 2014) and against the construction of power lines (Devine-Wright & Batel, 2013). This latter phenomenon is referred to as the *Not in my backyard (NIMBY) effect* (Devine-Wright, 2005), and is also relevant in the context of REFINE. In light of the NIMBY effect, it is imperative that the social science measurement in REFINE considers the community acceptance of the planned REFINE infrastructure alongside the socio-political acceptance.

With regard to the final product, solar fuels, market acceptance is of paramount importance. This is reflected in the willingness of motorists to use, buy, and pay for the fuel. Previous empirical findings on other types of alternative fuels suggest that low prices are an important precondition for their acceptance in terms of willingness to use. For example, Linzenich et al. (2019) found that low prices were a significant factor in the acceptance of ethanol as a fuel. Nevertheless, the value of precise price inquiries is debatable, given the low technology readiness level targeted in REFINE (TRL 5) and the evolving circumstances for pricing decisions by prospective customers in the future. Nevertheless, comparative willingness to pay, i.e., in comparison to existing products, and general trends provide valuable insights for the acceptance perspective on solar fuels and should therefore be collected to complement the other acceptance measures.

The most prominent acceptance theories, such as the Technology Acceptance Model (Davis, 1985) and its successors (e.g., the Unified Theory of Acceptance and Use of Technology 2 (Venkatesh, Viswanath., Thong, James, Y.L. & Xu, 2012), are not readily transferable to the REFINE context, as they explain acceptance regarding technologies in the workplace and consumer products. The "Technology Acceptance Framework" by Huijts et al. (2012) (cf. Figure 2) and the model for the acceptance of Carbon Capture and Utilization by Arning et al. (2020) (cf. Figure 3) provide a more suitable basis and starting point for the acceptance measurement in REFINE and the development of a factor space of acceptance factors, as it is described in the succeeding chapter.

Risk Perception:

In the forthcoming months, further specification of risk perceptions as a target variable will be conducted and reported in the final Deliverable version.

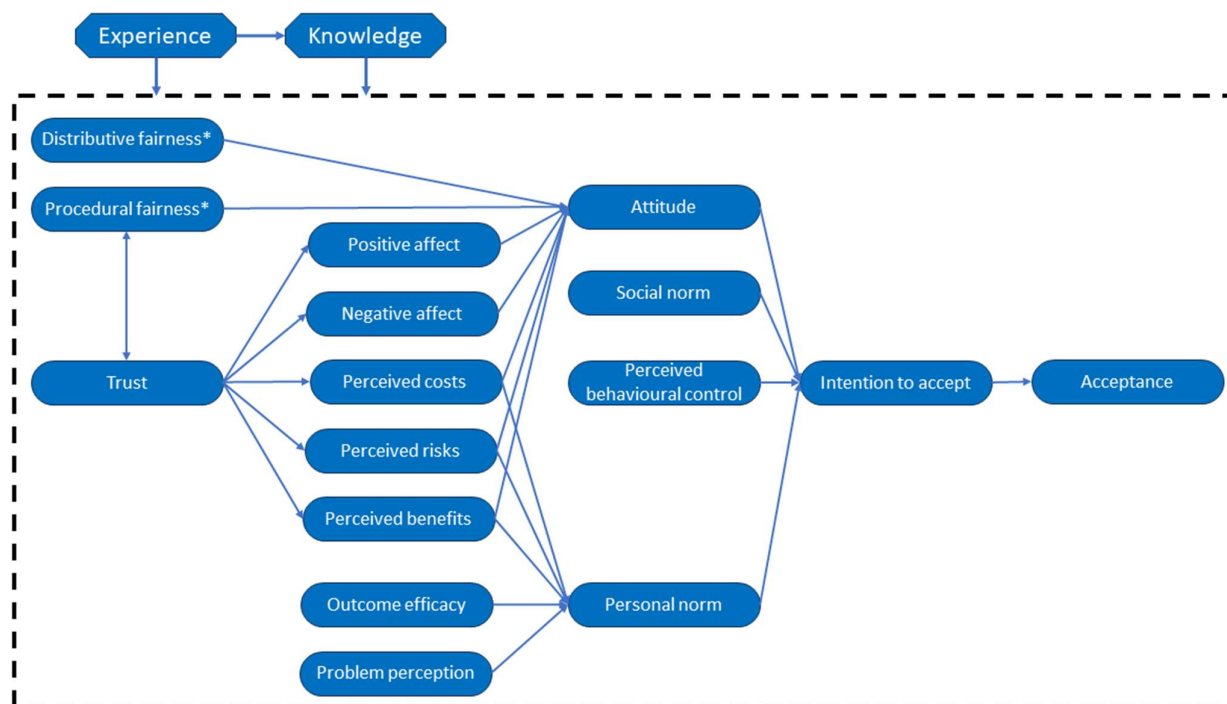


Figure 2: The Technology Acceptance Framework by Huijts et al. (2012).

