D2.2

R1.2: Causal diagram: methodology and results

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EXECUTIVE SUMMARY

The objective of this task, and its associated deliverable, is to build a Causal Diagram for the electricity consumption at households including the reasons that affect consumer participation in EE, DR, ES and DG actions. The original plan consisted in conducting a face to face Delphi Method where a group of experts covering at least one expert from all the subjects identified in Task T1.3.

However, the COVID19 knocked on all our doors and what initially was thought to be a physical approach has been converted to an online endeavour. To this purpose, we expanded the aspects of the energy transition to be studied. In the DoA we were only concerned with the electrification of the transport and heating sector, while in the current deliverable we were more ambitious to expand the study to the energy efficiency sector and to the flexibility markets. With all of these four aspects of the energy transition, we created an online activity based on fictional scenarios in which recruited experts (N=33) had to identify the overarching determinants that affect or load over constructs related to making an investment decision.

The qualitative information collected was analysed using the universal psychological needs, such as competence, relatedness, popularity, stimulation, meaning, security, or autonomy (many of them very much connected to the self-determination theory) as a framework to create a common glossary of 32 terms. The glossary is made up of two levels. The top tier level is all about the psychological needs plus one theme related to financial factors. The second tier is related to the determinants in each category.

With the glossary created, the research team drafted a relationship diagram, very close to a causal diagram, of the determinants that impact an investment decision having in mind the different end-user archetypes/profiles that may be present in households. Therefore, for each profile/archetype identified, the research team selected the most relevant determinants that can make a person or a family to finally invest money and time on one of the four different aspects of the energy transition identified. To this aim, the stages of changes inspired on the transtheoretical model of behaviour change were used. The results open space for further refinement and validation. Therefore, most of this work and outcomes will be further explored in the following task of the WP3 which is the creation of the causal model.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Long text
EE	Energy Efficiency (including energy sufficiency)
DR	Demand Response
DG	Distributed Generation
ES	Electrification of Services
EV	Electric Vehicle
LFM	Local Flexibility Markets
LEM	Local Energy Market
DSO	Distribution System Operators
DHW	Domestic Hot Water
ToU	Time of Use
TTM	Transtheoretical model

1. Introduction

In this deliverable we will present the methodology used to build the causal diagram of the reasons that affect energy investment on the energy transition. The causal diagram is a directed acyclic graph in which each node is an internal or external variable that is related to an investment decision and the relation between nodes informs about the causal relations between the variables. Causal models are built based on expert knowledge. To this end, we have defined a methodology loselly based on the Delphi Method to retrieve the knowledge of a panel of experts and built the causal diagram. The next sections detailed the methodology used:

- Section 2 presents the methodology used.
- Section 3 includes a review of the state of the art on the aspects of the energy transition.
- Section 4 describes a set of fictional scenarios used to retrieve the determinants that affect the investment decisions.
- Section 5 defines a series of online activities carried out.
- Section 6 explains the procedure followed to codify the experts' contributions and the creation of a common glossary.
- Section 7 presents the clusterization of the determinants on behavioural archetypes.
- Section 8 presents initial causal diagrams for each one of the archetypes.
- Section 9 defines a series of surveys to be developed in T2.3 to validate the initial outcomes.

The causal diagram build will be later used in the rest of the project. In particular, T2.3 and T2.4 will use the diagram to fit a causal model. This model will be later integrated into the WHY toolkit as the first stage on the model pipeline.

2. Methodology

The objective of this section is to present the overall methodology that we have followed to retrieve the relevant factors that participate in the decision making of households with respect to the energy transition. The methodology loosely follows a traditional Delphi Methodology[1] but using an online framework given the COVID19 restrictions in place during the time this activity was carried out. The Delphi method has a long tradition in several sectors as a consensus building method. It is based on the fact that group decisions tend to be more accurate than individuals. Delphi method has shown to be superior to other alternatives like prediction market or statistical groups[2]. This approach is an iterative procedure designed to help a panel of experts to reach consensus about a topic. Give its simplicity and flexibility it has been adapted to almost any task where it is needed to reach a consensus as for example to issue judgmental forecast[3], to select the projects to fund[4] or to forecast the use of technology.

It consists on the following steps:

1. A panel of experts is assembled.
2. Forecasting tasks/challenges are set and distributed to the experts.
3. Experts return initial forecasts and justifications. These are compiled and summarised in order to provide feedback.
4. Feedback is provided to the experts who now review their forecasts in light of the feedback. This step may be iterated until a satisfactory level of consensus is reached.
5. Final forecasts are constructed by aggregating the experts' forecasts.

A visual representation of these steps could be seen in Fig. 1.

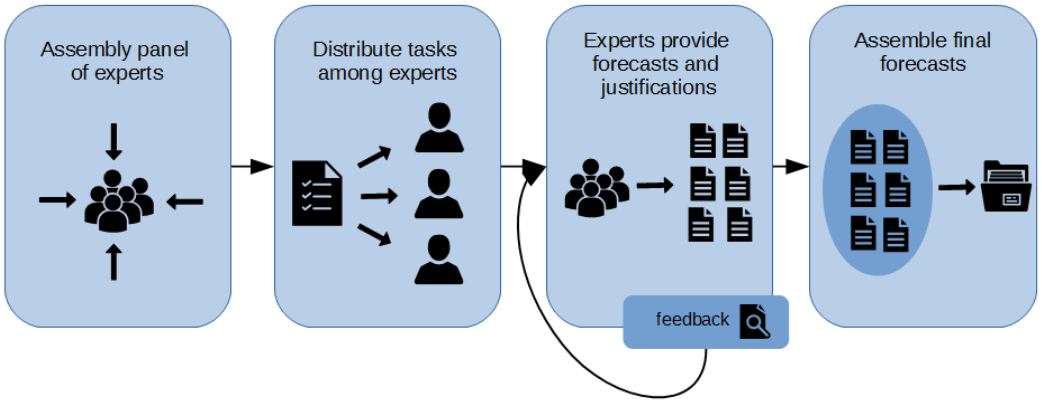


Figure 1: Visual representation of the Delphi method.

Delphy methods are best suited when rankings or quantitative objectives are discussed. Nevertheless, in this task the objective is to provide a qualitative description of the

[1] G. Rowe and G. Wright, 'Expert opinions in forecasting: the role of the Delphi technique', in Principles of forecasting, Springer, 2001, pp. 125–144.
[2] K. C. Green, J. S. Armstrong, and A. Graefe, 'Methods to elicit forecasts from groups: Delphi and prediction markets compared', 2007.
[3] R. J. Hyndman and G. Athanasopoulos, Forecasting: principles and practice. OTexts, 2018.
[4] European Commission (2015) Grants Manual - Section on: Proposal submission and evaluation. http://ec.europa.eu/research/participants/data/ref/h2020/grants_manual/pse/h2020-guide-pse_en.pdf

reality (the elements, determinants, that form the Causal Diagram) so an adaptation is needed. For this end, we proposed the following methodology:

- Phase 0: Literature review;
- Phase 1: Definition of the four main aspects of the energy transition;
- Phase 2: Generation of fictional scenarios (Minimum, Probable, Plausible, and Ideal) on the four different aspects of the energy transition;
- Phase 3: Building the panel and distribution of the tasks on each aspect of the energy transition;
- Phase 4: Creation of a common glossary (coding and agreement of the answers collected in each aspect by several researchers);
- Phase 5: Creation of decision-makers archetypes at household level;
- Phase 6: Selection of the most impactful determinants to each archetype and creation of a Causal Diagram for each of them;

Fig. 2 includes a general description of the phases of the proposed method. The next sections provide a detailed description of the results of each one of the phases.

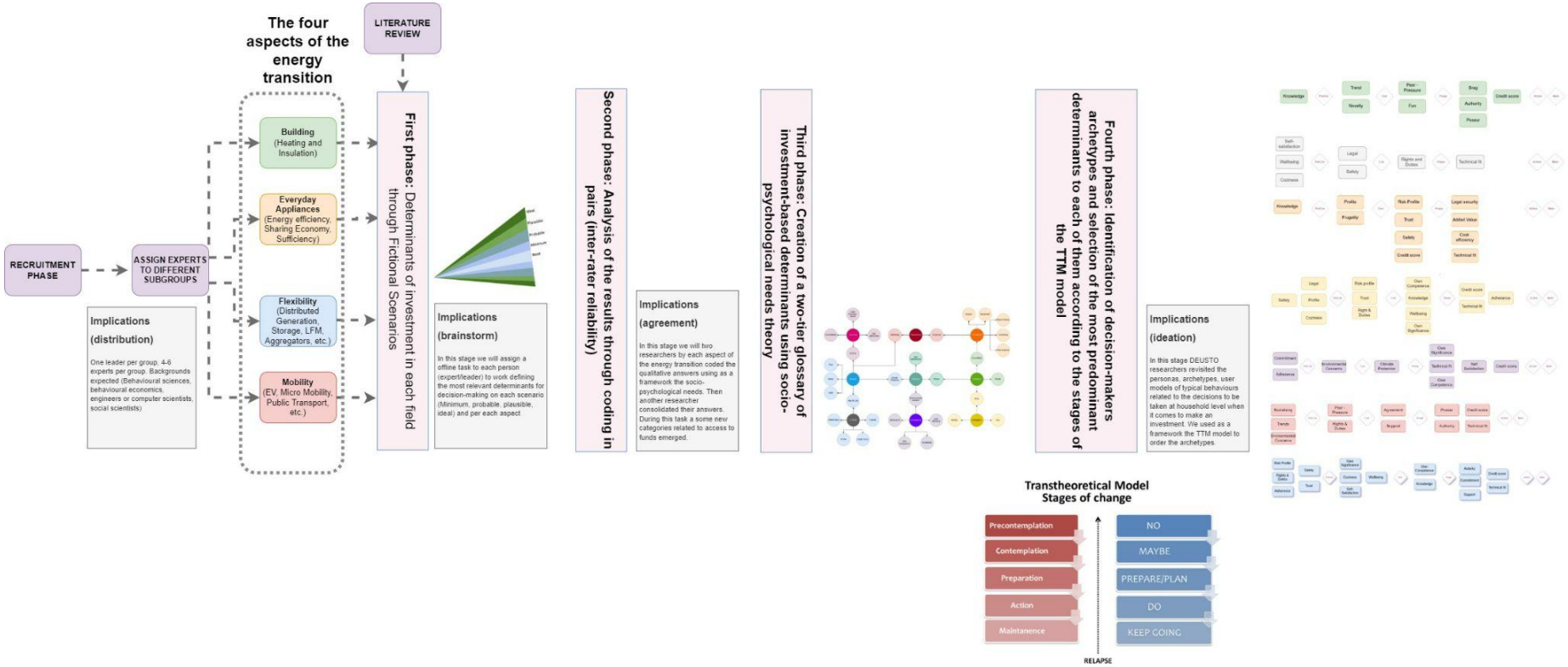


Figure 2: Overall methodology to obtain decision-makers' archetypes at household level

3. Literature review

In order to extract determinants for behaviour change or investment decision-making, the researchers proposed the use of fictional scenarios which is a quite unconventional methodology in research, but that can provide inspiring and meaningful results overall if experts are involved. Indeed, there are many complex, socially-based phenomena that cannot be easily quantified or experimentally manipulated. In user-centre research, there is an understanding that the focus on tasks is not enough to design and implement an effective system or framework. Therefore, identifying users' social drives and perspectives; their motivations, expectations, trust, identity, social norms and so on, are paramount for creating more than 'just appealing' results. To address this challenge, and taking into account that our genre of study is related to ideate decision-maker archetypes, this study follows a user-centre approach by asking experts the most predominant determinants that impact over fictional scenarios created by the researchers and inspired by the ideas of Dunne and Raby on speculative design and imaginary futures[5]. Furthermore, the choice of scenarios is a simple and alternative way to ask for experts' inputs without having to fully implement a real system or make simulations. According to Auger[6], who was one of the initiators of the design speculation through fiction and followed the work of Dunne and Raby, "a design speculation requires a bridge between the audience's perception of their world and the fictional element of the concept". Thas was the reason why we proposed scenarios in which technology and ICT advances (e.g. cutting-edge or emerging technology) were central to the proposals.

According to Xiao[7], futures are central to speculative design. Within this context, the future is seen as a range of possibilities. Futures can be characterised as probable, plausible, possible, and impossible, depending on the likelihood of it occurring. A time horizon of ten years (the near future) is considered ideal for speculative design. According to Phil Balagtas, founder of the Design Futures Initiative[8], if we project too far into the future, we're more likely to end up with mere speculation. At the other end of the spectrum, if we stay too close to the present, our predictions would have to be thoroughly and critically researched. Speculative design, therefore, exists somewhere in between. It also allows us to identify wild card scenarios, or low-probability, high impact events, that can jolt society in a major way. Based on this model, the future is something that we shape and build through the choices we make today.

Taking into consideration all these theories, we constructed 5 speculative scenarios (see Section 4) on 4 aspects of the energy transition: Energy efficiency through appliances, insulation in buildings, mobility with decisions related to the car use and the penetration of flexibility markets. Annex A presents for each of the scenarios the theory behind its definition. As a summary, it seems that internal factors such as beliefs, values or environmental concerns are the prominent drivers that foster a change in people's daily behaviour to invest time and effort in reducing carbon and energy footprint in their personal dwelling. Besides, the dominant external factors for such pro-environmental behaviour to occur seem to be peer pressure, social comparison and social norms.

[5] Dunne, A., & Raby, F. (2013). Speculative everything: design, fiction, and social dreaming. MIT press.
[6] Auger, J. (2013). Speculative design: crafting the speculation. Digital Creativity, 24(1), 11-35.
[7] https://www.editorx.com/shaping-design/article/speculative-design
[8] https://www.futures.design/

Finally, Annex B provides an extensive review of the theoretical framework used in this task. Including:

- An theoretical approach to causal models including all the basic operations.
- An introduction to several psychological theories that will be used to code the contributions made by the experts. In particular, a brief introduction to the Social Cognitive Theory and the Self-determination theory are presented.
- Finally, a description of the Transtheoretical model is included. This model will be used in later sections to sort determinants on the different archetypes.

4. Generation of scenarios

In order to obtain specific determinants to create the causal diagram, we have followed a *divide and impera* strategy. In this sense, we have divided the task into 4 use cases/fields of application (appliances, building renovation, flexibility services and mobility). Moreover, for each field, we have created 5 speculative scenarios in which each panellist has to define which are the factors that induce or elicit them to make an investment decision. Each scenario is meant to describe a different reality for each of the aspects analized borrowing on the ideas of Dunne, Raby and Auger that have been introduced in the literature review:

- **Baseline:** these scenarios try to reflect the current status of the aspects. They attempt to be a general description of a regular house in a city in Europe now.
- **Minimum:** in this case, these scenarios include the minimum effort required to improve the base scenario towards the decarbonization of the particular use case/field of application (appliances, building renovation, flexibility services and mobility). Usually these scenarios are based on behavioural aspects rather than monetary actions.
- **Probable:** these scenarios are a projection of the most probable decision making that citizens in whatever European city would take in the following years from the base scenario to advance to decarbonization objectives.
- **Plausible:** these sets of scenarios are less probable than the previous ones (probable), yet their happening would not be too strange to be observed in some EU cities and family units in the following years towards attaining decarbonization objectives.
- **Ideal:** these are the ideal scenarios towards attaining decarbonization objectives, yet these are highly unlikely to happen due to the massive social innovation that should carry on or the cultural change that they entail.

Fig. 3 visually represents the scenarios. Please remember that the scenarios described here do not reflect on individual buildings but are rather the representation of an entire city. Next we will provide a description of each scenario for each aspect.

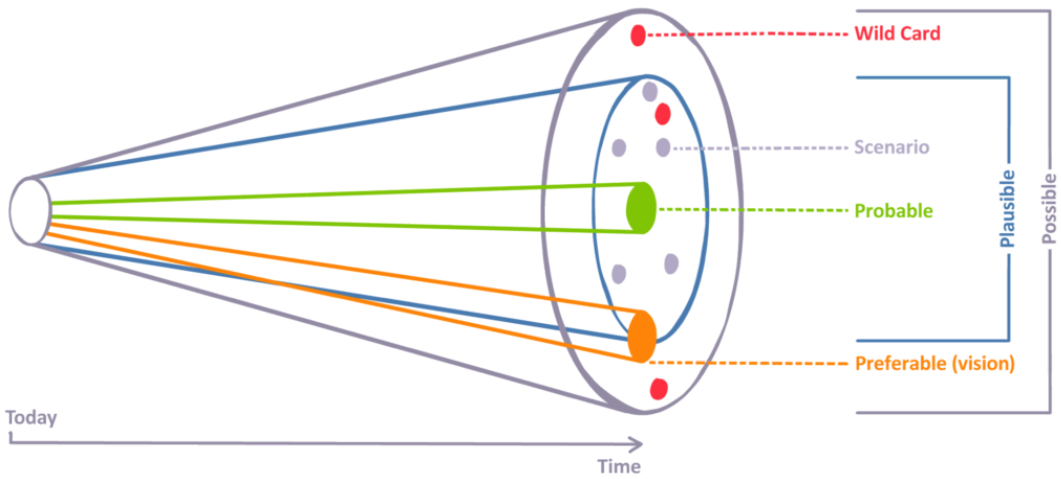
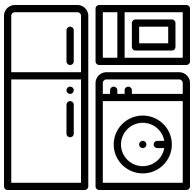
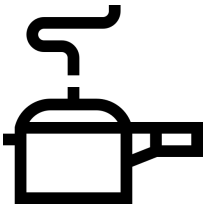


Figure 3: Potential future scenarios

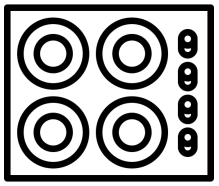
4.1. Appliances



Legacy Appliances (Baseline): You have been living in the same house since you moved for work 10 years ago. The appliances in your home are still working but are starting to break down more and more frequently. This situation worries you about the cost-benefit between keeping the equipment and extending its useful life for longer or upgrading to more efficient options (at least the most energy-consuming appliances such as refrigerator, TV, lighting, the oven or the ceramic hob). If your appliances were evaluated according to the new European labelling that goes from A (the most efficient) to G (the least efficient), your equipment would be labelled between F and G. It is important to note that your environmental values are in line with the European decarbonization challenges to achieve climate neutrality by 2050. However, you are not very clear on how to contribute to it.