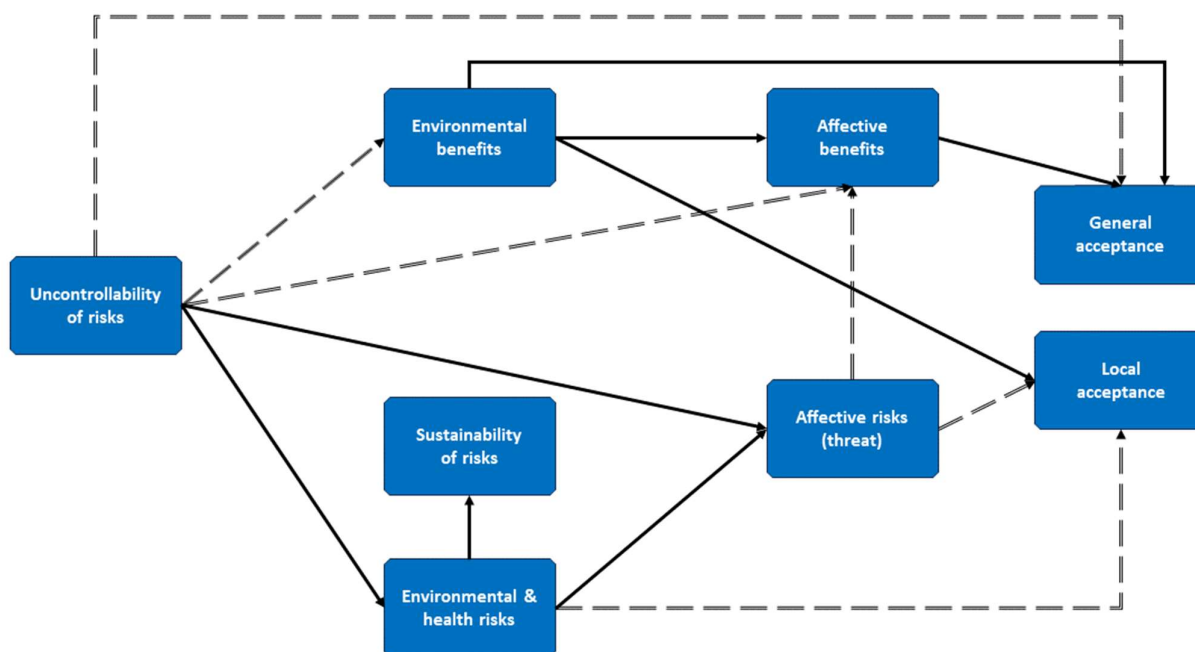


Figure 3: The CCU Acceptance Model by Arning et al. (2020) (dotted lines indicate negative effects).

Communication Needs:

In order to derive guidelines and recommendations for an effective public communication strategy, it is necessary to assess communication and information needs in addition to the valuable information that is provided by the results on acceptance and risk perceptions. While the specific definition of the target concepts is ongoing, the Lasswell communication model (Lasswell, 1971) has been identified as a suitable framework for this purpose. The Lasswell Model defines the fundamental components of the communicative process. In order to apply the aforementioned communication concepts to the

development of the REFINE project, a sixth component has been added, as depicted in Figure 4. This component, “how”, pertains to the properties of the message and its presentation. Furthermore, it is of paramount importance to consider the interrelations between the aforementioned components, for example, in the context of fitting components to a target group.

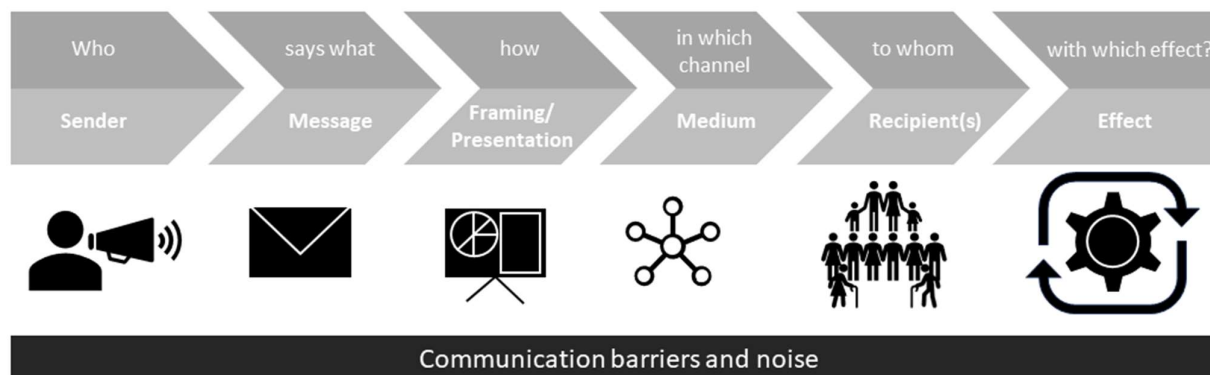


Figure 4: Adapted Communication Model by Lasswell (1971).

5.2 Identification of Acceptance-Relevant Factors and Their Modelling

Although the target concepts can be identified at this stage, a list of potentially relevant acceptance factors (the *independent variables*), such as perceived benefits, barriers, risks, and individual factors, is constructed during the iterative mixed-methods approach. This we often call a factor space to emphasize the diversity of the included factors. Qualitative research methods facilitate the comprehensive identification of acceptance factors, relevant beliefs and arguments, perceived risks, and benefits. These can then be confirmed and quantified using quantitative research methods. Further details regarding this mixed-methods research approach can be found in Section 7 of this Deliverable. As a starting point, basic theories of acceptance and risk perception (see above) as well as related empirical work in this area can be utilised. However, given the context-sensitivity of acceptance and societal perceptions, previous findings cannot simply be transferred to the new object of investigation; they must be re-examined in the REFINE context. Nevertheless, fundamental principles for the selection and development of the factor space can be established at this stage.

This includes the integration of *human factors*, such as psychometric constructs and attitudinal variables, as potential explanatory variables. Previous findings and theories have emphasised the explanatory power of personality factors, such as individual risk propensity and innovativeness, attitudes, such as environmental awareness and self-efficacy in dealing with technology, and knowledge and experiences.