Sufficiency (Minimum): You start looking for information for this change to happen. You start asking friends who are more or less knowledgeable on energy efficiency and you conclude that you should rethink your daily practices before investing in new energy efficient equipment. In other words, you ask yourself first if you are making efforts to minimise the impact of your energy use. Some of the actions you are considering are: reduce the temperature of the radiators while maintaining comfort, always cook with the pots covered so that heat does not escape, only to always use the shortest program for everyday clothing and reserve longer programs and/or high-temperature programs for linen, always fill the dishwasher to the maximum before running it, completely turn off the devices when not in use avoiding the standby, etc.



A+ (Probable): Let's imagine that your ceramic hob breaks down again (please, bear in mind that this is just an example and that we would like to get general ideas from a broader spectrum of appliances and situations. However, for the sake of clarity, we make up this explicit example for the scenario). This time, you decide to buy a new one according to your energy efficiency objectives. Thus, you decide to change your broken appliance and buy an induction cooktop which is much more efficient than the ceramic hob. Furthermore, among all the options that you have in the market for the new cooktop, you decide to get the one which offers you the best cost-benefit compromise at environmental and economic level.

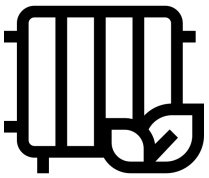
Service economy (Plausible): The washing machine breaks down again (please again, bear in mind that this is just an example and that we would like to get general ideas from a broader spectrum of appliances and situations. However, for the sake of clarity, we make up this explicit example for the scenario). As your main goal is to contribute to climate neutrality, you decide to find the nearest laundry and drying service to use regularly instead of buying a new washing machine. Luckily, there are coin-operated laundry machines within two blocks of your house. In addition, the service has a loyalty system, and you can buy more economical cleaning and drying vouchers. Hence, in economic terms your decision pays-off. Furthermore, the laundry service ensures you as a customer a high quality operation of their machines so the washing will be as good or better as the washing you may do at home if you owned this appliance.

Communal use (Ideal): One of the appliances you use occasionally (e.g. the oven, the washing machine, a drill or the vacuum cleaner) breaks down again (please again, bear in mind that this is just an example and that we would like to get general ideas from a broader spectrum of appliances and situations. However, for the sake of clarity, we make up this explicit example for the scenario). In order to contribute to the climate neutrality objectives, you decide not to buy a new piece of equipment for individual use but to propose its purchase to your community for shared and common use. To do this, you first try to convince your closest neighbour and then you try to persuade the entire community of your building (ten families) to share these household appliances for common everyday use. Luckily, you have space in the basement to accommodate them and you propose to your community to adhere to this initiative when they have to replace their equipment and not before. Otherwise, you also think that some families would be interested in making their appliance available for others to join the initiative sooner, so you open the room to this idea as well. In addition, if new equipment has to be acquired, you have recently learned that from this 2021 on all appliances must be easily repairable in the EU and that the suppliers or repair services must have spare parts for 10 years after you make the appliance's purchase. Therefore, these appliances will last for longer and the return on investment is assured for your community even for the top high-end and high-efficiency appliances.

4.2. Building

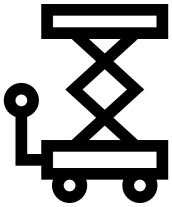
Not insulated (Base): You live in an old house (please consider the different possibilities mentioned in the introduction) built between the 1970s and 1980s that has either poor or no insulation (depending on country-level standards) and a heating system based on fossil fuels. It has no renewable energy generation and limited storage mechanisms (for instance a thermal storage tank for domestic hot water, DHW). The appliances in the house have a low to medium energy efficiency, and the house does not have an energy management system. Your electricity tariff for the dwelling is a standard tariff with a fixed energy price. In addition, there is no time-of-use (ToU) scheme, therefore you do not usually worry about what time you switch your appliances on. Thus, you plug them in and use them when needed.

Thermostat (Minimum): After reading about decarbonisation targets in the newspaper, you decide to find out what measures you need to take to ensure your comfort while reaching those targets. Consequently, you set the thermostat following your utility recommendation that the ideal temperature for a home ranges between 20 and 21°C during the day, and between 15 and 17°C at night; your clothing is suitable to the weather (for instance, in winter you wear different layers), you have checked your windows and doors for air leaks, replaced the seals on doors and windows, fixed any cracks inside and weather-stripped the windows, among others.



Minor Renovation (Provable): Several urgent renovation and repair measures are necessary. First, you need to repair and replace the roof and the facade, as water leaks are affecting different neighbours. Second, the oil heating system needs to be replaced for a more efficient gas model (although it does not decarbonise 100%, there will be a reduction

in emissions and probably savings on the bill). Thirdly, the installation of a lift would provide additional accessibility. These renovations cannot be undertaken simultaneously.

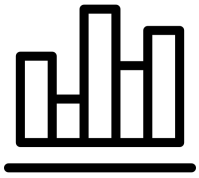


Deep Renovation (Plausible): At the last residents' meeting, the neighbourhood decided to renovate the building entirely to improve energy efficiency and comfort. The facade and roof will be insulated, air sealed, and waterproofed, and all the windows will be replaced with more efficient ones (for instance triple pane windows which can save you at least 3 % on your heating bill, more in colder regions without compromising the light). In addition, a lift is going to be installed. The government or a public authority may be granting aid to carry out comprehensive building renovations, giving you the opportunity to invest in the replacement of the old oil heating system for a modern heat pump system, or to connect to district heating.

Passive (Ideal): You live in a new passive home. In addition to having first-class facade, roof and window insulation, an intelligent high performance heat pump supplies the dwelling with low heating needs and hot water. An energy management system controls the heat pump and some other devices, giving the system the potential to exchange thermal energy with the neighbours. You are very environmentally conscious so you prioritise saving energy, and are willing to sacrifice your comfort, especially in the context of the thermostat temperature. You try to optimise energy consumption.

4.3. Flexibility

Consumer (Base): You live in a home that has poor insulation and fossil fuel-based heating (such as lignite, heating oil, or natural gas). It does not have mechanisms for generating or storing energy (except for a small thermal storage tank). The household appliances are not very efficient and there is no energy management system. Your electricity rate does not include time-of-use tariffs, so you do not worry about when you use the appliances. Simply, when you need them, you plug in and use them.



Time of Use (Minimum): A new electric tariff scheme has been approved, so several time-of-use tariffs are defined, with the possibility of each hour of the day having a different price. Since the difference between the low and high-tariff hours could be substantial, you decide to use an APP that informs you of the prices each day and you change your behaviour as much as you can. This includes the installation of several smart plugs to control some loads and adjusting the thermostat and other controls in accordance to the hours when the price signal is low.

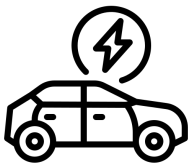
Prosumer (Probable): Some problems have been detected in the house's roof and you or your neighbours have decided to carry out comprehensive renovations. As the building is already well insulated and a large portion of the roof needs to be refurbished, it has been taken the opportunity to install an electricity generation system based on Building Integrated PV. It will be integrated into the façade and an energy community will be created to distribute the energy generation.

Energy Management (Plausible): The neighbours decide to carry out a comprehensive refurbishment of the building including an improvement of the insulation, the deployment of an electricity generation system integrated into the façade and the creation of an energy community. Moreover, given the actual price of the storage and its durability, they also include the installation of a community battery and an energy management system to increase the long term return on investment.

Local Market (Ideal): You live in a recently built passive house. The low heating demand is generated by an intelligent heat pump that uses low-temperature district heating as a source of energy. The heat pump also feeds the Domestic Hot Water (DHW). You have solar panels integrated into the building and a battery system that allows you to store excess daily energy to consume at night. The generation system is slightly oversized, and in summer, you have a surplus of energy generated that is used at the community electrolyzer that generates and stores H_2 that is later used in a community fuel cell CHP system. This CHP system only works in winter and is responsible for powering the district heating and helping the electricity generation during the low irradiation days. The system is controlled by energy management systems (EMS) that control not only the heat pump but also some other devices (including the battery, electrolyzer and the chargers of EVs). The EMS allows you to sell your energy surpluses and buy your energy needs from your neighbourhood. Moreover, all EMS coordinate with each other and can also participate in flexibility markets for the DSO, increasing or decreasing the energy consumption when requested.

4.4. Mobility

Fossil fuel (Base): You live in a metropolitan area where almost everyone has at least one combustion car. The car is used extensively, even for destinations easily reachable on foot or with personal mobility devices (i.e. bicycles). Public transport in short distance travels is seldom used, either by people that do not own a vehicle or for travel to zones where it is difficult to find parking. The public transport is partly electrified, though still dependent on fossil fuels. Travelling by foot or using personal mobility is common in some regions but is far from being the typical means of transport. Large distances are travelled usually by public transport or by private car more or less evenly. In low population density zones the only viable option is to have a car as the public transport is non-existent and the distances to travel are too large to be covered by other means of transport.



Electric Vehicle (Minimum): All transport modes are free of emissions (mainly electric except for very long range transport modes). Gas stations are converted into fast charging points and slow charging points are deployed everywhere. Apart from that, the behaviour of the citizens does not change.

Public transport (Probable): All public transport and private cars are electric and a significantly lower number of vehicles are needed (mainly in low density zones). The migration to cities and the blooming of teleworking change the modal split towards public transport and new modes of mobility, such as e-hailing (e.g. Uber, Cabify, MyTaxi…), ride-sharing (e.g.

BlaBlaCar) and micro mobility services (bikes, scooters, etc.). Car sharing (e.g. Car2go) and ride sharing businesses increase their market share even far from the big cities. Long distance transport is mostly made using high-speed trains and travel by plane is significantly reduced, mostly for long distances.

Robotaxis (Plausible): Electric robotaxis and new modes of mobility (e-hailing, ride-sharing, micromobility, etc.), made private vehicles obsolete in cities and low density zones, but it is not possible to live without using them. Cities continue to have high traffic density but now have a far better air quality and there is more space for pedestrians. Public transport continues to be used for medium distances (intercity) but the tradicional public transport means inside the city almost disappears (cannibalised by new modes of mobility). Long-distance transport is mostly made using high speed trains and the amount of travel by plane is reduced.

15' cities (Ideal): The cities are re-designed (for example with *15 mins cities*[9] or *superblocks*[10]) in a way that all services are at foot distance so the number of vehicles is drastically reduced and a combination of public or private personal mobility, robotaxis and electric public transport supply the rest of travel needs (inter and intra city). For these reasons, traffic jams are something from the past. Long distance transport is only made using high speed trains and the amount of travel by plane is drastically reduced to intercontinental travel.

4.5. Validation of the scenarios

In order to validate the scenarios, a group dynamic has been carried out with an interdisciplinary and intersectoral panel of experts[11]. Table 1 contains the list of experts and its affiliations. In the following, experts were presented with each of the scenarios without labels (namely, without the pre-classification made by the experts of the project). Then, experts had to read the scenario and carry on different tasks.

Name	Affiliation	Country
Astigarraga, Leire	GoiEner / WHY	Spain
Bätjer, Stephanie	Renewables Grid Initiative / WHY	Germany
Borges, Cruz E.	University of Deusto / WHY	Spain
Ceglarz, Andrzej	Renewables Grid Initiative / WHY	Germany
Chatterjee, Souran	Central European University	Hungary
Dalla Longa, Francesco	TNO / WHY	The Netherlands
Daniel, Ewelina	European Commission	Belgium
Edelenbosch, Oreane	Netherlands Environmental Assessment Agency (PBL)	The Netherlands
Fragkos, Panagiotis	E3Modelling S.A. / WHY	Greece
	Buildings Performance Institute Europe	Belgium
Lewarski, Michał	Centre for Climate and Energy Analyses	Poland
Loffredo, Jaume	The European Consumer Organisation (BEUC)	Belgium
Nacht, Thomas	4ward Energy Research / WHY	Austria

[9] https://en.wikipedia.org/wiki/15_minute_city
[10] http://bcnecologia.net/en/conceptual-model/superblocks
[11] https://www.why-h2020.eu/materials/past-events/improving-demand-side-modelling

Schibline, Amanda	Renewables Grid Initiative / WHY	Germany
Tual, Roland	REScoop	Belgium
Elena Verdolini	European Institute on Economics and Environment	Italy
Zucker, Andreas	European Commission	Belgium

Table 1: Panel of experts for the scenario validation group dynamic

First, the experts were asked to classify those scenarios as a base, minimum, probable, plausible, and ideal (as introduced in the previous step). Each evaluation was supposed to be done in the context of the three next decades (covering the 2020-2050 period). The results could be seen in Fig. 4.

		Flexibility determinants					Appliances determinants					Buildings determinants					Mobility determinants				
Decades	Scenarios	Consumer	Time of Use	Prosumer	Enery Management	Local Market	Legacy Appliances	Sufficiency	A+	Communal use	Service economy	Not insulated	Thermostat	Minor Renovation	Deep Renovation	Passive	Fossil fuel	Electric Vehicle	Public transport	Robotaxis	15' cities
2030	Not Applicable	1				2									2	1	1		1	3	2
	Base	2					3					3	1	1	1		1	1			
	Minimum		3					3	1						2		1	1			
	Probable												2	2			1				
	Plausible			2							1		1			2		2			
	Ideal			1	3					2	1		1		1	2	1		1		1
2040	Not Applicable	2					3										2				
	Base	1						1	2					1					1		
	Minimum		3					1	1			2	1		2						
	Probable			1									1			2		1			
	Plausible			2	1					1	2	1	1	1	1		1	2	1		
	Ideal				1	1				1	3					1	1		2	2	2
2050	Not Applicable	3					3					3		1			2				
	Base							1	3				2								
	Minimum		2	1				1								1		1			
	Probable				2						1					1		1	1		
	Plausible			2									1	2	2	1	1		1	1	1
	Ideal				1	1				3	1					1	1	1		1	2

Figure 4: Mapping of scenarios to labels

In general, for Flexibility and Appliance aspects, the experts map the scenarios as expected (nead the diagonal and move the elements up in each decade). Nevertheless, for Buildings and Mobility aspects, the trend is not clear. One potential explanation was that this was the first two aspects to be made and the description of the task could have not been clear for the experts (in fact, this was verbally said during the session by one of the experts).

The second task was to discuss which components or technologies should be included and prioritised in the WHY-toolkit. For this end, experts should write for each scenario the technologies they consider as more important. Fig. 5 shows six groups of technologies, and in which scenarios they are mentioned as drivers of change in people's behaviour. The last column ranks the technologies by priority, this value is based on the number of times a technology has been mentioned throughout the scenarios.

GROUPS	TECHNOLOGY	Flexibility					Appliances					Buildings					Mobility					Priority
		Consumer	Time of Use	Prosumer	Enery Management	Local Market	Legacy Appliances	Sufficiency	A+	Communal use	Service economy	Not insulated	Thermostat	Minor Renovation	Deep Renovation	Passive	Fossil fuel	Electric Vehicle	Public transport	Robotaxis	15' cities	
Generation	Photovoltaic energy (PV)			•	•	•						•				•						5
	Geothermal															•						1
	Renewable energy															•						1
	Biofuels (Advanced)																•					1
	Bioenergy					•																1
	Electrolyzer					•																1
Storage	Batteries (Energy storage)		•	•	•	•							•			•		•				7
	Thermal storage		•		•	•																3
	Buffer hot water storage systems							•														1
	Hot water tanks							•														1
Energy Efficiency	Smarts appliances								•				•									2
	Boiler (Gas, Oil)											•		•								2
	Smart thermostat		•		•								•									3
	Smart meters		•	•																		2
	Occupancy sensors		•																			1
	Reliable artificial intelligence					•	•															2
	Products for retrofitting (older buildings)														•							1
	Isolation		•	•		•										•						4
	Heating system							•								•					•	3
	Lighting								•													1
	Smart grids															•						1
	Smart infrastructure																				•	1
Electrification	heat pump backup system															•						1
	Charging spaces																	•		•	•	3
	Heating appliances								•													1
	Heat pump				•																	1
	Energy management system (EMS)				•																	1
	Virtual power plant (VPP)					•																1
	Appliances are used very seldom										•											1
Transport means	Cars									•												1
	Electric vehicles (EV)			•	•																	2
	Shared mobility									•												1
	good roads																•					1
	Public transport																					
	Personal transporter																					
Interventions	Dynamic tariff with price caps		•		•																	2
	Financial constraints													•							•	2
	Long term investment in infrastructure																		•	•		2
	New business model																		•			1
	Raw materials production and processing																	•				1
	Urban logistics/supply chain																		•		•	2
	Novel urban design concepts															•		•			•	3
	parking																•					1
	Behavioral change (in people)												•		•				•	•		4
	Broadband internet everywhere																		•	•		2

Figure 5: Distribution of the technologies per scenario

Annex E contains the complete description of the activity and the RAW information provided could be consulted.

5. Panel discussion to obtain the determinants

Now, after the validation of the scenarios, the objective is to acquire a comprehensive list of relevant factors that lead households to vote or invest / contribute time and / or money in making the scenario possible. For this end, we assembled another panel of experts and asked them to provide as many further determinants in each scenario as possible. Finally, we concluded the intervention by asking the experts about the reasons that would lead him/her personally to take the decisions provided and the barriers that would hinder the aforementioned scenarios.

In this section, we provide an overview of the creation of the panel and their roles and background to ensure interdisciplinarity on the answers collected as well as collecting evidence from different latitudes in Europe as well as trying to address the gender gap on energy projects.

5.1. Panel of experts

The panel of experts has been assembled within the advisory board of the project trying to mix experts of different fields from technical, societal, economic, psychology and end users. Table 2 contains a summary of the main characteristics of the panel of experts and the final composition can be seen in Annex F.

Aspect	Number	Interdisciplinar	Intersectorial	Internacional	Gender
Building	7 / 13	All four fields	Academia, Industry & Public Authorities	Austria, Spain, Romania, Croatia and Poland	1/7
Appliances	13 / 10	All four fields	Academia & Industry	Austria, Norway and Greece	3/13
Flexibility	7 / 12	All four fields	Academia, Industry & Civil Society	Spain, Austria, Germany, Sweden and Bulgaria	4/7
Mobility	4 / 10	Except psychology	Academia & Industry	Poland, Spain and Estonia	0/4

Table 2: Description of the panel of experts

As can be seen, except for the Mobility panel, the rest of the panels present a full international framework including interdisciplinarity and intersectionality. Moreover, they also present a good gender balance (except on the Building panel).