Given the apparent lack of general awareness and knowledge about alternative fuels (e.g., Linzenich et al., 2019, 2023; Nyári et al., 2024), and the REFINE approach's innovative nature, it is also crucial to assess and elicit prevailing mental models and beliefs about the novel technology. Mental models describe cognitive representations of objects and processes that individuals use to make sense of the world around them (Gentner & Stevens, 2014). Mental models help to simplify complexity. With regard to novel technologies and processes, mental models are often based on analogies to known technologies or natural processes. While mental models assist individuals in comprehending and interacting with the world, including influencing acceptance decisions, they can be erroneous and misleading (Byrne & Johnson-Laird, 2009). Therefore, identifying erroneous mental models is a crucial research objective to comprehend perceptions and the formation of acceptance regarding REFINE.

Similarly, it is crucial to incorporate not only logical arguments and rational perceptions of benefits and limitations, but also emotional responses and affective evaluations of the REFINE approach (e.g., Huijts et al., 2012; Simons et al., 2021; Zaunbrecher et al., 2018).

In order to adopt an appropriate methodological approach, it is essential to consider both, factors of acceptance and factors of non-acceptance. This entails assessing perceived benefits as well as perceived barriers and risks. The perception of negative aspects is not inversely related to the perception of positive aspects. Individuals can concurrently perceive the utility and advantages of a technology as strong, while also being concerned about barriers and significant risks (Arning et al., 2020; Siegrist, 2000). In some cases, characteristics of a technology raise conflicting aspects, so that individuals need to weigh the negative and positive aspects. This is exemplified by instances where the use of less sustainable materials could enhance the efficiency of a technology, resulting in a trade-off between sustainability and efficiency. Another example is the typical consumer trade-off between price and more sustainable products. Identifying such trade-offs in the formation of acceptance is crucial for comprehending societal perceptions. Consequently, in REFINE, both perceived advantages and perceived barriers and risks will be considered.

The operationalisation of the variables for the quantitative studies, namely the precise measurement instructions, such as the development and selection of measurement items and scales, must be based on a structured literature review of related work on similar energy and infrastructure technologies, in addition to the qualitative results. This must be optimised during the iterative research process. In the final Deliverable D16.1, the measurement framework will be able to report on the interim status of the factor space and the possible operationalisations of the variables. However, as in an agile and iterative process, further optimisation is most likely necessary until the end of the social science measurement (WP17 and WP18).

5.3 Objects of Evaluation

The object of evaluation is the REFINE approach. Correspondingly, the instructional base for the participants in the social science studies is the technical scenarios. It is important that the social perspective takes a holistic view and considers acceptance over the entire life cycle of novel technologies and products, which encompasses the associated production infrastructure, the production process itself, and finally, the end product. The development and description of the technical scenarios is covered in Section 3 of this Deliverable. At this juncture, it is imperative to differentiate the process steps, infrastructure, and end products. This differentiation is essential for the purpose of conducting social research in a manner that allows for a clear assessment of the sources and reasons for (non-)acceptance along the product life cycle.

6 Target Groups

Next, it is necessary to define the target groups (or *target population*) of the social science measurement and to specify the criteria for the recruitment of participants to the final samples. In particular, the social research will focus on perceptions and acceptance in the general public, with a specific focus on the European adult population. In addition, it is important to consider the views of other key stakeholders, including experts and decision makers.

6.1 Public Samples

A key quality criterion for social science studies is the sample representativeness. This refers to the extent to which a sample accurately reflects the characteristics of the target population from which it is drawn (Döring, 2023). A representative sample ensures that the findings from the sample can be generalised to the broader population, i.e. that inferences can be made about the target population based on the data collected from the sample. Key aspects of representativeness are proportionality, diversity, and the size of the sample. The sample should include individuals with a range of characteristics (e.g., age, gender, education level) that exist in the target population. For this, the sample should maintain similar proportions of the various subgroups as found in the population. For instance, if a population is 50% female and 50% male, a representative sample should ideally reflect this ratio. To achieve this, the size of the sample must be sufficient to capture the diversity and complexity of the population, reducing the margin of error and increasing the reliability of the results.

Nevertheless, in practice, it is infeasible to achieve perfect representativeness of the public. An example of an optimal sample would be a randomly selected subset drawn from a comprehensive list of all population members (e.g., all individuals residing in a country). It is also important to note that the individuals who choose not to participate in the study (the non-respondents) should be randomly selected. However, in practice, they may possess different characteristics compared to those who do participate, which is known as non-response bias. Additionally, some individuals may lack access to the sample, such as those who do not possess the necessary technical devices and infrastructure to participate in an online survey, or who do not have a landline phone or official license to be on official population lists. Furthermore, in practical research, it is not always possible to identify the specific characteristics that are relevant to the research question and that should be represented in the sample. Practical constraints, such as time, budget, and logistics, also limit the achievability of a representative sample. Consequently, perfect sample representativeness is rather a theoretical construct that can be discussed in theory but not necessarily achieved in practice. In REFINE, we do not aim to provide exact proportions of individuals who would accept the REFINE approach – as is the case in election polls, which aim to determine the proportion of voters who support each specific party. Instead, we aim to interrelate dependent and independent variables in order to gain insight into societal perception and acceptance in relation to the REFINE approach. Consequently, social science research in REFINE should endeavour to achieve appropriate samples for the given objectives.

In initial exploratory studies, particularly those employing qualitative methods, but also in exploratory quantitative pre-studies, small samples are often sufficient (Döring, 2023). The most viable recruitment strategies for these studies are: (1) selective recruitment (primarily for expert recruitment), (2) convenience sampling through the exploitation of social networks of the authors and other accessible distribution channels (e.g., social media, mailing lists, public notices), and (3) snowball sampling (where initial participants recruit additional participants from their networks, creating a growing "snowball" effect). The utilisation of these samples enables qualitative and quantitative pre-studies to identify a comprehensive range of factors and to preliminarily test their relevance to the acceptance of the REFINE approach.

In the main quantitative studies, it is aimed to include a diverse range of participants, with the utilisation of quotas on specific socio-demographic characteristics. A quota is defined as a predefined number (or proportion) of participants with a specific characteristic that should be present in the sample. Such quotas, for instance on age, ensure that individuals from all age groups are included in the sample and in a similar proportion to their representation in the population. In practice, this is achieved by recruiting participants until all quota groups are filled, thereby also excluding those participants who would exceed the quota in order to prevent the sample from being distorted by an oversampling of a specific group of the population.

The majority of variables examined in REFINE are latent variables, which are not directly observable. However, quotas must utilise manifest characteristics of which the proportion can be compared to the population proportion (which therefore needs to be known). For example, regional diversity is one important aspect. In German studies, participants should be selected from all 16 federal states or at least from northern, southern, eastern, and western regions, given the potential for regional diversity. Other main socio-demographic characteristics that can be used to describe the population are age, gender, and education level. Socio-economic status presents another important factor to describe individuals of the public. However, this is much more challenging to quantify and evaluate, particularly in the context of international comparisons. As a result, it has been dismissed from the REFINE research. As an illustration, in the appendix, Table 1 delineates the quota targets for the German population with respect to age, gender, education, and region, based on data sets from the Federal Statistical Office of Germany (Destatis, 2024). With respect to the evaluation of the end-product, solar fuels, special focus should be put on motorists and potentially future motorists, in order to focus on a group that has a vested interest in using and purchasing solar fuels.

6.2 Stakeholder Input

For an appropriate approach to the objectives of the REFINE social science measurement, it is essential to identify and investigate a number of additional stakeholder groups, in addition to the public. These stakeholder groups may be designated as "experts" in related domains, such as experts on the technical process, but also experts on the utilisation of butanol as the end-product of the REFINE process when it is employed as a platform chemical, or (legislative) decision-makers in the technology roll-out. In order to identify key stakeholders for REFINE whose input could prove valuable to the project, a stakeholder map will be created. This map will illustrate the influence and interest of identified stakeholder groups in order to select important candidates for expert interviews. To create this map, the expertise of the technical partners from work packages 2 to 15 will be drawn upon, and questions regarding key stakeholders will be included in the data collection as part of the development of the technical scenarios. The stakeholder map will be included in the final Deliverable.

6.3 Target Countries

It is crucial to acknowledge the existence of significant cultural divergences in the reception of novel technologies. These divergences may originate from varying norms, specific practical conditions (e.g., infrastructure characteristics, mobility needs), diverging legislations, and more. The influence of these differences on the acceptance of alternative fuels is demonstrated by Arning et al. (2023). In comparing the acceptance of sustainable aviation fuels (specifically, CO₂-based jet fuels, or e-kerosene), the Norwegian perspective exhibited a notable divergence from the German, Dutch, and Spanish perspectives. The authors posit that these discrepancies can be attributed to the necessity of air travel in a geographically expansive and sparsely populated nation. Furthermore, the Eurobarometer polls, which survey the populations of the member states of the European Union (EU) on a regular basis regarding a range of topics, demonstrate the diversity of attitudes present in Europe, for instance with regard to climate change (European Commission, 2023a) and energy supply (European Commission, 2023b).

Given the unfeasibility of data collection in all European countries within the REFINE project, it is essential to identify target countries for social science measurement with precision. This approach enables the generation of results that can be transferred to a European perspective, while also facilitating the examination of specific national differences and their underlying causes. The final selection of target countries for the main quantitative studies is the subject of ongoing research, which will be finalised prior to the commencement of the international studies. The selection of target countries will be informed by findings in related contexts (e.g., Arning et al., 2023; European Commission, 2023a, 2023b), a review of specific conditions in European countries (e.g., specific legislation, mobility needs, existing industries), and the involvement of project partners, who will contribute their knowledge about technology reception in their country of origin. Should the need arise, an exploratory media analysis could be employed to provide further insight.

The majority of pre-studies will focus on the German population. This decision is driven by practical and economic considerations (with the social science research team situated in Germany), as well as the suitability of Germany as a sample country. Germany is the most populated country in the EU, offering a sizeable potential market for solar fuels as an end-consumer product. Additionally, Germany hosts a significant automotive and chemical industry, which may be of importance regarding acceptance and risk perceptions. Furthermore, the German public has historically demonstrated a selective approach to energy technologies, opposing and protesting against certain developments they find unacceptable (e.g. the E10 boycott or the nuclear phase-out). Consequently, the utilisation of Germany as a case study may facilitate the identification of potential impediments and points of conflict.

In contrast to the data collection aimed at the public, the stakeholder interviews will not be geographically limited.

7 The Mixed-Methods Research Process

The social sciences employ two principal methods: qualitative and quantitative. The long-standing debate concerning the relative merits of these two approaches is now largely considered outdated (Döring, 2023). Each paradigm has its own set of advantages and disadvantages, which can be effectively combined in the context of REFINE social research in order to capitalise on the strengths and mitigate the weaknesses.

Qualitative social science research is intentionally less structured in order to facilitate the emergence of unexpected findings. Qualitative research is best suited to answering open research questions and focuses on detailed and comprehensive analyses of a small number of cases. In REFINE, qualitative methods can provide insights into potential acceptance factors, perceived risks and benefits. They can also elicit insights into argumentative lines, normative beliefs, and mental models. Qualitative procedures are particularly useful for gaining in-depth insights from experts. Thus, qualitative methods advance *understanding*.