5.2. Task to be carried out

Given the restriction in place due to the COVID pandemic, the activity was held entirely online. Experts were contacted by email and after its agreement to participate in the activity, a second email was sent with some rules. Below could be found the email send:

> ***Title: [WHY] Instructions to complete the study on human behaviour towards the energy transition***
>
> Dear XXX/ representative of XXX,

Thanks for participating in this activity organised as part of the H2020 project WHY.

As I have informed you already, the objective of this task is to identify the factors that influence human energy behaviour. In order to retrieve this information, we will ask you to read 4 short texts describing different scenarios (minimum, probable, plausible and ideal) in the attached Google Slides [LINK]. For each one of the scenarios we will ask you to complete a list of the internal and external determinants that would lead you to invest your time and effort in order to participate in the scenario described.

The attached file includes an introduction, an example completed and several slides with tips to help you to complete the task. If you feel confident, you can skip these but you can go back and consult them if you need inspiration.

*We expect that each week you complete one of the scenarios. As there are 4 scenarios, the deadline to complete this task would be the **18th of July.** You can complete all 4 scenarios in one row but we would encourage you to divide it over several days in order to allow you to review your own contributions. We estimate that you would need to dedicate between 1 - 2 hours in total to finalise the task. Every week we will contact you to remind you to complete the scenario of the week and to provide information about the status or some insights collected from other experts, as they will be completing this task simultaneously. On the **23th July**, we would contact you again to provide an assessment of the results and ask for additional feedback, if relevant. After summer we will contact you again to complete the second task of this activity. Further instructions will be provided in this communication.*

All contributors to the study will be invited to collaborate as co-authors of the end results. Moreover, you can abandon the task at any point or ask to delete all the information collected. Finally, your participation does not produce any costs for you.

If you have any questions in the meantime, please do not hesitate to contact me.

Kind regards,
The WHY project team

As can be seen, the task to be carried out was to add relevant reasons for a person to invest time or money in each of the scenarios. Intrinsic, extrinsic and barrier factors have also to be provided as well as potential spillover effects. Fig. 6 contains a snapshot of the template used. Moreover, the documentation sent with the email includes information explaining some psychology concepts that could help to complete the task. Annex C contains a copy of the complete documentation sent to each panellist.

More than 1000 individual determinants were provided by all the experts. Table 3 contains the distribution per scenario and aspect. As can be seen there, the distribution is

fairly homogeneous (even in the mobility scenario where only half of panellists are in contrast with the other three).

	Minimum	Probable	Plausible	Ideal	
Flexibility	84	70	72	65	**291**
Appliances	107	101	88	92	**388**
Buildings	58	97	67	70	**292**
Mobility	59	60	43	45	**207**
	308	**328**	**270**	**272**	**1178**

Table 3: Contributions by the experts

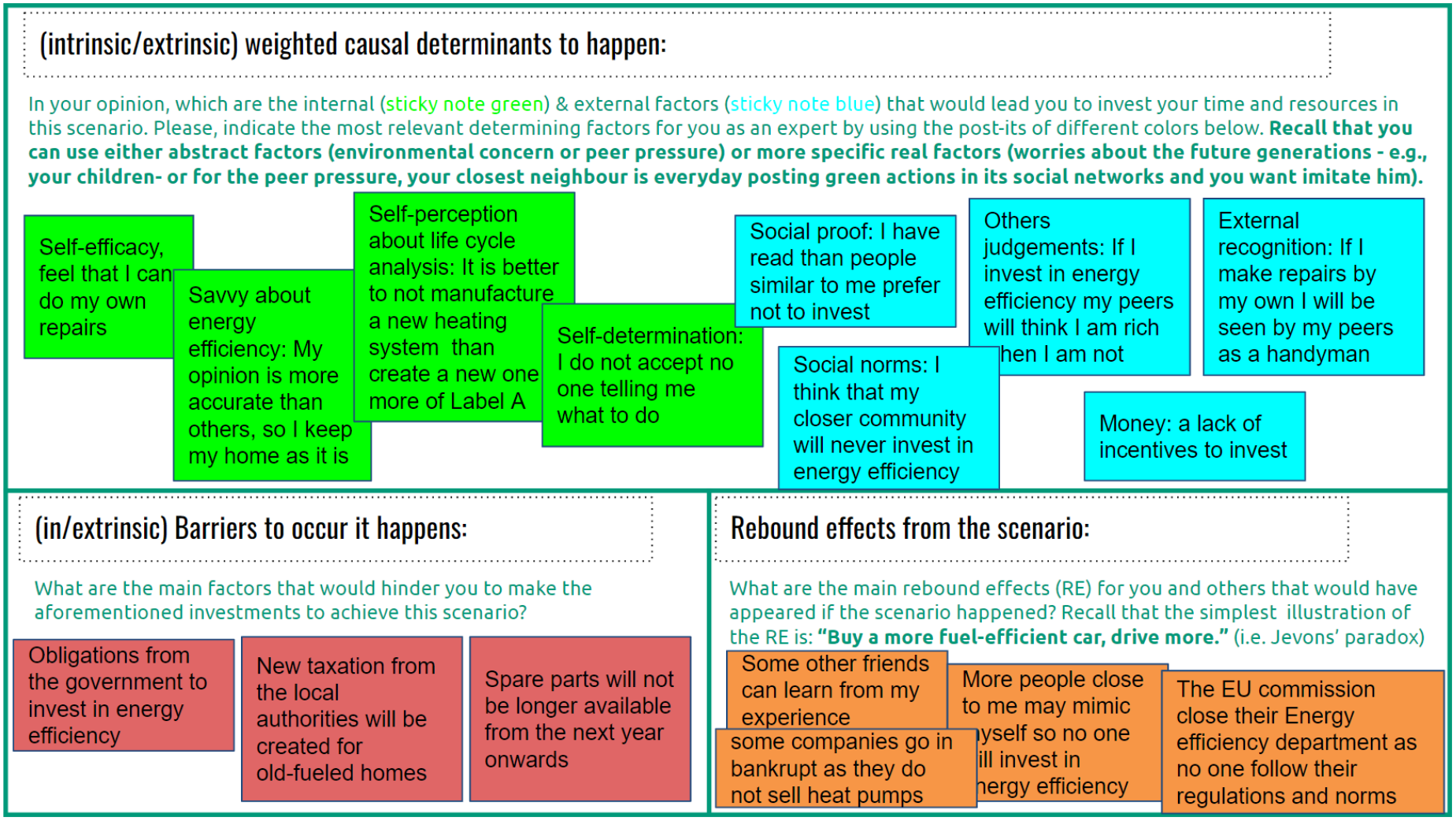


Figure 6: Template given to expert for retrieving determinants (intrinsic/extrinsic), barriers and rebound effects envisaged.

6. Agreement on the contributions received

Upon receiving all the contributions from experts on each of the different aspects of the energy transition and by each of the future scenarios presented to them, an agreement over the codification of data has been made. To this aim:

- **Coding by two researchers**. The consensus of the expert panel generated a list of determinants, which were grouped, according to the cognitive learning theory[12], into personal cognitive factors that are affected by the environment influence behaviour (see Section 6.1). The classification of the determinants was done individually by a pair of researchers. Then, these two researchers met and tried to resolve any despair between them. This resulted in a first codification, in which there was consensus on most of the determinants but for these determinants without consensus, a third round was carried out.
- **Homogenise.** This round was carried out by a third expert. The aim was to homogenise the answers from all four panels and solve any potential disagreement left.

6.1. List of determinants

Table 4 includes the list of determinants that emerged from the coding phase and their descriptions. 32 determinants were found following the research of Hassenzahl[13] where are described a list of psychological needs, which can be a source of positive experiences – also when interacting with technical products or potential futures. Need cards were used to define this top tier category and provide both orientation and inspiration for the design of interventions. The set consists of 8 need cards and a cover with a short instruction: Relatedness, Security, Competence, Popularity, Stimulation, Autonomy, Meaning, Physicalness. Apart from these needs, a new one called "Financial" emerged related to access to budget. Please, recall that we were dealing with investment decision-making.

FINAL CODING	CONCEPT	DESCRIPTION
FINANCIAL	Profits	All kind of economic gains and losses including direct revenues streams (like selling energy or flexibilities to the grid) to reduction of losses (like reduction on heating bills) from carrying out the actions (not by invest on third parties)
	Credit Score	Access to funding (for example access to loans), direct investment on technology (by crowdfunding, for example or use of actual capital), grants or other fiscal instruments, etc.
	Risk Profile	All kinds of economic risks related to the investment carried out (like for example long paybacks periods, uncertainties on the cash flows, unknown long term behaviour of the infrastructures, etc.)
	Added value	Other indirect economic gains (or losses) related to the investments carried out (like increase of the real estate value)

[12] Nabavi, R. T. (2012). Bandura's social learning theory & social cognitive learning theory. Theory of Developmental Psychology, 1-24.

[13] http://www.experienceandinteraction.com/tools

	Frugality	Values to voluntarily reduce the consumption and spendings even at the cost of reduce the quality of live (including people that values the money above all of things)
SECURITY + MEANING	Climate Protection	All actions related to protecting or fighting to improve the climate condition. The important message is that climate is at risk and actions should be taken to keep it in its present or past status.
SECURITY	Legal	All legal aspects that allows (or not) to carry on a certain action (including the uncertainties given due to changes on the legislation)
	Trust	Degree of trust on the institutions (for example access to grants, availability of funds, creation of laws based on the best interest of enterprises and not citizens), people (for example related to the behaviour of neighbours) and technology (for example its actual performance, future support of the technology, etc.)
	Safety	Values related to the safety of the infrastructures and all types of actions that could change it (for example increasing the risk of structural damages) including also the safety and security of the people (for example risk of robbery or get an infection disease).
COMPETENCE	Cost-Efficiency	Reflexible values related to the evaluation of the activities / investments to be carried out in terms of different criterias (for example after considering the pro and contra of the investment the person decides to not carry out due to the lack of added value, or large risks)
	Knowledge	Internal knowledge of the person or personal abilities / contacts to retrieve the knowledge required to solve a task. The knowledge considered here is mostly from a theoretical point of view (for practical knowledge see Own Competence). Fake news or hype (as anti knowledge) are also considered here
	Own Competence	Practical knowledge of the task at hand (that increases self esteem because is done in a rightful way). This includes the familiarity with the technologies and similar values
	Technical Fit	Technical issues of all kinds that foster or hinder the adoption of technologies like space for deployment of the technologies, access to qualified installers or waiting time, but also grid stability or unavailable access to the grid, etc.
COMPETENCE + MEANING	Environmental Concerns	Values related to the responsibility for our own actions towards the climate and the future perspective.
AUTONOMY	Self-Satisfaction	The happiness from the feeling like you are the cause of your own actions. Emotions related to the freedom and the fulfilment of the inner essence of the individual.
	Commitment	The willingness to give your time and energy to a job, activity, or something that you believe in. Besides, it is related to a firm decision to do something.#3299b0
	Adherence	The capacity to maintain any given behaviour, task or action during the time.
SECURITY + AUTONOMY	Autarky	Autarky is related to the auto-sufficiency of the people. Having the own control of the things, and producing their own goods to feel independent from companies.
PHYSICALNESS + SECURITY	Wellbeing	Related to the the wellbeing of the individual: any issue related to health, and to the impact on the physical wellbeing of the people(For example, having a adequate home for a child)

PHYSICALNESS + RELATEDNESS	Cosiness	Related to the comfortability of living. It involves the emotional side of being at home with your loved ones and feeling comfortable and happy at home
RELATEDNESS	Rights and Duties	Related to specific issues that may appear when living in a community: obligations and rules of neighbourhoods or tenants/landlords, and also the benefits and rights that are involved.
	Peer-Pressure	Capacity of being influenciable by peers that actually enforce the social norms.
	Support	Support is related to the idea of contributing to the community (or any other social cause) and doing your best for the improvement of the society (at any level)
	Socialising	The idea of having regular intimate contact with people who care about you rather than feeling lonely and uncared for. Feeling connected to other people and part of a community.
	Agreement	Understanding and cooperation between peers among any given issue
STIMULATION	Novelty	Values related to the positive feedback mechanism for doing new things. This include the early adopters and the fear to new things
	Fun	Values related to the enjoyment (or the opposite) of carrying out a activity or invest on something
POPULARITY + STIMULATION	Brag	Values related to the persons that actively believe on the activities they are carrying out and perform proselytising or brag about it
POPULARITY	Trends	Capacity of being influenciable by external third parties (like advertisement or abstract social norms)
POPULARITY + RELATEDNESS	Authority	Capacity of being influenciable by the knowledge or examples carried out by peers (especially know and direct peers like family, friends or neighbours)
MEANING + POPULARITY	Poseur	Feelings, attitudes and actions are influenced by external factors (money, popularity) and not due to internal motivation. For example, accepting and following trends that are not inherent or truly representative of the individual
MEANING	Own Significance	Feeling that you are developing your best potentials and making life meaningful rather than not getting anywhere and experiencing nothing of importance. Ideas related to their own significance and internal factors as emotions or feelings.

Table 4: List of determinants and their description

Fig. 7 shows a mind map of the distribution of these diagrams. Please take into consideration that some of the determinants belong to the intersection between two categories of the social cognitive theory.

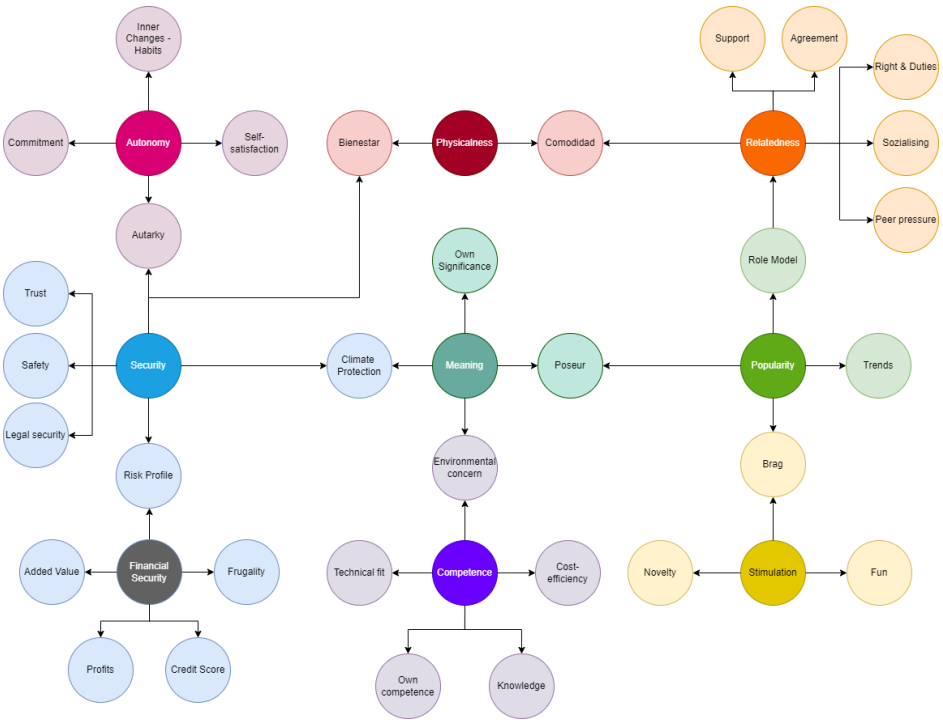


Figure 7: Final codification puting the socio-physiological needs on the first tier of the taxonomy

Table 5 shows the weight that the determinants have in each of the scenarios studied. As can be observed, Competence (feeling very capable and effective in your actions) is the weightest determinant in three of the four scenarios as well as in the average of all responses. In the case of the building aspect, according to the data retrieved, it seems that the financial needs are more relevant than other topics. This is possibly mainly due to the fact that investment on building infrastructure is more expensive than the other aspects. It is very important to emphasise that the financial aspects are always present on all the aspects being on average the second most important according to the expert knowledge. On the third place we find Relatedness, which is a construct related to the relationship between peers and the importance that others have on their personal decisions. On the other hand, the Flexibility aspect is all about changing routines and shifting some loads to different times. Therefore, in line with appliances, Relatedness loads higher as it implies changes in the families behaviour. Nevertheless, it seems to be not the case for the mobility aspect. It might be the case that mobility decisions are usually more individualistic and the social aspects have a lower relevance. In this vertical, Security appears to be a salient determinant as the people would like to make changes but always putting on the front the personal safety and trust. On the lower part of the selected determinants we can find Physicalness and Stimulation. This might mean that making investments for fun or to ensure cosiness or wellbeing at home are surprisingly less important than other factors. Security and Physicalness have some intersections, so this latter argument can not be true as the results are a bit blurred. The complete list of results could be consulted on Annex D.

	Flexibility	Appliances	Building	Mobility	TOTAL
Financial	**18%**	**13%**	**32%**	**15%**	**20%**
Security	10%	11%	10%	**24%**	13%
Competence	**26%**	**29%**	**15%**	**25%**	**24%**
Autonomy	7%	6%	4%	5%	5%

Physicalness	0%	1%	5%	4%	2%
Relatedness	**24%**	**21%**	**18%**	12%	**19%**
Stimulation	3%	4%	3%	1%	3%
Popularity	7%	10%	8%	7%	8%
Meaning	5%	6%	6%	5%	6%

Table 5: List of determinants depending on the energy aspect

7. Creation of the decision-making archetypes

There are different methods to create personas[14] or data-driven archetypes[15]. Personas are fictional characters, which someone can create based upon a research endeavour to represent the different user types that might make an investment decision in a household. Creating Personas will always help to better understand end-users' needs, experiences, behaviours, goals and hurdles. It can help to recognize that different people have different needs and expectations, and it can also help to identify with the user we are designing for. Thus, the examples created with this Personas approach should be understood as user case approximations that exemplify some of the real individuals that can be intensified on any energy related project dealing with dwellings.

Given the large amount of determinants found, it is very difficult to retrieve statistical information from the European population in terms of all the determinants. To overcome this problem, a set of a finite, low number of personas will be constructed following the taxonomy of determinants found in Section 6. The personas archetypes presented here are based on data reviewed on the body of knowledge and the expert knowledge from the research team. Thus, a combination of an inductive and deductive approach that lead us to identify the next seven typical end-users with specific characteristics. Nevertheless, these personas have not been validated and in fact, Task T2.3 will be devoted to the validation of these findings.

7.1. The Early Adopter

A Person who is always affected by novelty, always wants to be on trend and be the first to make changes at home or in their personal life with cutting-edge technology. Their motivations are purely technical and their enjoyment of what he does is a predominant factor for their actions. They have a social status to maintain and their peers expect from them to behave in this way. It may be the case that they like to show off or that they want to appear as an authority. Only lack of access to finance or budget can make him/her desist of its endeavour.

7.2. The Uninterested

A person who does not pay particular attention to external incentives to make any kind of intervention at home or in their personal life. Personal comfort predominates as the maxim of their everyday life. Will only make a decision whether it is legally imposed or it is the default option when moving house, buying a car, etc. In rare cases, they accept changes without resistance. Only lack of access to funding, or that the technology is not available or cannot be installed, will make them give up their way of doing things.

7.3. The Homo Economicus

A person who has a medium-high degree of knowledge about economics and/or energy. Their motivations for undertaking any activity are purely economic, either to make an

[14] https://www.interaction-design.org/literature/article/personas-why-and-how-you-should-use-them

[15] Salminen, J., Guan, K., Jung, S. G., & Jansen, B. J. (2021). A survey of 15 years of data-driven persona development. International Journal of Human–Computer Interaction, 37(18), 1685-1708.

economic profit or to reduce expenses. They will be more or less involved in adopting new technologies or making investments depending on their perception of risk, confidence, security, and their access to financing. The final decision to make or not an investment will depend on the added value and cost-effectiveness balance. Only the lack of an adequate legal framework to provide security for their decision or technological problems will deter them from making your final decision.

7.4. The Fearful

A person with average environmental awareness who is able to understand the need to make changes of any significance (legal, economic, personal, etc.). However, thy are usually lazy or afraid of change because of the amount of risk and time involved. Therefore, their only motivation to make a substantial change will be a lack of confidence in the current situation that may affect their personal security. Their knowledge of the subject matter, their personal competence and desire to maintain well-being will help them to make the necessary and meaningful changes. Adherence to their decision will lead them to be able to take the final action. Only lack of access to funding, or that the technology is not available or cannot be installed, will deter them from your endeavour.

7.5. The Stubborn

A person who is highly committed with environmental issues. This person is distressed or angry about the current environmental situation and wants to take meaningful actions. Their main objective is to protect the environment and this leads them to take action whatever it takes. The ambition of the actions they will take will depend on their competence, the personal satisfaction this gives them, the capabilities of the technology and access to funding.

7.6. The Influencee or Influencer

A person with high social capital who is easily influenced by peers or group trends or who enjoy influencing its peers. Their main motivation to undertake changes is to comply with what the group expects of them, either because of social norms or because it is an obligation for them. The feeling of belonging or their will to support the community are what drives them to take action. Depending on whether these people want to establish themselves as an authority in their community or whether they are simply complying with social norms, their actions will be reinforced to a greater or lesser extent. Only lack of funding or technical problems will prevent them from taking action.

7.7. The Careful

A person whose main priority is its personal or peer well-being and security. Any kind of decision they make is strongly influenced by their perceived safety and confidence in the action. The main driver of their behaviour is their personal or group satisfaction, in particular maintaining the physical and mental comfort of themselves and those who are close to them. Decisions will be made on the basis of their competence and knowledge. The ambition of the actions to be taken will depend on the degree of self-sufficiency and

the benefits he wants to obtain for himself and for the community to which they belong. Only lack of funding or technical problems will prevent them from their endeavours.

8. Creation of the Causal Diagrams per archetype according to the TTM

Once the seven archetypes were identified, the researchers decided to do an exercise to map the most relevant determinants of investment decision making to each archetype. For doing that, we decided to use as a framework the Transtheoretical model of behaviour change (TTM). TTM characterises behaviour change as a process that unfolds over time, a non-linear transition through a sequence of qualitatively distinct stages. At each stage there are individual, stage-specific sources of resistance to change that can keep people stuck at an early stage for a long period of time, so specific skills and strategies are needed. Successful transition through the stages is reflected in increasing readiness to change. The TTM is explained thoroughly in Annex B, but in a nutshell, it is based on six stages of change:

- **Precontemplation:** A stage where people do not intend to act for a short period of time, usually measured as the next six months. People may be in this stage because they are not well informed about the consequences of their behaviour or they may have tried to change several times and have become demoralised.
- **Contemplation:** A stage where people are trying to change their behaviour over the next six months. They are more aware of the pros of change, but are also very conscious of the cons. This balancing of pros and cons can produce deep ambivalence and keeps people stuck in contemplation for long periods of time.
- **Preparation:** A stage where people intend to act soon, usually within the next six months. Usually they have already taken some significant step towards the behaviour in the last year and have a plan of action.
- **Action:** Stage where people have made concrete and overt lifestyle changes in the last six months. Not all behavioural changes count as action in this model, certain criteria that scientists and practitioners consider sufficient must be met.
- **Maintenance:** Stage where people have made specific and overt lifestyle modifications and work to avoid relapse, they do not apply the change processes as frequently as people in action. They are increasingly confident that they can continue with the changes.
- **Completion**: Stage where people have zero temptation to relapse and 100% self-efficacy. It is as if the behaviour never existed in the first place or their new behaviour has become automatic. This criterion may be too strict, being an ideal goal for most people.

In the following, we provided an overview of the most relevant determinants identified by each of the different phases of the TTM on each archetype. The identification of those determinants allows us to understand what are the needs that have to be fulfilled by each individual behind an archetype to eventually take an investment decision through transitioning for the different stages. These initial diagrams can be understood as the causal diagrams that the overall T2.2 intends to create.

8.1. The Early Adopter

Fig. 8 shows a potential causal diagram for an early adopter. Early adopters usually have the knowledge. To transition to contemplate, a new trend or novelty has to be issued in the market. To continue progressing towards the preparation stage, they might need a little peer pressure or do the actions for fun and self-fulfilment. The final determinants

for transition to attain the goal of the investment (action stage) are being perceived as an authority, or to make themselves with enough social power to brag about their new investment. **Only lack of access to finance or budget can make him/her desist of its endeavour.**

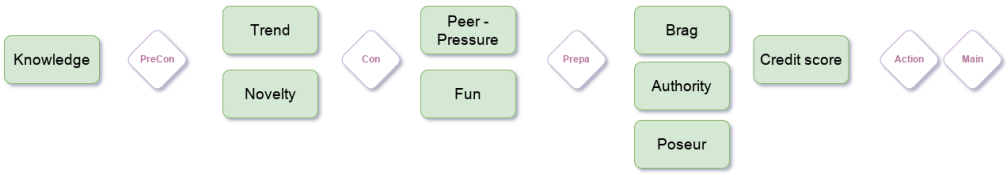


Figure 8: Causal diagram for the early adopter

8.2. The Uninterested

Fig. 9 shows a potential causal diagram for an uninterested person. Uninterested people are only driven by their self-satisfaction, their wellbeing and their cosiness. Unless the aspect to be implemented increases any or the three of them, they will not show any interest. In order to transition to the contemplation stage, all legal and safety requirements have to be clear. The uninterested will need further help to transition to the preparation stage. Any strong peer pressure or having rights and duties are the only determinants able to push them towards the investment decision. **In general, any minor problem in any of the steps could make the uninterested people desists but specially the technical fit.**

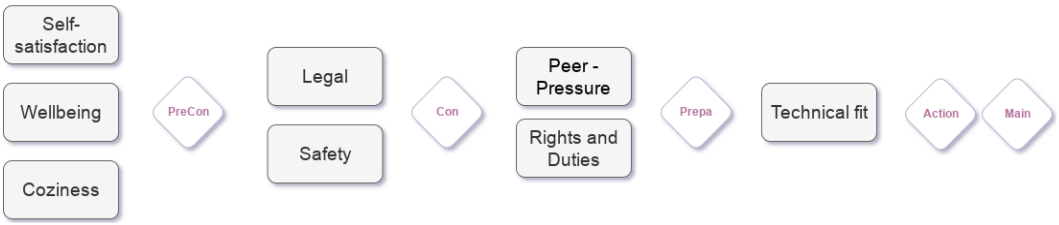


Figure 9: Causal diagram for the uninterested

8.3. The Homo Economicus

Fig. 10 shows a potential causal diagram for the homo economicus. An Homo Economicus has the knowledge to understand investments so generally as soon as a potential opportunity appears they jump to the contemplation phase. There, depending on the type of the homo economicus, if it is more oriented to maximise profit or more oriented towards the reduction of losses (frugality), they will assess the opportunity differently before advancing to the contemplation stage. In this stage, the homo economicus will perform a more careful assessment taking into consideration the risks (including the trust in the solution and the safety they felt), its added value and the cost-efficiency of the solution. If the pros and cons of the assessment continue to the preparation stage. There, the homo economicus will carry down its final assessment evaluating if they could financially manage to perform the investment. **At this point only, only the lack of technical fit or problem with the legal security will make an homo economicus to desist of its endeavour.**

Figure 10: Causal diagram for the homo economicus

8.4. The Fearful

Fig. 11 shows a potential causal diagram for the fearful. Fearful people react only to opportunities to increase their safety of cosines or to threads that could reduce its profits. When fearful people are in the contemplation stage, they evaluate the risks of the investment / countermeasure in terms of their trust, its alignment with the legal aspects and their rights and duties. If this assessment satisfies their fears, they will transition to the preparation stage where they will assess other spillover effects like the wellbeing and own significance of the action. Moreover, they will evaluate its competence and knowledge to carry on the investment before transition to the action stage. Finally, at this point they assess the potential adherence to the investment before carrying it out. **Only a lack of access to finance or budget or a problem with the technical fit of the solution can make him/her desist of its endeavour.**

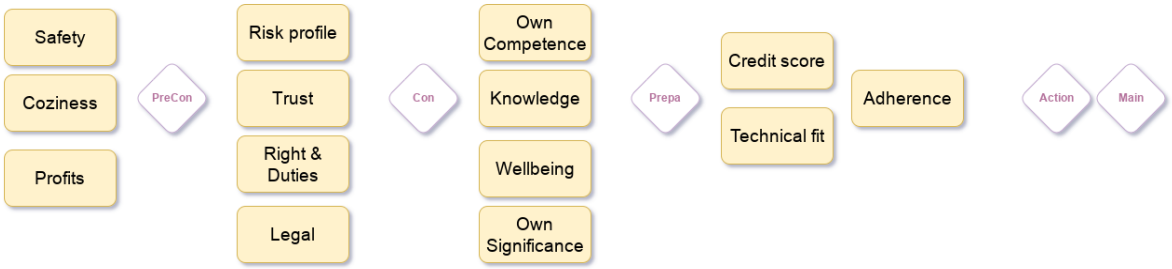


Figure 11: Causal diagram for the fearful

8.5. The Stubborn

Fig. 12 shows a potential causal diagram for the stubborn. Stubborn people are usually activists with a high commitment and adherence to. They usually are already contemplating new possibilities to mitigate their environmental concerns and their impact on the climate. When such opportunities arise, they quickly jump to the preparation stage where they assess their competence, self satisfaction and own significance towards the action. If the assessment is fruitful, they usually carry out the action unless **they cannot access finance or a problem with the technical fit of the solution make them desist of their endeavour.**

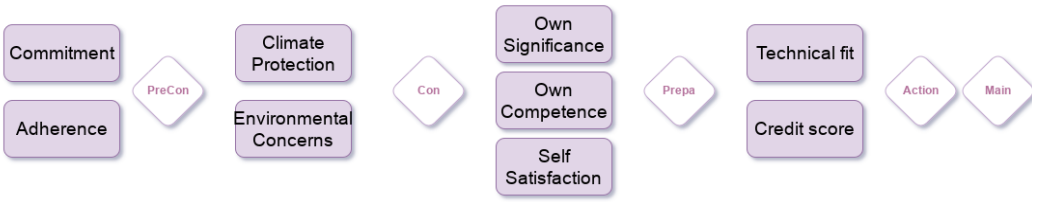


Figure 12: Causal diagram for the stubborn

8.6. The Influencee or Influencer

Fig. 13 shows a potential causal diagram for the influencee or influencer. The influencers family are always monitoring new trends. They enjoy socialising and this is its primary way to jump from the precontemplation stage to the contemplation stage. At this point, the peer-pressure and the right and duties is the main drive to advance towards the preparation stage. At this point, the influencers assess the level of agreement with their peers and the support they will have on the community to carry on the action. The final assessment will include a trade-off between the increase in its status in the community in terms of its gain in authority or as a poseur. As usual, **only a lack of access to finance or budget or a problem with the technical fit of the solution can make him/her desist of its endeavour.**

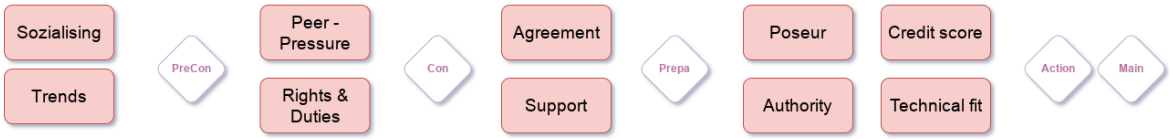


Figure 13: Causal diagram for the influencer or influencee

8.7. The Careful

Fig. 14 shows a potential causal diagram for the careful. These people do a very detailed assessment very soon in the process. In order to contemplate a potential investment they need to trust the source and be sure that the investment presents no risk for them. Of course, their safety will need to continue to be the same or increase and they also need to ensure that they will be able to actually use the investment in the long term. After this preliminary screening is carried out they jump to an assessment of their personal or group satisfaction in terms of their cosiness, wellbeing, own significance and self-satisfaction with the investment. They will also assess if the investment allows them to reduce their external dependencies. In case, the investment opportunity overcomes this assessment, the careful will assess its competence and knowledge to make a decision and will seek support in case they need. Finally, they like to make long term commitments, so they assess if they will keep it up in the long term. At this point, **only a lack of access to finance or budget or a problem with the technical fit of the solution can make them desist from its endeavour.**

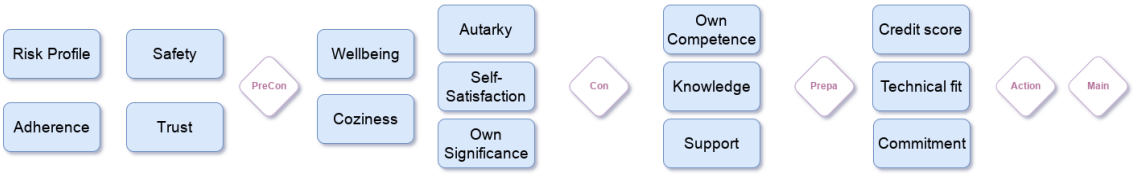


Figure 14: Causal diagram for the careful

9. Conclusions and future work

This document presents the methodology and the results for building a causal diagram of the reasons for households to invest on the energy transition. Given the complexity of the endeavour, the task has been splitted in several steps. First we split the energy transition in four aspects: Every day appliances, Building insulation, Local Flexibility Markets and Mobility. Then, for each of the aspects we build 6 scenarios with different futures. The scenarios were validated with a panel of experts and a list of technologies associated with each of the scenarios have been built.

On the other hand, a different panel of experts were built to retrieve the internal, external determinants that are related with the decision making at households towards investment on each one of the scenarios. Using the information retrieved from this panel of experts, and following different psychological theories, a taxonomy of determinants were built.

Nevertheless, the taxonomy is complex enough that it is very difficult to be applied directly. To overcome this difficulty a set of 7 archetypes of behaviours is built using the taxonomy. These archetypes consist of a set of determinants sorted following the TTM model making a causal diagram. Unfortunately, neither the seven archetypes nor their causal diagrams are validated so a proper validation has to be carried out.

The validation will consist of three activities that will be carried out under the framework of Task T2.3 and the results will be reported on Deliverable D2.3.

- Cross-sectional survey to validate (or create new ones) the defined archetypes
- Longitudinal survey to sort determinants of the archetypes founds into the stages of the TTM
- Expert workshop to sort determinants of the archetypes founds into the stages of the TTM

The next subsections provide details about each one of them.

9.1. Cross-sectional survey

A cross-sectional survey collects data about a population of interest at one point in time. They could be considered as snapshots of the populations about which they gather data. In this case, our intention is to characterise the European population with respect to the taxonomy to try to locate clusters of similar behaviours. Identifying these clusters allows us to build the different investment archetypes and compare with the ones we initially identified.

The survey is relatively straightforward, it is just a survey to retrieve socio-economic information and, for some of the scenarios / technologies we have used so far, ask each person to score each one of the 32 determinants presented in Section 6.1 when considering “investing” in that particular scenario. To assess the information, we just need to use clustering techniques such as K-means[16] and SOM[17] that will provide groups of individuals that share similar values of the determinants. If the determinants with

[16] https://en.wikipedia.org/wiki/K-means_clustering
[17] https://en.wikipedia.org/wiki/Self-organizing_map

largest values on these groups are similar to the ones provided, we can validate the archetypes. Another different option is to use variable reductions techniques such as PCA[18]. These methods will produce a new set of determinants made of linear combinations of the old determinants keeping the largest amount of variance of the sample. Under this framework, each determinant will consist of the "new determinants" provided, and the determinants associated with the archetype will be the ones present in the linear combination. The Nudge project has already used a similar strategy[19] as they have focused only on energy efficiency and their glossary of determinants is completely different.

This is a long survey (almost 100 questions) that needs to be carried out in multiple countries with a relative unbiased sample. Some rough calculations indicate that at least 1000 answers must be retrieved. A draft of the survey could be consulted in Annex G. The survey is scheduled to be carried out after summer using the PROLIFIC[20] platform.

9.2. Longitudinal survey

After the archetypes are validated, we need to sort the determinants of each archetype on the TTM model to build a causal diagram. The best way to carry on this task is with a longitudinal survey. Longitudinal surveys try to interview the same people periodically in order to assess the changes in the population over time. The objective of the survey is to capture as many changes of status in the TTM for each archetype and scenario.

This way, the survey is basically composed of a question to assess the archetype, another to assess in which stage of the TTM the person is and, finally, another question to score the importance of the determinants of the archetype.

The assessment of the answers is basically the estimation of different descriptive statistics by each one of the stages of changes per escenario and archetype. The main hypothesis is that the scenarios are not relevant and only it is going to be needed to assess the sorting of determinants by archetype (and stage, of course). Please note that the results of this survey will not only validate the archetypes but also to adjust the causal model.

In contrast to the previous survey, this is a short survey (25 questions, mainly socio-economics that could be answered just one time) that does not need to be carried out in multiple countries or with unbiased samples. A draft of the survey could be consulted in Annex H. Nevertheless, the main problem is that in order to capture changes on stages of the TTM (for example, that a person goes from not wanting to invest in PV panels to starting thinking about it), the periodicity has to be quite large. In the order of biannually or even annually. This obviously made the survey quite long in time (as all the longitudinal studies) and its assessment has to be made after the end of the project. In order to ensure that the survey continue running after the project ends, we are discussing with RESCOOP[21] to use it as a yearly poll among its customers.