In contrast, quantitative research measures the characteristics of variables from a larger sample of subjects, statistically analyses the measured values and their interrelations, and tests hypotheses. It is therefore recommended that quantitative methods are employed to confirm hypotheses derived from qualitative studies, thus providing *explanation*. The findings from quantitative studies that adhere to the requisite quality criteria may be used to infer about the larger population. The quantitative studies conducted as part of the REFINE project will be employed to quantify the levels of acceptance and to examine the perceptions held by society at large. Furthermore, the interrelationship between the various factors influencing acceptance will be investigated, as will the differences between different groups. In addition, the project will examine the impact of different roll-out scenarios and differentiate between the various patterns of acceptance.

In the *mixed methods* paradigm, which describes the systematic combination of qualitative and quantitative approaches, qualitative approaches are typically used as pre-studies to quantitative studies. However, qualitative approaches can also be employed retrospectively to elucidate specific quantitative findings. Social science measurement in REFINE will utilise a combination of qualitative and quantitative studies to optimally address the research objectives.

7.1 Qualitative Methods

Qualitative data will be collected through interviews and focus groups with members of the public and experts in the field. Additionally, media analysis may be employed at specific points to inform about the current media presentation and reception of solar fuels and related technologies. Besides these data collection methods, the data preparation and analysis method are described in the following.

7.1.1 Interviews

Interviews permit researchers to obtain detailed and nuanced information directly from participants. By establishing a conversational atmosphere, interviews can elicit rich, detailed data, and even more reticent respondents typically become more forthcoming. Through open-ended questioning, respondents can share their experiences, perceptions, and insights in their own words (Flick, 2005). Interviews can be structured, semi-structured, or unstructured. A semi-structured approach combines the advantages of unstructured interviews, which allow for the collection of rich data and the pursuit of detailed information, with the assurance that all essential questions are posed, and respondents are instructed in a uniform manner to ensure comparability. This is achieved through the use of an interview guideline that delineates the primary instructions and questions while allowing for the exploration of more nuanced topics and the utilisation of open-ended questions.

7.1.2 Focus Groups

A focus group is defined as a group discussion regarding a specific topic, which is led by a moderator. The focus group method is particularly suited for the uncovering of multi-layered causes of behaviour or motives, or for the generation of a multitude of ideas. This is due to the fact that the group process

allows for a greater potential for ideas to be exploited than is the case with individuals. Additionally, focus group discussions are more akin to natural dialogue, which fosters greater openness and authenticity in participants' responses (Vogl, 2014). The discursive exchange prompts participants to refine their arguments and elucidate underlying attitudes. Focus groups are particularly effective when employed in conjunction with interviews, as they facilitate the identification of a comprehensive range of aspects (Scheufele & Engelmann, 2009).

7.1.3 Data Preparation

Audio and, where appropriate, video recordings will be made of interviews and focus groups in order to capture the complete context and nuances of participants' responses. These recordings will then be transcribed verbatim into text, with personal identifiers removed in order to maintain the anonymity of the participants. It should be noted that transcripts may contain much detail beyond the spoken words, including paraverbal aspects and non-verbal actions. In REFINE, minimalistic transcripts are sufficient; the focus is on the spoken content to capture the meaning that the participant intended to convey, with only essential additional details (minimal transcript convention, Selting et al., 2009). These anonymous transcripts form the basis for further analysis, allowing researchers to examine the data in a systematic manner while protecting the confidentiality of those involved.

7.1.4 Qualitative Content Analysis

Qualitative content analysis is a systematic, rule-based approach used to analyse textual material, such as the transcripts of interviews and focus groups. The central instrument in this method is the category system, which is crucial for structuring and summarising the content. Categories can be developed inductively, derived directly from the material without pre-existing theoretical influences (data-driven or bottom-up approach), or deductively, based on existing theories (top-down). Mayring (2010) outlines three fundamental analytical techniques: summary, explication, and structuring. These techniques can be employed independently or in a combined manner, with further sub-differentiations. The process involves defining the analysis units, structuring the dimensions and attributes, followed by iterative loops of category system application and revision. In these iterative loops, the text segments, namely the transcribed statements made by the participants, are assigned to categories. This process culminates in a structured overview of the content of the material in relation to the research question. The ultimate objective is to abstract the material progressively, enabling conclusions that transcend the immediate data. The systematic, rule-based approach ensures intersubjective verifiability (Fenzl & Mayring, 2014).

7.1.5 Media Analysis

Media analysis constitutes one particular application of content analysis. In general, media analysis is employed to examine and interpret the content, structure, and impact of media, including newspapers, television programmes, social media, films, and advertisements. This process involves identifying and categorising themes, narratives, and representations within media texts, with the aim of understanding the underlying messages and ideologies (Altheide & Schneider, 2012). The material for this content analysis is a systematic selection of published media articles, for example, newspaper articles. Media analysis can be a useful tool for refining our understanding of how solar fuels and related technologies are currently presented and framed in media. Furthermore, readers' comments, for instance in online newspapers, can also be analysed to gain insights into the reception of such writings about the REFINE topic. However, it is important to note that the findings from media analysis cannot be interchangeably used with findings from participatory data collections of interviews, questionnaires, and the like. Rather, they can be used as a supplement to those with the special advantage of media analysis being a non-reactive data collection method, i.e. the data collection situation does not influence the observations.

7.2 Quantitative Methods

The primary quantitative data collection methodology employed in the social research within REFINE will be the administration of online questionnaires, which will be designed in a variety of formats to accommodate diverse analytical techniques.