[18] https://en.wikipedia.org/wiki/Principal_component_analysis
[19] https://www.nudgeproject.eu/report-profiling-of-energy-consumers-psychological-and-contextual-factors-of-energy-behavior/
[20] https://www.prolific.co/
[21] https://www.rescoop.eu/

9.3. Expert workshop

Given that the survey described in Section 9.2 most probably will not be completed during the project, in order to complete the validation of the causal archetypes a different activity is proposed.

The original "pre COVID" plan to carry on this deliverable was to do a face to face meeting in one of the Summer Courses (or similar event). In this workshop, the plan was to do basically something similar to what we have described in this deliverable but using physical cards instead of virtual posits. Now that the restrictions due to COVID have been lowered, we plan to invite around 20 experts to a face to face meeting in Bilbao on the 20th of October.

The idea for the workshop is basically to complete the same task asked in the survey made in Section 9.2 but instead of being answered by people about their own experience, by experts using their expert knowledge. In fact, while the survey needs to collect enough answers on each archetype, stage of change and scenario, the experts will complete all of them in the same meeting.

For this end, several decks of cards with the determinants of the archetypes and mats with the different stages of the TTM will be prepared. The experts will need to sort the cards in the deck on the mat according to their belief. As the experts will be splitted in groups trying to mix experts of different fields, sectors and regions, it is expected they will have a truly interdisciplinary discussion while completing the task.

The assessment of this activity is trivial as basically the end results are the causal diagrams for each archetype and stage of change.

9.4. Just in time survey

Finally, we also plan to complete a "role playing game" survey using an APP. The objective of the game is to force the users to enter into a similar mental state as the one we could get from the longitudinal panel. Namely, we will ask the surveyee to take the role of one person of a particular archetype and imagine what would this person do towards an investment decision. In particular, we will ask the person to answer all the questions from the "Investment scenario" section of the survey described in Annex H. As with the Longitudinal Survey, the assessment of the answers is basically the estimation of different descriptive statistics by each one of the stages of changes per escenario and archetype.

10. ANNEX A: Literature Review

10.1. Appliances and energy efficiency

10.1.1. Minimum

When it comes to changing daily behaviour in a sustainable way, one of the major determinants is the degree of information that an individual already has or receives. Ecological awareness is found particularly in individuals who were educated in the family environment from an early age, about consumerist actions and their consequences on the environment. For these people, the propensity to act on a daily basis by limiting energy consumption is important.[22]

Another factor that fosters ecological action in one's home is the public display of its energy consumption. The experiment was carried out in a group of students: for each of them, a poster in their residency showed the most economical (the students' names were highlighted in green) and the most consumerist (those were highlighted in red). Quickly, changes in behaviour were observed among the "red students" who began to reduce their electricity consumption by simple gestures: turning off the lights, lowering the thermostat and wearing warm clothes... Putting people in competition is a way to trigger behavioural changes.

Finally, another factor that leads to behaviour change is allowing the individual to see the habits of a similar group. The experiment was conducted in a hotel: each room had a poster in its bathroom informing that 75% of the guests were reusing the same towel, thus limiting laundry expenses. Rapid results were observed, as guests increasingly reused the same towel.[23]

10.1.2. Probable

When we look at the behaviour of individuals in a purchasing process (in our scenario, the replacement of ceramic hobs), one of the major reflexes is to consult the existing offer on the internet: on average, consumers consult 4 websites before buying.[24] On these sites, 70% of buyers consult customer feedbacks beforehand. Many also watch videos of the products in operation, and take into account the advice of family or close friends if they know the product (by having tested it or by expertise in the field).

After learning about the product from a distance, via the internet and word of mouth with friends and family, the next step is usually to go and see the product in store. This is the case for 68% of buyers, who go to the shop and talk to the salespeople.

In the shop, before the final act of purchase, the criteria of choice differ from country to country. In France, the first factor is the selling price as well as the technical performance

[22] Kelleher, Kathleen, *Researcher finds ways to convince consumers to reduce their energy usage.* https://techxplore.com/news/2016-07-ways-convince-consumers-energy-usage.html, July 2016.

[23] Graffeo Michele, Ritov Llana, Hadjichristidis Constantinos, *To make people save energy tell them what others do but also who they are: a preliminary study.* https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4551825/, August 2015.

[24] Attali Sophie, et al. *Mécanique de la décision d'équipement des consommateurs en électroménager performant.* *https://gbrisepierre.fr/wp-content/uploads/2020/07/Etat-de-lart-Bibliographie-MECAPERF-diffusable.pdf, January 2020.*

of the product. Then comes the consumption and the energy label. Finally, to a lesser extent, the design. In Italy and Germany, on the other hand, the energy criterion is as important as the price.

10.1.3. Plausible

There are many things that can encourage an individual to do their laundry in a laundromat. Even if you have to count the travel time, washing at a professional laundry is faster than at home: 60 minutes on average, that is to say 30 minutes less. Since you have to get out of the house, one of the arguments in favour of using such a service is productivity: take advantage of the washing time to do activities such as shopping, sports, walks.

Another element to take into account is the level of performance of the equipment available from a professional. They are more economical in water and electricity than domestic equipment and can accommodate up to 20kg of laundry (compared to 5kg on average for a standard washing machine). The quality of the wash is also better, the toughest stains will be removed. Finally, as the in-line capacity is larger, you can take advantage of it to wash large fabrics: tablecloths, curtains, carpets…[25]

If the above elements are present, one factor in the decision will obviously be the proximity of the laundromat to the living area. As with the purchase of a new household appliance, customers of this type of service look to user feedback to make their decision. If additional services are offered (like wash-dry-fold services, dry cleaning, or even seemingly small amenities like WiFi, to make the wait pleasant if you decide to stay during the wash), this will encourage people to go to a professional.

Finally, an individual wishing to see the laundromat with his own eyes in order to make a decision will take into account the visual aspect of the place: he will associate the cleanliness, the aesthetic aspect with the quality of the service, in particular because it is about (laundry) cleaning. The paintings and lighting of the facade but also the cleanliness of the interior, the visual aspect of the washing machines and dryers will be taken into account. Details that will influence the decision: advisors in the laundromat and also the possibility to see the water level through the washing machines.[26]

10.1.4. Ideal

When it comes to sharing a home appliance within a community (multi-apartment building), the first decision factor is the guarantee of the same benefits as private ownership. These are proximity, autonomy of use, availability at the moment of need, permanent good functioning. Also, a person considering moving to the pooling of household goods will not want to be in charge of it and maintain it; he will only want to use it for his function.[27]

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[25] *5 raisons de laver son linge dans une laverie automatique.* Accessed December 2016. https://www.libre-ecran.net/5-raisons-de-laver-son-linge-en-laverie/

[26] Russo, Paul, *Understanding why a customer chooses a laundromat.* Accessed January 2019. https://americancoinop.com/articles/understanding-why-customer-chooses-laundromat-part-1

[27] Lemoine, Yann, *Les biens en commun - Mutualisons nos appareils domestiques.* Accessed June 2022. https://www.zeste.coop/fr/lesbiensencommun.

If these conditions are met and demonstrated (via a member of the dwelling who would succeed in convincing the community), the benefits obtained would be the following: access for all to a variety of better quality appliances (implying speed of washing, allowing residents to do more loads per week[28]), energy[29] (and therefore financial) savings, reduction of constraints (of space and maintenance in particular).

In the literature, the "space saving" factor is recurrent and a decision factor in particular for students or young workers living in small apartments, where a washing machine generally takes a non-negligible space. Sometimes, there is no space for such an appliance or the individuals cannot afford to buy it. In other cases it is the discouragement at the idea of mounting the appliance on several floors that is mentioned. In these contexts, people are inclined to share household goods. Finally, if an isolated space in the building is dedicated to laundry, it will save the residents from noise pollution.

10.2. Buildings

The scenarios for this aspect were constructed using previous results from the researchers. In particular it has been used the following results:

- Álvaro Hermana, R. (2022). Eficiencia energética y energías renovables en los sectores residencial y comercial. ISSN: 2340-7638. Orkestra. Bilbao. Retrieved from: Eficiencia energética y energías renovables en los sectores residencial y comercial - Orkestra Instituto Vasco de Competitividad (deusto.es)
- Amos-Abanyie, S.; Abrokwa Gyimah, K.; Akyereko Adjei, E. (2021). Towards Climate Responsive Building Design: Bio-Climatic Design Features of Residential Building Typologies in the Warm-Humid Climate of Ghana. Journal of Building Construction and Planning Research. Vol.9 No.2, June 2021. Retrieved from: Towards Climate Responsive Building Design: Bio-Climatic Design Features of Residential Building Typologies in the Warm-Humid Climate of Ghana (scirp.org)
- Mastouri, H.; Bahi, H.; Radoine, H.; Benhamou, B. (2020). Improving energy efficiency in buildings: Review and compiling. Material Today Proceedings. Volume 27, Part 4, 2020, Pages 2999-3003. https://doi.org/10.1016/j.matpr.2020.03.270
- Niamir, L.; Ivanova, O.; Filatova, T.; Voinov, A.; Bressers, H. (2020) Demand-side solutions for climate mitigation: Bottom-up drivers of household energy behavior change in the Netherlands and Spain. Energy Research & Social Science, Volume 62, 101356, ISSN 2214-6296, https://doi.org/10.1016/j.erss.2019.101356.
- Álvarez Pelegry, E.; Larrea Basterra, M.; Suárez Díez, C.. (2017). Energías renovables en calefacción y refrigeración en los sectores residencial y terciario. ISSN: 2340-7638. Orkestra. Bilbao. Retrieved from: Energías renovables en calefacción y refrigeración en los sectores residencial y terciario - Orkestra Instituto Vasco de Competitividad (deusto.es)
- Medal, L.; Kim, A. (2017). Key factors prioritizing energy resource conservation measures in a portfolio of buildings. A literature review. CSCE-SCGC. Canada. Leadership in Sustainable Infrastructure. Retrieved from The buildingSMART Canada BIM Strategy (csce.ca)

[28] *MLA response to COVID 19.* https://mla-online.com/MLAOnline/Why_Community_Area_Laundry_Rooms.aspx.
[29] *Why a communal laundry is superior.* https://coinmeter.com/archives/1084, March 2017.

- Mundo-Hernández, J.J.; Hernández-Alvarez, J.; Valerdi-Nochebuena, M.C.; Sosa-Oliver, J. (2014) Designing sustainable and healthy homes. European Scientific Journal. vol.10, No.20 ISSN: 1857 – 7881 (Print) e - ISSN 1857- 743

A summary of each one of them is provided below to make this document self-contained.

10.2.1. Álvaro Hermana, R. (2022)

This report reviews the current energy efficiency situation and renewable sources in the residential and commercial sectors (in the European Union, Spain, and the Basque Country). It identifies and describes the main challenges to be overcome for the decarbonization of these sectors; and proposes different ways and tools to increase energy efficiency and the penetration of renewable energy.

According to it, reducing the environmental impact of the building sector involves: (a) establishing strict standards for new construction; (b) encouraging the energy rehabilitation of existing buildings in areas such as lighting, air conditioning, automation and control of energy use, maintenance of installations, renovation of building envelopes or the installation of new domestic hot water systems, with zero or low greenhouse gas emissions; (c) favouring the replacement of equipment (e.g., household appliances) with more efficient ones.

The main drivers of transforming buildings into energy hubs will be renewable energy (e.g., solar photovoltaic), energy storage, new energy consumption and control devices, the massive deployment of heat pumps, and the increasing penetration of electric mobility. Housing retrofitting will strengthen the support and protection of the most vulnerable consumers and those at risk of exclusion or energy poverty and improve the population's quality of life and health.

10.2.2. Amos-Abanyie, S., (2021)

Due to the lack of guidance to assist building designers (in Ghana) with the best design parameters to achieve a safe and sustainable environment, this study aims to assess bioclimatic design features for residential buildings and identify those that improve the environmental responsiveness of buildings. The results showed that building characteristics that reflect the recommended design guidelines differ depending on the building types analysed.

Specific recommendations for the Kumasi climate include air movement, openings, the position of openings, protection of openings, walls and floors, roofing and rain protection. Examples are that walls and roofs should be lightweight materials with low thermal capacity. Adopting cavity walls or composite walls can be very useful for heat control. Thermal storage in this region is not essential. Roofs should have a reflective surface and be constructed with an insulating cavity. In addition, they should be designed with a suitable slope to facilitate run-off and a rainwater drainage system.

It is hoped that the results will spark renewed interest in building design in response to the climatic conditions of the environment and in order to reduce dependence on energy use. Simultaneously, it is hoped that they will serve as a valuable reference for contemporary architectural design practice and education.

10.2.3. Niamir, L., et al. (2020)

This paper explores individual energy consumption practices and behavioural aspects that affect them because changes in individual behaviour and management practices are often understudied. The authors use a quantitative technique to set the main determinants of three energy actions: (1) investments in house insulation, solar panels and energy-efficient appliances, (2) conservation of energy by changing energy-use habits like switching off unused devices or adjusting house temperature, and (3) switching to green(er) electricity sources.

The results show that, in general, the probability of households' investing is highly correlated with residents' education level, personal norms, and the type and size of their residence. Therefore, personal goals, knowledge and awareness, and the type and size of the dwelling, are crucial elements in promoting energy efficiency investments in households.

Regarding the conservation of energy measures, the likelihood of households implementing this kind of measure is related to personal standards and the type, energy label, and age of their dwellings. Finally, when switching to renewable electricity sources, switching to one green supplier and from one green supplier to another is often affected by several types of somewhat similar explanatory variables. In the specific case of switching to another renewable supplier, personal norms play an essential role.

10.2.4. Mastouri, H. et al. (2020)

The research of this project aims to reduce energy consumption in the building sector while maintaining a satisfactory level of thermal comfort. It investigates the effect of integrating passive or semi-passive techniques (i.e., thermal insulation, thermal inertia for external walls, effects of a double slab, and integration of solar systems for heating, among others). For example, thermal insulation (one of the most reliable passive systems that improve thermal comfort in winter and summer) and ventilation techniques must be applied to reduce the risk of overheating. The installation of shading devices outside the windows is necessary. Well-located vegetation can create a natural fresh air reservoir for cooling.

This project considers low-energy buildings (LEB), which have a primary energy consumption for heating, cooling, ventilation, hot water, and lighting of less than 50 kWh/year. The energy production in these buildings is generally achieved through renewable energy systems. Thermal solar panels provide heating and cooling and hot water, and the electricity consumed by lighting and ventilating is generated from photovoltaic solar collectors or small wind turbines.

10.2.5. Álvarez Pelegry, E. et al. (2017)

This report analyses, after making a short description of the leading European regulation related to renewable energies in buildings, the degree of penetration of renewable energy sources (RES) in the final uses of energy (i.e. in heating, cooling and domestic hot water systems and others such as cooking), comparing the overall situation with the situation in electricity, transport and final energy.

It includes an analysis of the situation mainly in the residential sector in Spain and the Basque Country, focusing on biomass, solar thermal, geothermal energy and heat pumps. In the conclusions and suggestions section, some existing challenges in the heating and cooling sector were pointed out to address its more significant involvement in meeting the renewable targets in the medium and long term.

10.2.6. Medal & Kim (2017)

This article's main objective was to identify the main decision factors for green retrofits, particularly the selection and implementation of energy-efficient retrofits, considering a literature review. The results concluded that the underlying dimensions relate to occupant impact, environmental impact, stakeholder support, the economic feasibility of the proposals, and practicality and ease of implementation of the proposals.

10.2.7. Mundo-Hernández, J.J., et al. (2014)

This paper aims to present research on designing a sustainable home with passive and active systems to improve the health of the inhabitants of a poor Mexican town called Azumiatla. The proposals made have taken into consideration the lifestyle and characteristics of the families (also considering the poverty of its citizens) and included the views and needs of the population (local materials, walls and roof materials with good thermal and acoustic properties, "dry" toilets, green roof, vegetable garden, daylight access, natural ventilation, and energy-efficient oven and lamps, as well as solar energy systems).

The architectural design approach includes natural ventilation, daylight, thermal mass, solar protection, evaporation, insulation, climate characteristics, and all forms of passive houses or, in general, bioclimatic architecture.

In conclusion, developing countries with low-quality housing stock should seek environmentally friendly and user-friendly solutions. These solutions include a flexible design of adaptable, comfortable and affordable houses according to people's needs, beliefs and traditions, families' changes and characteristics, and climate conditions.

10.3. Flexibility

As with the previous case, the scenarios of this aspect were constructed using previous results from the researchers:

- K. Zabaleta et al., "Barriers to Widespread the Adoption of Electric Flexibility Markets: A Triangulation Approach," 2020 5th International Conference on Smart and Sustainable Technologies (SpliTech), 2020, pp. 1-7, doi: 10.23919/SpliTech49282.2020.9243744.
- Guntram Pressmair, Evgenia Kapassa, Diego Casado-Mansilla, Cruz E. Borges, Marinos Themistocleous, Overcoming barriers for the adoption of Local Energy and Flexibility Markets: A user-centric and hybrid model, Journal of Cleaner Production, Volume 317, 2021, 128323, doi: 10.1016/j.jclepro.2021.128323.
- Cruz E. Borges, Evgenia Kapassa, Marios Touloupou, Jon Legarda Macón & Diego Casado-Mansilla (2022) Blockchain application in P2P energy markets: social and legal aspects, Connection Science, 34:1, 1066-1088, DOI: 10.1080/09540091.2022.2047157

A summary of each one of them is provided below to make this document self-contained.

10.3.1. Barriers to Widespread the Adoption of Electric Flexibility Markets: A Triangulation Approach

This paper has identified that Local Flexibility Markets are gaining attention across Europe but there are some barriers that hinder its penetration. To this extent, a comprehensive study of the existing barriers from a review of current literature in energy efficiency, renewables and demand response have been provided.

Extensive and systematic literature review; triangulating the barriers detection for renewable energy technologies by conducting a literature review, pilot-sites visits and interaction with stakeholders; online surveys; a combination of in-depth workshops, expert interviews and literature research, all these were strategies to identify a concrete list and a categorization of the barriers by applying two phases, (1) *Barriers identification*: In this phase, all the barriers and 2) *Barriers classification (Taxonomy)*: In the second phase all the barriers identified during the first phase were classified in different categories and subcategories with the aim of creating a barriers taxonomy. The barriers were found to be organised among six main themes: (1) fit to current lifestyles, (2) administration, (3) standardisation, (4) trust, (5) technical, and (6) costs.

Each of these barriers along with those identified in the state-of-the-art were clustered in categories as can be observed in Fig. 15.

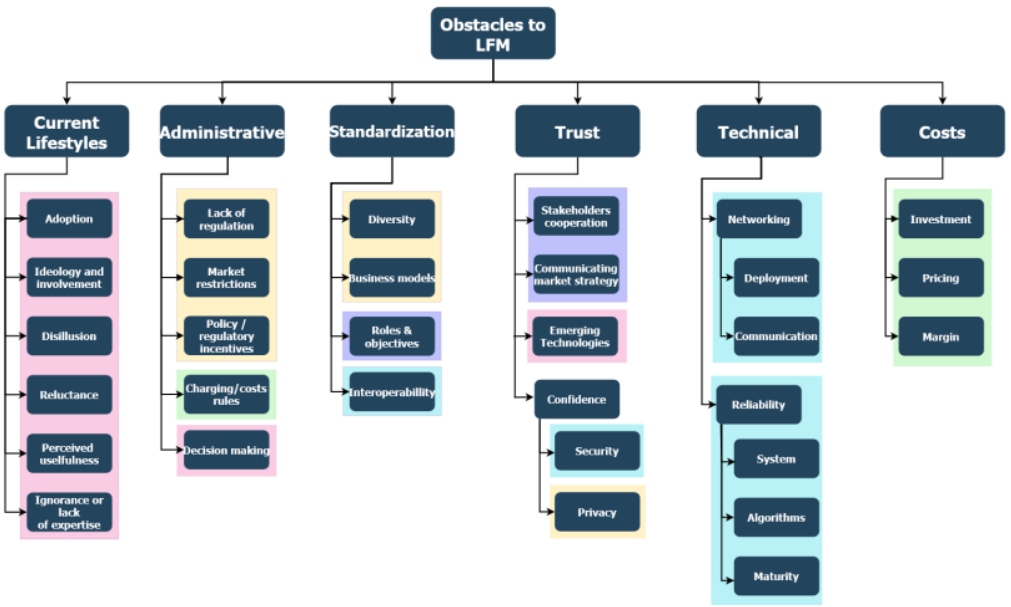


Figure 15: Taxonomy of the barriers identified for the adoption of Local Flexibility Markets

10.3.2. Overcoming barriers for the adoption of Local Energy and Flexibility Markets: A user-centric and hybrid model

In this paper, a user-centric hybrid market model has been proposed to enable the widespread adoption of Local Flexibility Markets (LFM) and Local Energy Market (LEM) in the Europe Union. This work has been carried out within the Horizon 2020 PARITY project[30]. The aim includes analyses to which extent the novel approach fits the needs of the participants involved and if it is able to overcome some of the previously identified barriers.

The key parameters for characterising a new market model are identified and reviewed. The results of the applied Delphi method are presented, prioritising barriers for the widespread adoption of LEMs and LFMs, and identifying conflicts of interests in such new schemes, from the perspective of energy market participants. The findings highlight the strengths and weaknesses of the proposed market model.

The aim of the local market is threefold. Firstly, the overarching purpose is to provide flexibility services for the DSO to perform congestion management and voltage control. , secondly, that especially small-sized prosumers connected to the distribution grid should be able to participate in the flexibility provision. Thirdly, flexibility should be activated in a transactive way, meaning through energy transactions among prosumers.

The results showed that for market participants such as Distribution System Operators (DSOs), energy retailers or aggregators, the most critical barriers for such markets arise with regard to standardisation. This includes technical standards, but also the lack of standardised business models and the diversity of flexibility markets.

[30] https://parity-h2020.eu/

10.3.3. Blockchain application in P2P energy markets: social and legal aspects

This paper analyzes the reluctance or concerns of potential end users of any flexible energy market. One of the most relevant concerns is information transparency to ensure a fair and secure market. In Flexible and distributed energy markets, contracts between prosumers or intermediaries are a key information exchange. The digitisation of these contracts through smart contracts, based on blockchain technology, is one of the natural steps in these markets; and blockchain appears like one of the key technologies in the proliferation of flexible and distributed markets. It will provide security and transparency to many of the information flows that will be generated between energy prosumers.

The energy distribution is the consequence of transmission across many grid levels and the interaction of numerous entities across several interconnected infrastructures, this complexity has shifted away from the energy sector from the traditional and centralised structure into more distributed schemes. In this context, blockchain might bring a significant improvement in the way energy systems function by providing decentralised and secure communications systems.

This paper analyses three sequential lines of work, (10 Setting up the scene, (2) Stakeholders' perception of blockchain, and (3) Legally enforceable smart contracts. It is established that a smart contract in simple terms is a piece of code and one of the most important characteristics is their immutability. The usage of blockchain and smart contracts can make peer-to-peer power distribution networks more efficient and provide several advantages,such as accuracy, speed and security.

The prosumer's perception on blockchain applications within PEMs is positive, and prosumers ranked Systems/Algorithms and lack of regulation on the top of the risks. Fig. 16 shows graphically the results.

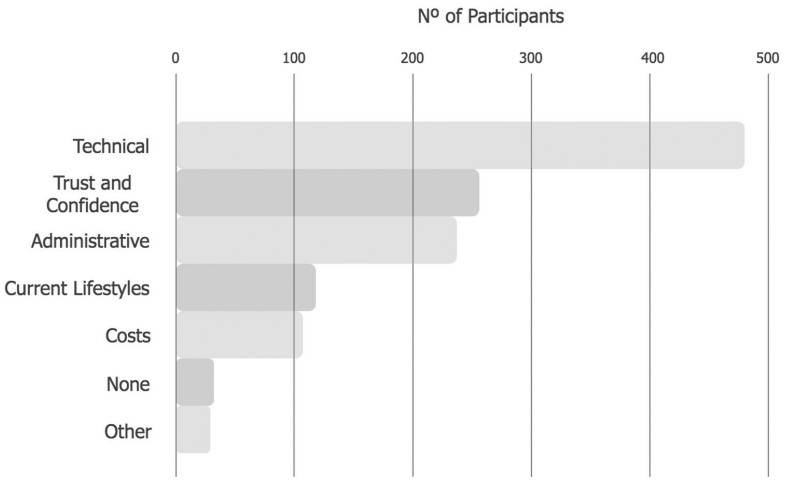


Figure 16: Barriers founds for Local Flexibility Markets

10.4. Mobility

When transport users evaluate the transport mean to be used, the variety of alternatives they are likely to face during the decision-making process increases as a function of the

information exchange and the factors they evaluate during the process. Several theories have been proposed to assess these decision-making process such as the following:

- Theory of reasoned action, based on the relationship between attitude toward behaviour, behavioural intention and actual behaviour and subjective norm[31].
- The Theory of Planned Behaviour includes the perceived behavioural control[32] that dimension and describes how actual behaviour towards a specific action is an effect of behavioural intention which in turn is an immediate result of attitude towards behaviour, subjective norms and perceived behavioural control ability; when there is a correspondence between perceived behavioural control and actual behavioural control, this also exerts a direct influence on behaviour[33].
- The Technology Acceptance Model proposes the dimensions of perceived usefulness and perceived Ease to Use to explain and predict the acceptance of new technologies. This model also explains how external factors can influence internal attitude, beliefs and behavioural Intention.
- Innovation Diffusion Theory explains how users adopt innovations, for users, new ideas, products, services or experiences are innovations. The innovative decision-making process (innovative decision-making process) can be divided into the stages of: perception, persuasion, decision making, implementation and confirmation.
- The customer satisfaction theory is based on the assessment of perceived service quality, customer satisfaction and behavioural intention. The relationship between satisfaction and intention reflects that those who perceive a high level of service quality are more likely to be positively satisfied and pleased[34].
- Consumer choice behaviour theory states that consumer preference is influenced by consumer satisfaction with the available transport modes and their importance to the consumer, although individual perception and perceived suitability differ due to the socio-economic status of the consumer and the different intrinsic characteristics of the transport modes, which makes them neither directly observable nor measurable (latent variables).
- The hybrid choice model, which integrates consumer choice behaviour theory and discrete choice models to assess the impact of latent variables (perception, aptitude) on the decision-making process.
- The Integrated choice and latent variables model adds social influence to the hybrid choice model, thus defining a set of five latent variables to achieve a more accurate interpretation of the individual factors affecting transport mean choice. The variables are: Service environment, Personal safety, Modal comfort, Feeling of waiting, Convenience.

The theories and behavioural models mentioned above are used to establish a theoretical framework to explore the factors that influence consumers' behaviour in their intention towards the transport mean to be used.

[31] Tu, J.-C., & Yang, C. (2019). Key Factors Influencing Consumers' Purchase of Electric Vehicles. *Sustainability*, *11*, 3863. https://doi.org/10.3390/su11143863

[32] Kaufmann, Vincent. *Understanding the Real Reasons Why People Choose a Particular Type of Transport*. https://en.forumviesmobiles.org/video/2015/06/09/understanding-real-reasons-why-people-choose-particular-type-transport-2881. Accessed 18 Dec. 2020.

[33] Fu, X., & Juan, Z. (2017). Understanding public transit use behavior: integration of the theory of planned behavior and the customer satisfaction theory. Transportation, 44(5), 1021–1042.

[34] Chen, J., & Li, S. (2017, August 14). Mode Choice Model for Public Transport with Categorized Latent Variables [Research Article]. Mathematical Problems in Engineering. https://doi.org/https://doi.org/10.1155/2017/7861945

10.4.1. Why and how do people choose a particular type of transport in their daily lives?

Over the last 20 years, improvements in public transport, planning and telecommunications systems have contributed to a significant reduction in people's preference for car travel.

From the point of view of economics, travel is a combination of price and travel time, and users tend to compare the two and as far as possible, use the cheapest and fastest means of transport or combination of means of transport[35]. There are other factors that may influence the choice of a particular mode of transport in our daily lives and that may lead us to use other means of transport than the car, Table 6 lists and describes these factors.

Factor	Description
Combining pleasure, security and privacy	People are likely to use their cars for work, even if it takes them longer, because they enjoy driving and like to be in their own protected space.
More efficient telecommunications systems	Internet and multimedia have changed the way we use our time; PT users can connect to facebook, send messages, make phone calls or other similar activities, even the user can do the same on foot, but obviously it is more difficult to do so if driving (of course it is forbidden).
An improved and more diverse range of public transport solutions	This refers to improvements in PT supply: rail system, tram line, metro, private hire cars, taxis; a PT system that allows people to move anywhere, almost anytime, as a result, people have started to use PT more and more. Investment in alternatives to the car can lead to a change in people's practices and aspirations regarding the use of different modes of transport.
Cycle lanes and pedestrianised cities	Urban planning and cycling has a major impact, cycling has become a mode of transport in its own right; the idea of mobility allows people to think of their daily commute as a source of physical exercise as well. Pedestrian-friendly urban planning initiatives have made walking more ergonomic.
The importance of routine	Studies and research on this topic have shown that modes of transport are not interchangeable; they offer different types of accessibility. People have a daily routine and use it to do different things, if they were to use another mode of transport, they would have to do things differently, in different places and in a different order, and this is also very important in the decision-making process and ways of thinking.
Travel as an activity in its own right	Traditionally, commuting was seen as a waste of time between activities, so people sought to minimise their time, the shorter the better, because it is simply a waste of time, but now people see their daily commute as a way of staying healthy.

Table 6: Factors that may influence the choice of a particular mode of transport

10.4.2. Factors to consider when choosing the most appropriate mode of public transport

Understanding the motivations underlying transport mode choice is of utmost importance for interventions aimed at changing travel behaviour. In this sense, the theory of planned behaviour and CST are integrated in a third model with the Comprehensive

[35] Lopez, Napier. "E-Bike or Electric Scooter: Which Is Right for You?" Plugged | The Next Web, 8 July 2020, https://thenextweb.com/plugged/2020/07/08/e-bike-or-electric-scooter-which-is-right-for-you/.

Psychological Process performed on individual transport mean use decision making in order to predict intention and behaviour; this last resulting model identifies as key factors those described in Table 7. On the other hand, Fig. 17 shows the relationship between these factors and their degree of influence on the choice of a mode of transport.

Factor	Description
Intangible services	Whether it's convenient, comfortable and safe to travel by TP
Information	Opinion about timetables, online information, station information, TP route/line information
Cost	Opinion about the costs generated by using TP
Satisfaction	Enjoys and/or prefers to travel by PT
Perceived behavioural control	Can relax when travelling by PT
Attitude	It is really difficult to stop using PT
Subjective norms	Supportive comments from family and friends about PT use
Habits	Travelling on PT is part of daily life
Behavioural intention	Whether PT will be the first mode of transport in the future and willingness to use PT
Behaviour towards public transport use	Frequency of use and willingness to travel by PT

Table 7: Table of factors to consider when choosing the most suitable public transport mode

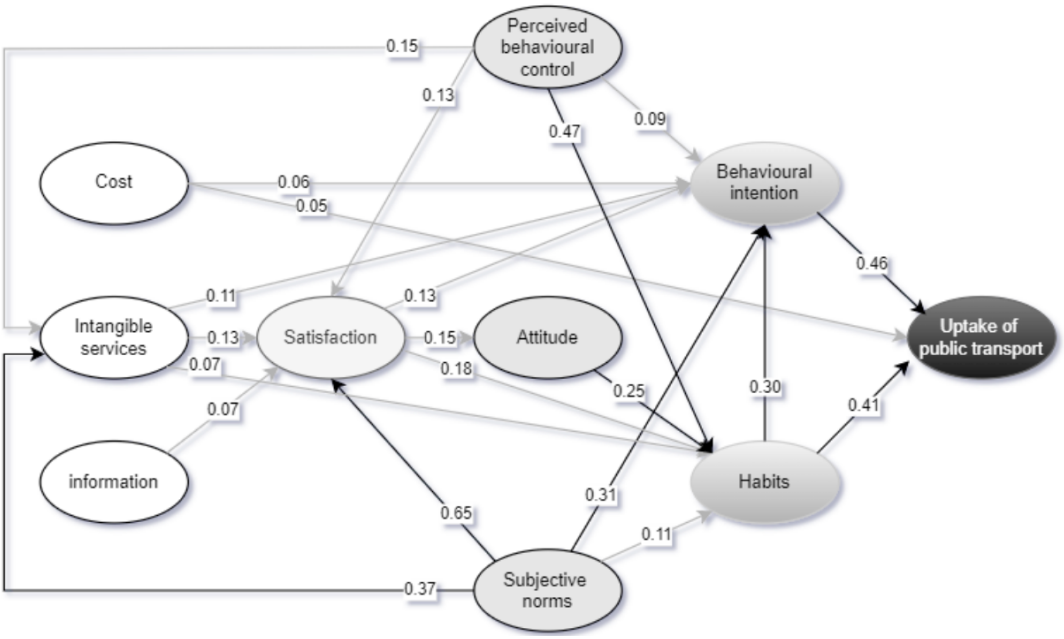


Figure 17: Relationship between factors and their degree of influence on the choice of a means of transport

Additionally, based on the Consumer Choice Behaviour Theory, the Hybrid Choice Model and the Integrated Choice and Latent Variables Model, the set of latent variables used to

explain the individual factors and their degree of influence (Cronbach α) on the mode of choice of public transport[36] are mentioned and described in Table 8.

Variables	Description	Cronbach α (*)
Service environment	Degree of cleanliness, ventilation inside the PT. Safe ascent/descent. Quality of the operator's attention. Overall satisfaction with the PT environment.	0.869
Personal safety	Emergency exit and equipment in the PT. If the dissemination of information about how to act in case of: accident, fire, earthquake, etc., is correctly carried out. General satisfaction and feeling of safety in a PT.	0.768
Modal comfort	Degree of ergonomics, comfort and entertainment (radio, internet, etc.) in the PT. Clear and correct information on PT routes and stations.	0.759
Waiting feeling	Punctuality of departure and arrival of the PT. Timely departure/arrival information on notice boards, actual waiting time is very close to the estimate shown on notice boards. Other information provided at stations is interesting.	0.742
Convenience	When the time between the place of departure and the PT station is short. Convenience to transfer to other similar transport or other modes of transport. Information at PT stations is clear.	0.696

Table 8: Latent variables of the mode of choice of public transport

10.4.3. Other factors to consider when choosing the most appropriate mode of transport include the following:

- Travel distance
- Number of passengers, discounts for travelling as a couple, family, children, etc.
- Speed of transport / Time: Time required to complete the journey based on the type of transport and routes.
- Flexibility, operating services on fixed routes and/or pre-planned schedules.
- Efficiency
- Diversity of transport
- Reliability
- Intermodal points
- Cycleways
- Pedestrian-friendly cities
- The importance of routine

10.4.4. Influence of climate on public transport use

In general, public transport services must operate in a manner that adequately meets the needs of passengers, from daily commuting to less routine and more spontaneous trips[37]. Adverse and extreme weather conditions (e.g., heavy precipitation, low temperatures and high winds) are known to have the capacity to degrade service quality (e.g., disrupting

[36] Chen, J., & Li, S. (2017, August 14). *Mode Choice Model for Public Transport with Categorized Latent Variables* [Research Article]. Mathematical Problems in Engineering. https://doi.org/https://doi.org/10.1155/2017/7861945

[37] Tao, Sui, et al. "To Travel or Not to Travel: 'Weather' Is the Question. Modelling the Effect of Local Weather Conditions on Bus Ridership." Transportation Research Part C: Emerging Technologies, vol. 86, Jan. 2018, pp. 147–67, doi:10.1016/j.trc.2017.11.005.

service schedules) and passenger experience (e.g., waiting times and prolonged journeys), with the potential to induce temporary and long-term declines in ridership[10] .

In this regard, Fig. 18 shows the most common weather conditions and the potential to negatively influence the use of public transport, bicycle and scooter use and pedestrians.