7.2.1 Online Questionnaires

The use of online surveys as a means of gathering structured data has become the most prevalent technique in the field of survey research (Nina Baur & Blasius, 2019). Online surveys are distributed via links, email, social messengers and so forth, and may be answered by the participants using different devices (computers, tablets, mobile phones), which increases accessibility. Furthermore, they permit the simple collection of data and are highly adaptable in design, allowing for the implementation of complex survey designs, such as automated filters, randomisation of quasi-experimental set-ups, and the integration of various media (e.g., high-resolution images, videos, and mouse-overs for detailed explanations). In addition to their efficiency in terms of speed and accessibility for the participants, it should be noted that the manual transmission of responses is eliminated as a source of error. In REFINE, only anonymous data will be collected from the participants and only after their informed consent (please see also Section 2.3 for further information on the privacy protection of the participants). The technical scenarios will be used to instruct the participants about the REFINE approach (*scenario-based* questionnaires).

7.2.2 Eliciting Stated Preferences

In addition to the conventional survey methods, which rely on rating scales to assess the participants' level of agreement with specific statements, further test methods may be incorporated into the REFINE social measurement process to elicit stated preferences. While rating scales are highly useful and flexible in most application cases, in specific instances, methods such as Maximum Difference Scaling and Choice-Based Conjoint may yield more accurate and detailed findings. These methods are more suited to understanding preferences and capturing trade-offs among different attributes or options. Conjoint experiments (or Discrete Choice Experiments) resemble more closely actual real-world decision-making processes than traditional rating or ranking methods. In real-world decision-making we cannot evaluate each factor independently, but we need to weigh benefits and barriers. Using Conjoint Analysis, we can simulate these decision-making processes, thereby providing more realistic and actionable insights (Bansak et al., 2021; Sawtooth Software, 2017).

- **Maximum Difference Scaling (MaxDiff)**, also known as Best-Worst Scaling, is an appropriate method for comparing the relative importance of multiple items or of preferences for multiple characteristics. Participants are presented with sets of items and asked to indicate the most and least preferred (or most and least important) items in each set. This approach reduces the bias often found in rating scales and provides more discriminative and reliable data (Sawtooth, 2008). The advantages of MaxDiff include its simplicity for respondents, its ability to handle a large number of items without overwhelming participants, and its provision of interval-level data that can be used for various statistical analyses (Sawtooth, 2008). During the survey process, participants typically undergo a series of comparisons where each set contains a subset of the total items, ensuring comprehensive coverage and robust data on preferences and importance. For example, Arning et al. (2021) employed MaxDiff in the context of e-fuels to ascertain the relative importance of the benefits of CCU and e-fuels and to derive different acceptance profiles.
- **Choice-Based Conjoint (CBC)** was initially employed primarily in market research but has since been demonstrated to have significant merit in the study of human decision-making regarding technologies (Arning, 2017; Naous & Legner, 2018). The CBC technique presents respondents with a series of hypothetical products or services, each defined by a set of attributes with varying levels and asks them to choose their preferred options. This approach allows the relative importance of each attribute and the trade-offs that respondents are willing to make to be identified. The advantages of CBC include its capacity to handle complex, multi-attribute decisions and its generation of choice data that can be analysed using advanced statistical models to predict market share and customer preferences. The utility of Choice-Based Conjoint (CBC) analysis in the context of alternative fuel acceptance research has been demonstrated by Linzenich et al. (2019, 2022).

7.2.3 Data Preparation and Data Cleaning

The data obtained from online surveys (including MaxDiff and Conjoint Data, which are embedded into online questionnaires) is readily accessible. Nevertheless, data preparation, particularly data cleaning, is a pivotal stage in the process, as it serves to guarantee the accuracy, reliability, and validity of the data.

In accordance with the quality criteria detailed in Section 2.2, the data preparation process comprises of two principal stages as depicted in Figure 5.

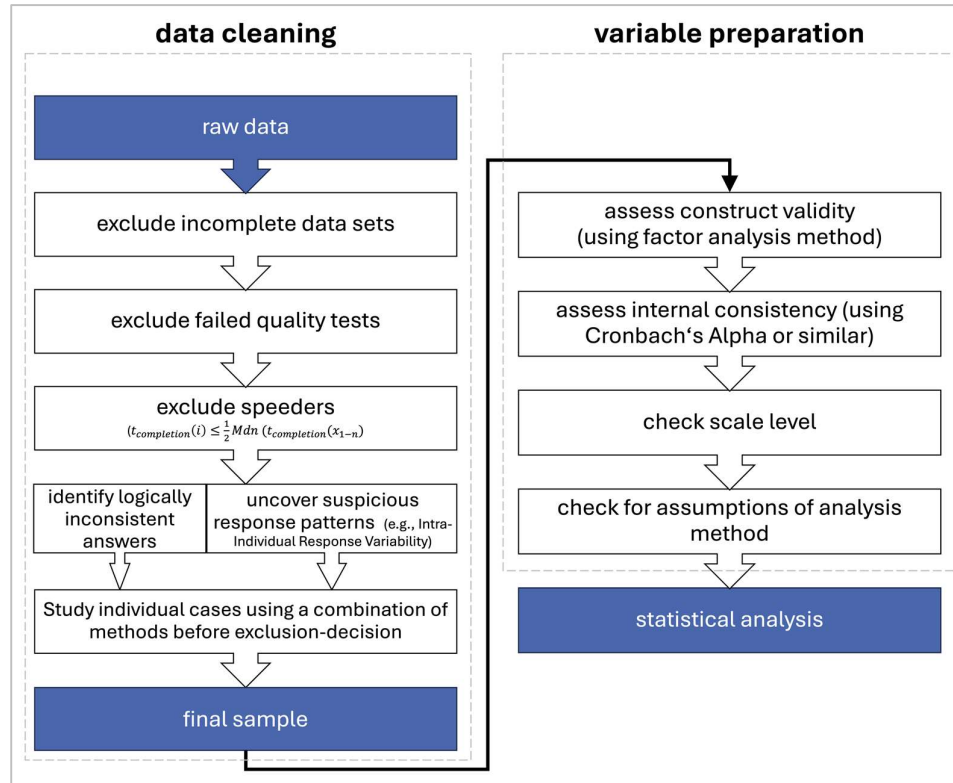


Figure 5: REFINe data cleaning and preparation process.