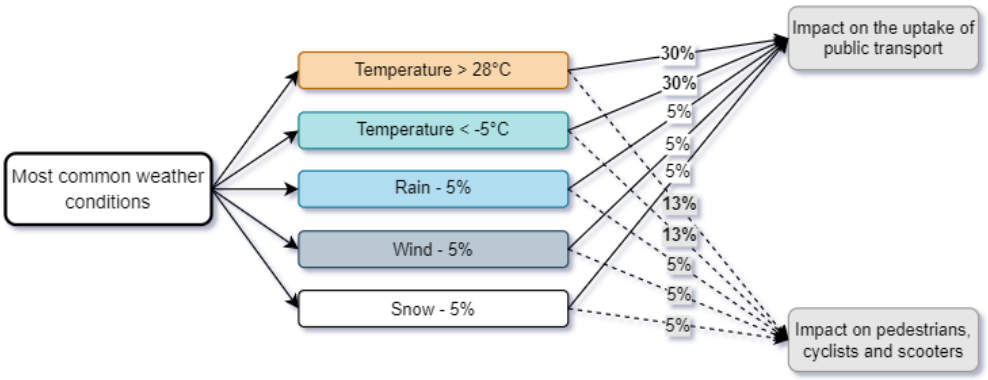


Figure 18: Impact of climate on public transport use

10.4.5. Why does a person buy a certain vehicle or not?

According to TRA and TPB, the key factors that positively influence consumer acceptance of electric vehicles and purchase intention are

1. Perceived Usefulness, Perceived Ease of Use, Compatibility and Personal Innovation as sources of Behavioural Attitude;
2. Interpersonal Influence and External Influence are sources of Subjective Norms;
3. Self-Efficacy, Enabling Conditions and Perceived Behavioural Control as similar dimensions that consequently form a new dimension named Self-Control Ability.
4. Finally, Behavioural Attitude, Subjective Norms and Self-Control Ability are considered as the sources that influence Behavioural Intention or Behavioural Intention towards the purchase of electric vehicles;

These elements are described in Table 9 while Fig. 19 shows graphically the relationship between these factors.

Factor	Definition
Attitude towards behaviour	Consumer attitudes towards the purchase of EVs
Perceived usefulness	Consumers' perception of the efficiency of electric vehicle functions.
Perceived ease of use	Consumers' ability to learn how electric vehicles work and use them without too much effort.
Compatibility	Consumers do not need to adapt to electric vehicles
Personal innovation	Consumer acceptance of electric vehicles
Subjective standards	Subjective opinions of friends, family, media, government policies and internet information about electric vehicles
Interpersonal influence	The impact of groups with whom consumers have frequent interactions, including parents, relatives, friends and supervisors, on the purchase of electric vehicles

External influence	The impact of media, expert opinions and other non-interpersonal information on consumers' purchase of electric vehicles
Self-monitoring	Consumers' ability to self-monitor their purchasing behaviour
Self-efficacy	Consumers' self-monitoring ability to purchase electric vehicles, including capacity, knowledge and expression of confidence
Enabling conditions	Consumers' opportunities and resources necessary for EV purchase, i.e. support from external resources.
Perceived behavioural control	Consumer control over the opportunities and resources necessary for EV purchases

Table 9: Factors description table

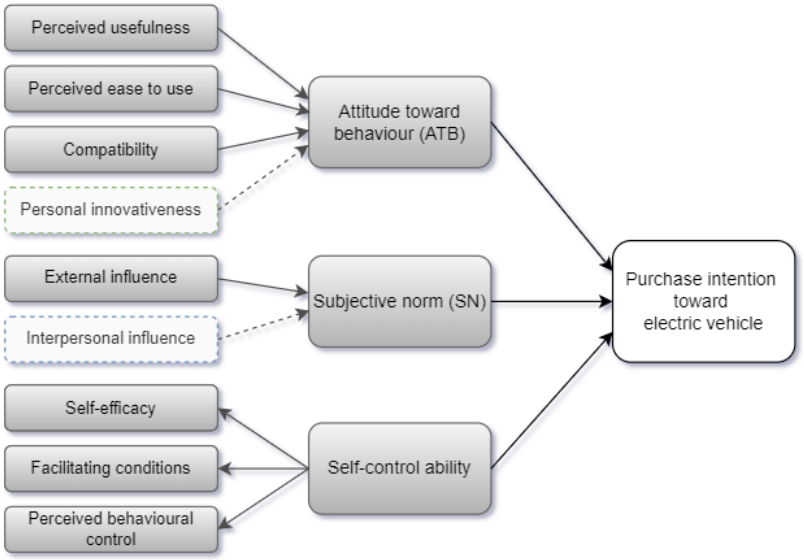


Figure 19: Relationship between factors

Based on table 5, the following is confirmed[38]:

- Behavioural attitude, subjective norms and self-control ability have significantly positive impacts on behavioural intention. Specifically, self-control ability is the most influential, followed by subjective norms and attitude towards behaviour, indicating that consumers' control over the resources needed to purchase electric vehicles has the greatest impact on behavioural intention. In addition, the opinions consumers hear from their environment also have a large impact on consumers' intention to purchase electric vehicles. In addition, consumers' environmental awareness and their acceptance of technological products are also factors that affect their behavioural intention.
- Perceived usefulness, perceived ease of use and compatibility have significantly positive impacts on behavioural attitude. Specifically, perceived usefulness has the strongest influence, followed by perceived ease of use and perceived compatibility, indicating that when consumers believe that electric vehicles are more beneficial on an individual, environmental or national level, or believe that it is easier and more convenient to use electric vehicles, they have a more positive attitude towards the purchase of electric vehicles. In addition, consumers think that electric vehicles are forward-looking technology products with similar driving operation and cost of use as traditional vehicles. These opinions and factors have

[38] Chen, J., & Li, S. (2017, August 14). *Mode Choice Model for Public Transport with Categorized Latent Variables* [Research Article]. Mathematical Problems in Engineering. https://doi.org/https://doi.org/10.1155/2017/7861945

a positive relationship with consumers' attitudes towards the purchase of electric vehicles. In contrast, personal innovation has a negative impact, showing that when consumers think that they do not understand electric vehicles better than those around them, they will not prioritise electric vehicles. In addition, their interest in EVs is also almost equal to that of traditional vehicles.

- Interpersonal influence negatively affects consumers' subjective norms, implying that the opinions of family, friends, peers or supervisors will not affect their attitude or behaviour towards EV purchase. External influence positively affects consumers' subjective norms, implying that, compared to the opinions of people around them, consumers are more convinced by objective information, expert opinions and support for government policies.

10.4.6. Buying an electric vehicle

While it is fairly easy to get to most cities, getting the last mile to your final destination is not easy. The same happens on the other end of the journey (the first mile)[39]. The last mile has found a solution in personal electric vehicles which can range from bicycles, scooters and even skateboards, all of which are electric. While it is a 1000 W electric bicycle that can go 47 km/h and is faster than almost anything else, it can still travel fast on smaller electric bicycles, electric scooters and electric skateboards.

When deciding to purchase an electric vehicle one initially thinks about a set of general factors[40,41]. Then a EV is selected from the three basic options: car[42], bicycle[43] and scooter[44]. Fig. 20 shows the graph of this process and the factors that are recommended to be considered and evaluated.

[39] Toll, Micah. "The Ultimate 'last Mile' Personal Electric Vehicle Showdown: Electric Bicycles vs e-Scooters vs e-Skateboards." *Electrek*, 27 June 2018, https://electrek.co/2018/06/27/electric-bicycles-vs-scooters-vs-skateboards/.

[40] Canada, Natural Resources. *Choosing-Right-Vehicle*. Accessed 30 Apr. 2018, https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/personal-vehicles/choosing-right-vehicle/20998.

[41] "Which Electric Vehicle Best Fits Your Lifestyle?" Electric Vehicle Guide, https://content.sierraclub.org/evguide/pick-a-plugin. Accessed 21 Dec. 2020

[42] "Top Five Reasons to Choose an Electric Car | Union of Concerned Scientists." *Union of Concerned Scientists*, 3 Dec. 2018, https://www.ucsusa.org/resources/top-five-reasons-choose-electric-car.

[43] Lopez, Napier. "E-Bike or Electric Scooter: Which Is Right for You?" *Plugged | The Next Web*, 8 July 2020, https://thenextweb.com/plugged/2020/07/08/e-bike-or-electric-scooter-which-is-right-for-you/

[44] Toll, Micah. "The Ultimate 'last Mile' Personal Electric Vehicle Showdown: Electric Bicycles vs e-Scooters vs e-Skateboards." *Electrek*, 27 June 2018, https://electrek.co/2018/06/27/electric-bicycles-vs-scooters-vs-skateboards/

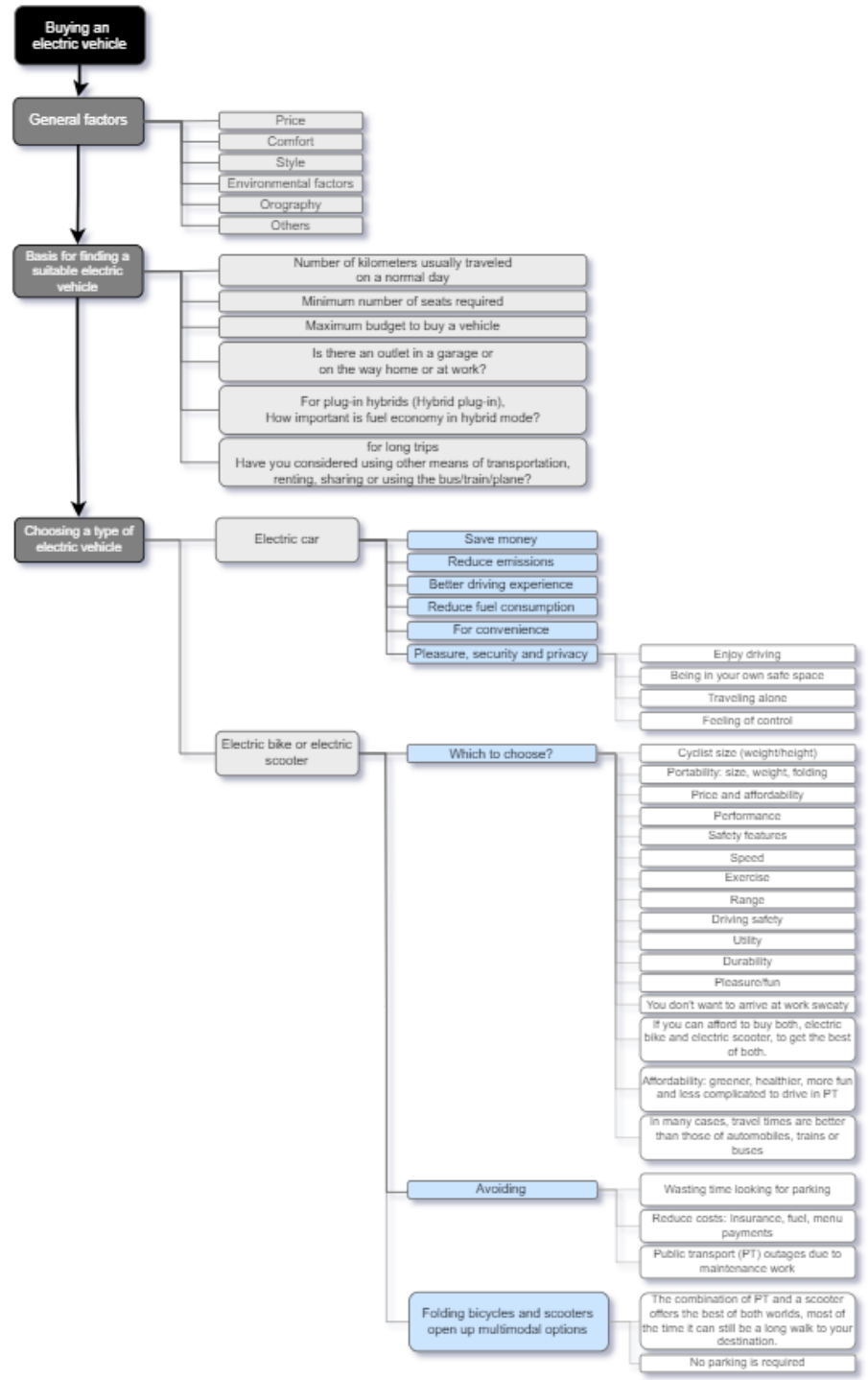


Figure 20: Factors to consider in selecting a vehicle

11. Annex B: Theoretical framework

11.1. Causal models

A Causal Model is a mathematical abstraction that quantitatively describes the causal relationships between variables. causal relationships between variables. First, causal assumptions or prior causal knowledge can be represented by an incomplete Causal Model. Causal assumptions or prior causal knowledge can be represented by an incomplete Causal Model. Then, what is missing can be learned from the data[45].

The two best known causal models are the Potential Outcome Framework (POF) and Structural Causal Models (SCM). Both allow for a consistent representation of prior causal knowledge, assumptions and estimates, and are therefore considered the foundations of causal analysis. In particular, the POF takes potential outcomes as a starting point and relates them through observational rules to observed outcomes. In contrast, the MTS perspective defines a model based on observed outcomes from which potential outcomes can be derived.

Both theoretical frameworks are logically equivalent, which means that an assumption in one can always be translated into its counterpart in the other. However, there are some differences between them. In POF, the causal effects of non-treatment variables, such as instrumental variables, are not defined, whereas in MCS it is possible to study the causal effect of any variable. Therefore, if all the causal relationships between a set of variables are known with certainty, it is preferable to use MTS, whereas if the objective is only to estimate a particular treatment effect, FOP may be much simpler. In the WHY project, the objective is causal analysis of a wide range of variables, so SCMs will be used.

11.1.1. Structural Causal Models

Formally, a Structural Causal Model consists of two sets of variables, U and V, and a series of functions f, called structural equations, which assign each variable in V a value, based on the values of the other variables in the model[46].

The variables in U are called exogenous variables, which means that they are external to the model, i.e. it is chosen, for whatever reason, not to explain how they are caused. V variables are endogenous variables, i.e. they are part of the model. Every endogenous variable is a descendant of at least one exogenous variable, while exogenous variables cannot be descendants of any other variable. If the value of all exogenous variables is known, the value of all endogenous variables can be determined from the functions in f with certainty.

Every SCM is associated with a Causal Diagram. These causal diagrams consist of a set of nodes representing the variables in U and V and a set of edges representing the functions in f . If the function fx for a variable X in V contains the variable Y, i.e., X depends on Y for its value, then there is an edge directed from Y to X. These causal diagrams will be mainly Directed Acyclic Graphs (DAGs).

[45] Judea Pearl, feb. de 2019. «The seven tools of causal inference, with reflections on machine learning». En: Communications of the ACM 62, págs. 54-60. doi: 10.1145/3241036.
[46] Pearl, Judea, Madelyn Glymour y Nicholas P. Jewell (2016). Causal Inference in Statistics: A Primer. John Wiley & Sons, Ltd. isbn: 978-1-119-18684-7

Causal diagrams allow us to give a graphical definition of causality: if, in a causal diagram, a variable X is a child of another variable Y, then Y is a direct cause of X; if X is a descendant of Y, then Y is a potential cause of X. In this way, causal diagrams encode causal assumptions.

An advantage of causal diagrams is that they allow joint distributions to be expressed in a very efficient way. For any DAG, the joint distribution of the variables is given by the product of the conditional distributions P (child|parents) over all families in the network, mathematically expressed as follows:

$$P(x_1, x_2, ..., x_n) = \prod_i P(x_i|pa_i) \tag{2.1}$$

where pa_i represents the parent values of the variable x_i and i = 1, ..., n. This rule saves time and memory when calculating joint distributions.

Although SCMs contain somewhat more information than causal diagrams, it is the latter that provide a more intuitive understanding of causality. Usually the knowledge about causal relationships is not quantitative, as required by an MCS, but qualitative, as represented by a causal diagram. In the next section, you will see how causal diagrams reveal much more information than is obvious at first glance - much can be learned about a dataset and inferred from it using only its causal history graph.

11.1.2. Causal Diagrams and their Applications

Another way of understanding structural causal models is to think of them as the mechanism by which data are generated. As discussed in the previous section, it is usually known which variables are caused by other variables, but the strength or nature of these relationships is unknown. Even with such limited information, much can be discerned about the data set generated by the model.

From the causal diagram it is possible to determine which variables in the data set are independent of each other and which are independent of each other conditional on other variables. These independencies will be true for each dataset generated by any SCM with the same graphical structure. any SCM with the same graphical structure, irrespective of the specific structural equations generating each dataset. equations that generate each dataset.

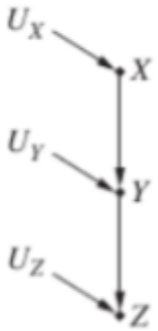
The following are the simplest and most relevant DAGs with which any causal diagram can be constructed. causal diagram and details the independence relationships underlying their structure. underlying their structure.

Chain

The configuration shown in the following figure, three nodes and two edges, with one edge pointing towards the edge facing the central variable and the other leading away from it, is called a chain.

Bearing in mind that in any causal diagram two variables that are connected through an edge are dependent, by simply observing the structure of the figure below, the following Theorem can be obtained:

Theorem 2.1.1. Relationship between variables in a chain, X → Y → Z:



Causal diagram of a chain showing the exogenous variables affecting the endogenous variables X, Y and Z.

- Z and Y are dependent.
  For some z and y, P (Z = z|Y = y) ≠ P (Z = z)
- Y and X are dependent.
  For some y and x, P (Y = y|X = x) ≠ P (Y = y)
- Z and X are probably dependent.
  For some z and x, P (Z = z|X = x) ≠ P (Z = z)
- Z and X are independent conditional on Y.
  For all x, y, z, P (Z = z|X = x, Y = y) = P (Z = z|Y = y).

The third point is given by the fact that if Z depends on Y , and Y depends on X, then Z is likely to depend on X. on X, then Z probably depends on X. However, by conditioning on Y , i.e. that is, filtering the data into groups in such a way that the value of Y is constant, the value of Z would remain unchanged, because of Z would remain unchanged, since it only depends on Y and UZ. Therefore, the selection of a different value of X does not change the value of Z, leading to the conclusion of the fourth point. fourth point.

An analogous reasoning to the previous one, would lead to the conclusion of the fourth point. any two variables X and Y , if the only path between them is built entirely of strings, these two variables would be independent. of strings, these two variables would be independent conditional on any intermediate variable on that path. intermediate on that path. This relation of independence holds whatever the functions connecting the variables, which is functions connecting the variables, which leads to a rule of thumb[47].