The initial stage of the data preparation process entails the assessment of the quality of the data sets, specifically the responses provided by the participants. Any participants who fail to meet the requisite quality standards will be excluded from the data set. This encompasses incomplete data sets, speeders, and responses of an unsatisfactory quality. Incomplete data sets are excluded, as many analysis techniques are unable to process missing data points. During the survey, participants are prompted to complete any unanswered items, thus ensuring that no data points are inadvertently omitted. A moderate speed criterion is set, whereby participants will be excluded if they are faster than half of the median of the completion time (Leiner, 2019). It may be reasonably assumed that these participants did not have sufficient time to read the instructions and items carefully and to give thoughtful consideration to their answers. Furthermore, the consistency and validity of the responses are verified. For example, surveys include questions designed to assess the quality of the data, such as "Please check the answer option 'I agree'." Participants who fail to read and correctly execute these requests are excluded. Additionally, reverse-worded items have been incorporated into the questionnaire scales, which will be employed to ascertain significant inconsistencies in individual responses. Furthermore, statistical techniques are employed to identify so-called "straightliners" and other suspicious response patterns and outliers, such as intra-individual response variability and the Mahalanobis Distance. Intra-individual response variability can be used to identify inconsistent responses from the same individual, while Mahalanobis Distance helps detect and remove multivariate outliers by measuring how far a data

point deviates from the mean, accounting for correlations between variables. This is done in order to identify suspicious cases for further investigation – instead of direct exclusion (Leiner, 2019). Instead, these techniques are used in conjunction with one another, and data sets are excluded conservatively in order to avoid the exclusion of genuine data sets and the introduction of bias (Curran, 2016).

Secondly, it is necessary to conduct a quality check of the scales and indices prior to calculation. This includes an assessment of internal consistency as an important reliability measure (Cronbach's Alpha > 0.7 (> 0.6 with a limited number of items on the scale, including reverse-worded items)). Furthermore, it is essential to verify the construct validity using factor analysis techniques (Field, 2013).

7.2.4 Statistical Analyses

A variety of statistical techniques are employed in order to answer the respective research questions. Prior to the application of statistical tests, the respective statistical requirements are checked. On the one hand, this pertains to the scale level at which the variables are measured. A multitude of powerful statistical techniques can only be employed if a high level of measurement is assumed. Likert scales are regarded as interval-scaled data if the quality checks permit the calculation of a scale value. In the case of variables with a lower scale (such as ordinal or nominal variables, including age and education level), alternative methods will be employed. In addition, the prerequisites for the application of specific statistical procedures are also verified. In many cases, this concerns the normality of the data distribution, or in analyses of variance (ANOVA), the homogeneity of variance. In the event that these assumptions are violated, and the procedures cannot be considered robust against these violations, non-parametric test procedures are employed.

In hypothesis testing, the significance level (α) is set at 5%. A p-value of less than 0.05 is indicative of a statistically significant result. This threshold indicates that there is a 5% probability of erroneously concluding that an observed effect or difference is genuine when it could be attributed to random chance (a phenomenon known as a Type I error). In other words, we accept that an effect can be considered real with 95% confidence. In addition to the calculation of test significance, effect sizes will be determined. These measures quantify the strength or magnitude of a relationship or difference, irrespective of the sample size. In contrast to the p-value, which indicates the existence of an effect, effect sizes provide information regarding the magnitude of the effect, thereby facilitating an understanding of the practical significance of the result. For example, in samples of a large size, a statistically significant p-value may be observed for effects that are relatively minor, whereas in smaller samples, such effects may not be detected. The interpretation of the effect size as small, medium, or large is carried out using predefined, standardized thresholds. Furthermore, a power analysis will be employed to ascertain whether the sample size is sufficient to detect meaningful effects.

Table 1: An overview of statistical tests, assumptions, measures of effect size including established thresholds, and potential nonparametric alternatives.

Test	Assumptions	Measure of effect size	Nonparametric alternative(s)
t-test	Independence, Normality, Homogeneity of variance	Cohen's d <i>small effect: $d = 0.2$</i> <i>medium effect: $d = 0.5$</i> <i>large effect: $d = 0.8$</i>	<u>Independent:</u> Mann-Whitney Test <u>Paired:</u> Wilcoxon Signed Rank Test
ANOVA	Independence, Sphericity*, Normality, Homogeneity of variance**	Eta squared <i>small effect: $\eta^2 = 0.01$</i> <i>medium effect: $\eta^2 = 0.06$</i> <i>large effect: $\eta^2 = 0.14$</i>	<u>Between-groups:</u> Kruskal-Wallis Test <u>Repeated-measures:</u> Friedman Test

Pearson correlation	Independence, Normality, Linearity, Homogeneity of variance	Pearson's r <i>small effect: $r = .10$</i> <i>medium effect: $r = .30$</i> <i>large effect: $r = .50$</i>	Spearman's Rank Order Correlation
Multiple regression	Independence, Normality, Linearity, Homogeneity of variance, No multicollinearity, No singularity, Independence of Residuals	<u>Variables:</u> standardised (beta), unstandardised (B) <u>Overall Model:</u> R^2 (R-squared), Adjusted R^2	None

*Repeated measures design requires Sphericity i.e., the equality of variances of the differences between treatment levels (e.g., Field, 2013, p.428)

**ANOVA decently robust with equal sample sizes (e.g., Field, 2013, p.324)

Table 1 provides an overview of the fundamental inferential statistical tests, their data and scale requirements, their effect sizes, and non-parametric alternatives.

Mainly, in REFINE, multivariate analysis methods will be employed, which are statistical techniques that simultaneously analyse multiple variables (Hair et al., 2014).

- **ANOVA procedures** will be employed to ascertain whether there are statistically significant differences between the means of multiple groups (Field, 2013).
- **Regression analysis** is employed to examine the relationship between a dependent variable and one or more independent variables. In regression analysis, a linear model is developed to predict the dependent variable from the independent variables. The goodness of fit of the model can be evaluated by calculating R^2 . Regression analysis enables the strength and nature of the relationship between each independent variable and the dependent variable to be understood.
- **Cluster analysis** is a statistical technique that groups participants into segments (or *clusters*) that are similar to each other with respect to the variables selected for analysis. The objective of cluster analysis is to ensure that the participants segmented into one group are similar to each other and differ from the cases in the other groups (Hair et al., 2014). This approach enables the discovery of unknown structures and patterns based on empirical data. A variety of clustering methods are available for analysing survey data, including hierarchical clustering and k-means clustering, which employ different similarity and dissimilarity measures. Latent Class Analysis provides a framework for cluster analysis using data from Choice-based Conjoint analysis (Sawtooth Software, 2017).
- **Structural equation modelling (SEM)** is a statistical technique that is used to analyse the relationships between variables. It is similar to regression analysis in that it can be used to examine the strength of relationships between variables, but it is capable of analysing much more complex relationships. It functions in an integrated manner, employing elements of factor analysis and multiple regression to develop an appropriate measurement model and to test the relationships between the constructs. This approach allows for the direct incorporation of unobservable (latent) variables through the use of indicator variables, which is a notable advantage over other techniques such as calculating scales from multiple items separately before the analysis. Structural equation modelling integrates this step, facilitating the accounting for measurement error in observed variables (Hair Jr et al., 2011). Moreover, SEM enables the modelling of not only the direct or indirect relationships between multiple

independent variables and one single dependent variable, but also the relationships between multiple dependent and multiple independent variables. This is illustrated in Figure 6.

As advanced multivariate analysis techniques, structural equation modelling and cluster analysis are well-suited to detect and visualize complex relationships between acceptance and perception factors in the context of the REFINE social science measurement.

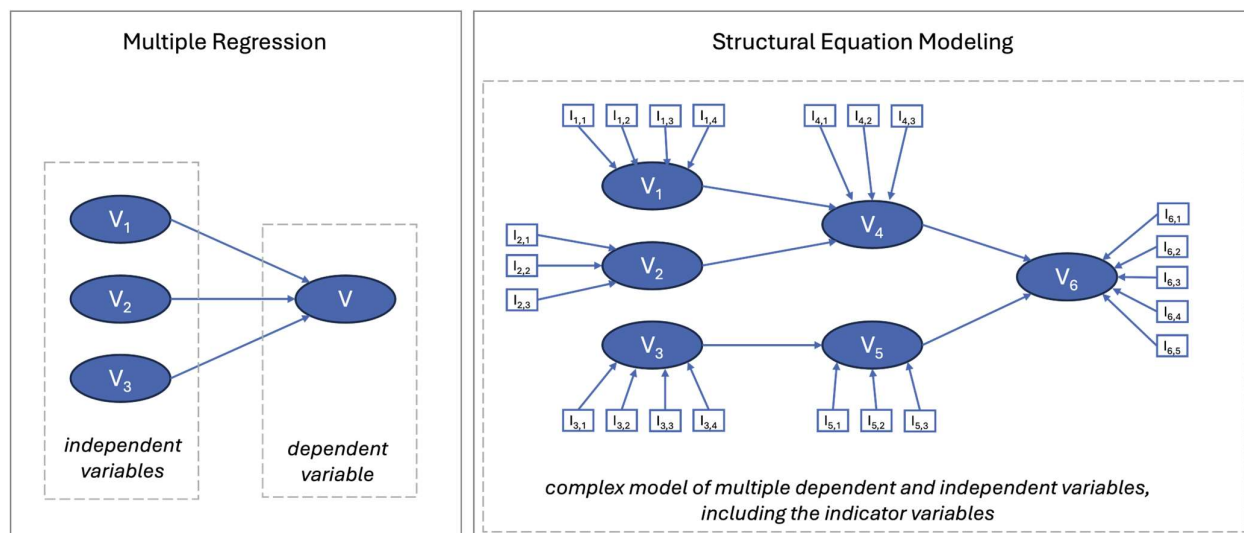


Figure 6: Schematic comparison of the model complexity between multiple regression and structural equation modelling.

8 Conclusion

Social research in REFINE aims to gain insights into the public acceptance and societal (risk) perceptions, and communication and information needs regarding the REFINE approach, as well as to examine the perceptions of other relevant stakeholders. This Deliverable presents a social science measurement framework that has been tailored to meet the specific needs and objectives of the REFINE project. The framework defines the quality criteria for REFINE's social research and outlines the importance and planned development of technical scenarios that will serve as an instructional basis to participants in the social science studies (these technical scenarios will be detailed in the final Deliverable). After refining the objectives of the social science measurement in REFINE, the framework offers detailed insights into the targeted research objects, underlying theories, research samples, and the qualitative and quantitative empirical methods suitable for the application in REFINE. This framework thus serves as a foundation for the design of each individual study within REFINE and for the coordination of the multiple studies in relation to each other.

As the Deliverable is finalised, in parallel to the first social studies, additional details will be specified for practical application. These include the selection and description of measurement scales, the choice of European target countries for comparative analysis, and the creation of a stakeholder map to guide the selection of expert interview partners.

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