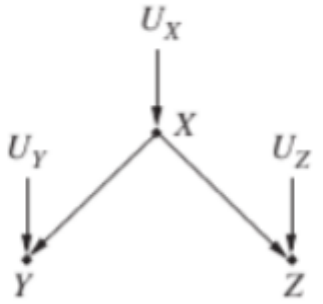
Definition 2.1.1. Rule 1 (Conditional Independence in Chains). Two variables, X and Y , are conditionally independent given Z, if there is only one unidirectional path between X and Y and Z is any set of variables that intercepts that path.

This rule only holds if the error terms UX, YY and UZ are assumed to be independent of each other.

Bifurcation

[47]Pearl, Judea, Madelyn Glymour y Nicholas P. Jewell (2016). Causal Inference in Statistics: A Primer. John Wiley & Sons, Ltd. isbn: 978-1-119-18684-7

The configuration shown in the following figure,, three nodes, with two edges leaving the central variable, is called a bifurcation. The central variable in a bifurcation is called the common cause of the other two variables and their descendants.



Causal diagram of a bifurcation showing the exogenous variables

Assuming that the error terms are independent, by examining the causal diagram in figure above, the following Theorem can be obtained:

Theorem 2.1.2. Relationship between variables in a bifurcation, Y ← X → Z:

- X and Y are dependent: For some x and y, P (X = x|Y = y) ≠ P (X = x)
- X and Z are dependent: For some x and z, P (X = x|Z = z) ≠ P (X = x)
- Z and Y are probably dependent: For some z and y, P (Z = z|Y = y) ≠ P (Z = z)
- Y and Z are independent conditional on X: For all x, y and z, P (Y = y|X = x, Z = z) = P (Y = y|X = x).

The first and second points come, once again, from the fact that Y and Z are directly connected to X, so when the value of X changes, the values of Y and Z change. If Y changes when X changes, and Z changes when X changes, Y probably changes along with Z, and vice versa. If we condition on X, we compare cases where X is constant, so that the values of Y and Z do not change according to X, but only with respect to UY and UZ , respectively. As the latter are independent, the third point is reached.

Following the same reasoning as in the chain case, if we compare the cases where the value of X is constant, the values of Y and Z do not change according to X, they only change in response to UY and UZ , which have been assumed to be independent. Therefore, any further changes in the values of Y and Z must be independent of each other, leading to the fourth point. Again, this reasoning leads to a rule[48].

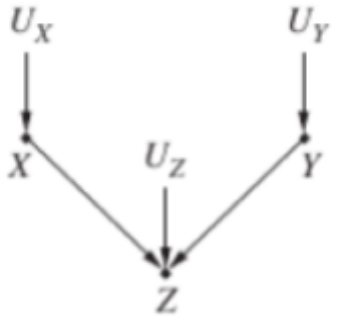
Definition 2.1.2. Rule 2 (Conditional Independence at Bifurcations). If a variable X is a common cause of variables Y and Z, and there is only one path between Y and Z, then Y and Z are conditionally independent at X.

Collider

The last configuration, shown in Figure 3.5, consists of three nodes, with two edges reaching the central variable, and is called a collider. The central variable is called the

[48] Pearl, Judea, Madelyn Glymour y Nicholas P. Jewell (2016). Causal Inference in Statistics: A Primer. John Wiley & Sons, Ltd. isbn: 978-1-119-18684-7

collision node or collider and represents a common effect of two causes, the other two variables.



Causal diagram of a collider showing exogenous variables

As in the other cases, by looking at the causal diagram in Figure 3.5, the following Theorem can be obtained:

Theorem 2.2.3. Relationship between variables at a collider, $X \rightarrow Z \leftarrow Y$:

- X and Y are dependent: For some x and y, $P(X = x|Z = z) \neq P(X = x)$
- X and Z are dependent: For some x and z, $P(Y = y|Z = z) \neq P(Y = y)$
- Z and Y are probably dependent: Para todos los x e y, $P(X = x|Y = y) = P(X = x)$
- X e Y son dependientes condicionadas en Z: For some x, y or z, $P(X = x|Y = y, Z = z) \neq P(X = x|Z = z)$

The first two points follow the same reasoning as in the previous cases. The third point in this case is an evidence, since neither X nor Y are descendants or ancestors of each other, nor do they depend on each other for their respective values. However, if you condition on Z, you limit the cases to which Z has a particular value. But Z depends on X and Y , so any change in the value of X has to be compensated by a change in the value of Y , otherwise the value of Z would change.

These considerations lead to a third rule[49]:

Definition 2.1.3. Rule 3 (Conditional independence at colliders). If a variable Z is the collision node between two variables X and Y , and there is only one path between X and Y , then X and Y are unconditionally independent but are conditionally dependent on Z and any descendants of Z .

Causal models are usually not as simple as the cases that have been studied so far. In particular, it is rare for a causal diagram to consist of a single path between variables. In most cases, pairs of variables will have multiple possible paths connecting them, and each of these paths will pass through a variety of chains, bifurcations and collisions. The following section presents a process that can be applied to any causal diagram, regardless of its complexity, to predict the dependencies between variables.

[49] Pearl, Judea, Madelyn Glymour y Nicholas P. Jewell (2016). Causal Inference in Statistics: A Primer. John Wiley & Sons, Ltd. isbn: 978-1-119-18684-7

11.1.3. d-Separación

The d-separation criterion makes it possible to determine, for any pair of nodes, whether they are d-connected, which means that there is a connecting path between them, i.e. the variables are probably dependent, or, on the contrary, whether they are d-separated, which means that there is no such path and therefore the variables they represent are definitely independent. It is sufficient that there is only one non-blocked path for both nodes to be d-connected.

Taking into account the relationships obtained in the previous section, a classification of the types of nodes that can block a path can be established, depending on whether an unconditional or conditional d-separation is performed:

- If not conditioned on any variable, only collision nodes can block a path, since unconditional dependency cannot pass through them.
- If conditioned on a set of Z nodes, the following types of nodes can block a path:
    - A collision node that is not in Z and has no descendants in Z (see Definition 2.1.1).
    - A chain or a branch whose central node is in Z (see Definitions 2.2.2 and 2.1.3).

Taking these relationships into account, it is possible to give a formal definition of d-separation:

Definition 2.1.4. d-separation. A path p is blocked by a set of nodes Z if and only if:

1. p contains a chain of nodes $A \rightarrow B \rightarrow C$ or a bifurcation $A \leftarrow B \rightarrow C$ such that the central node B is in Z, i.e., B is conditional, or
2. p contains a collider $A \rightarrow B \leftarrow C$ such that the collider node B is not in Z, and no descendants of B are in Z.

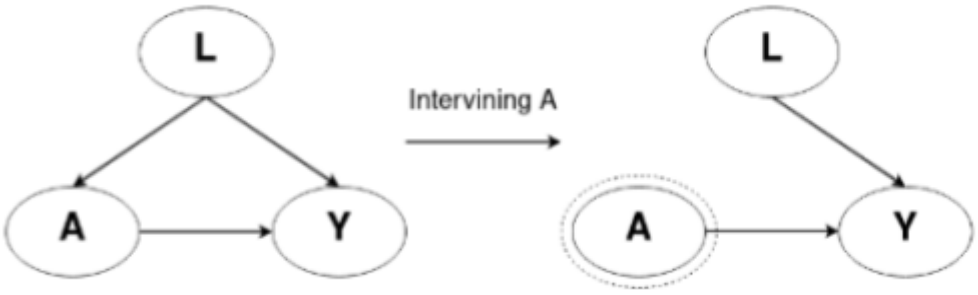
If Z blocks all paths between two nodes X and Y , then X and Y are d-separated, conditional on Z, and therefore they are conditionally independent conditional on Z.

With the d-separation criterion it is possible to analyse more complex causal diagrams and determine which variables are independent and dependent, both marginally and conditional on other variables. This is possible regardless of the causal model to which the diagram belongs, i.e. whatever the types of variables and the relationships between them. At this point, it is possible to enter into the ultimate goal of many statistical studies, the prediction of the effects of interventions.

11.1.4. Interventions

When you intervene to fix the value of a variable, you restrict the natural tendency of that variable to vary in response to other variables. This is tantamount to performing a kind of surgery on the causal diagram, removing all edges directed at that variable.

The following figure shows how the causal diagram for the example presented in Section 2.1.3 would change after an intervention in treatment A. It can be seen how intervening on a variable results in a completely different pattern of dependencies than the pattern of dependencies caused by conditioning on the variable.



Causal diagram after an intervention in A

To understand the efficacy of a treatment in the population, a hypothetical intervention is imagined in which the treatment is administered uniformly to the entire population and the outcome is compared with the outcome that would be obtained with the complementary intervention. This would be denoted as:

$$P(Y = y|do(A = 1)) - P(Y = y|do(A = 0)) \quad (2.1)$$

This difference is known as the difference in causal effect or average causal effect, which, as can be seen, corresponds to expression 3.12 As is well known so far, causal effects cannot be estimated directly from the data without a causal diagram. However, from the causal diagrams above, an expression for calculating such an effect can be obtained from Equation 2.1.

The key to calculating it is to keep in mind that the causal effect is equal to the conditional probability in the manipulated diagram after the intervention, i.e:

$$P(Y = y|do(A = a)) = P_m(Y = y|A = a) \quad (2.2)$$

So the manipulated probability P_m shares two essential properties with the probability P, corresponding to the original probability in the diagram before intervention:

- The marginal probability $P(L = l)$ is invariant under intervention (the proportions of males and females remain constant after intervention)
- The conditional probability $P(Y = y|L = l, A = a)$ is invariant under intervention, since the process by which Y responds to A and L is the same, regardless of whether A changes spontaneously or by manipulation.

Moreover, it can be checked that L and A are d-separated in the modified diagram, since they meet the criteria given in Definition 2.1.4, which means that $P_m(L = l|A = a) = P_m(L = l) = P(L = l)$. Therefore:

$$P(Y = y|do(A = a)) = P_m(Y = y|A = a) = \quad (2.2)$$

$$= \sum P_m(Y = y|A = a, L = l)P_m(L = l|A = a) = \quad (2.5)$$

$$= \sum P_m(Y = y|A = a, L = l)P_m(L = l) \quad (2.6)$$

Equation 2.4 is given by definition, i.e. by directly applying Equation 2.3. Equation 2.5 is obtained from Bayes' Rule, Equation 2.6, by conditioning on L and summing over all its possible values. Finally, equation 2.6 is obtained from the independence of L and A in the

modified diagram. Thus, using the invariance relationships described above, we obtain an expression for the causal effect in terms of the probabilities before the intervention:

$$P(Y = y|do(A = a)) = \sum P(Y = y|A = a, L = l)P(L = l) \quad (2.7)$$

Known as the fit formula, which, as can be seen, calculates the association between A and Y for each z-value of Z, averaging over those values. Furthermore, it can be seen that this expression corresponds to Equation 2.7. It should be noted that in a randomised controlled experiment no adjustment is necessary, since, in that case, the data are generated by a model that already has the modified structure, so that Pm = P regardless of any factors affecting Y . This derivation of Equation 2.7. is thus a formal proof that randomisation yields the quantity to be estimated, P (Y = y|do(A = a)).

This adjustment formula is easily generalisable. The procedure leading to this formula dictates that L must coincide with the parents of A, denoted by P A, since it is the influence of these parents that is neutralised when the value of A is fixed by an external manipulation. Therefore, a rule can be established[50].

Definition 2.1.5. (The Causal Effect Rule). Given a graph G in which a set of variables P A are designated as the parents of X, the causal effect of X on Y is given by:

$$P(Y = y|do(X = x)) = \sum z P(Y = y|X = x, PA = z)P(PA = z) \quad (3.8)$$

or in a more convenient and summarised form:

$$P(y|do(x)) = \sum z\, P(x, y, z) / P(x|z) \quad (3.9)$$

where z encompasses all combinations of values that the AP variables can take.

As can be seen, The Causal Effect Rule is nothing more than an application of the Total Probability Theorem, $P(x) = P(x; y_1) + P(x; y_2) + : : : + P(x; y_n)$ and $P(x; y) = P(x|y)P(y)$. Moreover, there is a strong similarity between this expression and Eq:

$$P(Y^a) = \sum_l \frac{P(Y, A = a, L = l)}{P(A = a|L = l)} = \sum_l P(Y, A = a, L = l)W^a$$

and similarly, the factor P (X = x|P A = z) is known as the propensity score.

This result is very interesting, because using causal diagrams and their underlying assumptions, it is possible to identify causal relationships in purely observational data, i.e. data that do not come from controlled experiments.

However, in most practical cases, this is not as straightforward as in the example shown. Usually the parent set of X will contain unobserved variables that would preclude calculating the conditional probabilities needed to use the fitting formula. In the next two sections, two criteria are shown that allow other variables in the causal diagram to be adjusted to replace the unmeasured elements of P A, the back-door criterion and the front-door criterion.

[50]Pearl, Judea, Madelyn Glymour y Nicholas P. Jewell (2016). Causal Inference in Statistics: A Primer. John Wiley & Sons, Ltd. isbn: 978-1-119-18684-7

11.1.5. Backdoor criteria

The Back Door Criterion allows one to determine, for any two variables X and Y in a causal model represented by a DAG, on which set of variables Z of that model one should condition when looking for the causal relationship between X and Y[51].

Definition 2.1.6. (The Backdoor Criterion). Given a pair of variables (X, Y) ordered in a directed acyclic graph G, a set of variables Z satisfies the backdoor criterion relative to (X, Y) if no node in Z is a descendant of X, and Z blocks all paths between X and Y that contain an edge towards X.

If a set of variables Z satisfies this criterion for X and Y , then the causal effect of X on Y is given by the following formula:

$$P(Y = y|do(X = x)) = \sum z\, P(Y = y|X = x, Z = z)P(Z = z) \tag{2.10}$$

It is worth noting that the parents of X always satisfy the backdoor criterion, so one can always use this equation if Z = P A(X).

The logic behind this criterion is quite simple. In general, one seeks to condition a set of nodes Z such that:

- Block all spurious paths between X and Y , i.e., all paths that do not belong to the causal or direct path from X to Y.
- Leave all direct paths from X to Y undisturbed.
- Do not create new spurious paths between X and Y.

When you want to find the causal effect of X on Y , you want the nodes you condition on to block any backdoor paths where one end has an edge to X, since such paths can make X and Y dependent even though they are obviously not transmitting causal influences from X, and if they are not blocked, they will confound the effect that X has on Y. Therefore, you condition on backdoor paths to meet the first requirement.

On the other hand, you do not want to condition on any nodes that are descendants of X. The descendants of X would be affected by an intervention on X and could themselves affect Y ; conditioning on them would block those paths. Therefore, the descendants of X are not conditioned, fulfilling the second requirement.

Finally, to fulfil the third requirement, one must not condition on any collider that unlocks a new pathway between X and Y . The requirement to exclude the descendants of X also protects from conditioning on the children of intermediate nodes between X and Y. Such conditioning would distort the passage of the causal association between X and Y, much as conditioning on their parents would.

11.1.6. Front Door Criterion

The back-door criterion provides a simple method for identifying the sets of covariates, i.e. variables that possibly predict the outcome under study, that need to be adjusted for when seeking to estimate causal effects from observational data. However, it is not the

[51]Pearl, Judea, Madelyn Glymour y Nicholas P. Jewell (2016). Causal Inference in Statistics: A Primer. John Wiley & Sons, Ltd. isbn: 978-1-119-18684-7

only way to estimate such effects. The do() operator can be applied to causal diagrams that do not satisfy the backdoor criterion to identify effects that at first glance appear to be beyond our reach. One such criterion is the Front Door Criterion.

Definition 2.1.7. (Front Door Criterion). A set of variables Z is said to satisfy the front door criterion relative to an ordered pair of variables (X, Y) if:

1. Z intercepts all direct paths from X to Y.
2. No unblocked path exists from X to Z
3. All back-door paths from Z to Y are blocked by X.

Theorem 2.1.4. (Front Door Setting). If Z satisfies the front door criterion relative to (X, Y) and if P (x, z) > 0, then the causal effect of X on Y is identifiable and is given by the front door formula:

$$P(Y = y|do(X = x)) = \sum z\, P(Z = z|X = x) \sum x'\, P(Y = y|X = x', Z = z)P(X = x') \qquad (2.11)$$

where z represents all possible values that the variables in Z can take and x′ all possible values that X can take.

The conditions stated in Definition 2.1.7 are too conservative, some of the backdoor paths excluded by the last two conditions may actually be allowed as long as they are blocked by some variables.

The combination of the adjustment formula, the back-door criterion and the front-door criterion covers numerous causal scenarios. However, there is a powerful symbolic machinery called do-Calculus that allows us to analyse all kinds of causal diagrams regardless of their complexity. In fact, the do-Calculus discovers all causal effects that can be identified from a given graph.

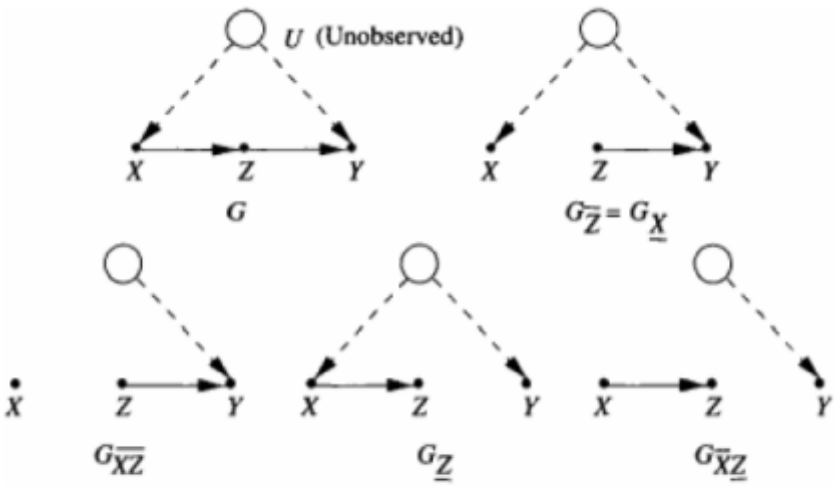
11.1.7. do-Calculus

This section establishes a set of inference rules by which probabilistic operations involving interventions and observations can be transformed into other such statements, thus providing a syntactic method for deriving statements about interventions. Each inference rule shall respect the interpretation of the do() operator as an intervention that modifies a selected set of functions in the underlying model. The set of inference rules that emerge from this interpretation will be called do-Calculus[52].

The structure of the causal diagram is assumed to be known in which some of the nodes are observable while others remain unobserved. The aim is to facilitate the gradual reduction of expressions of the type P(y|do(x)) to equivalent expressions involving standard probabilities of the observed quantities, known as derivation of the causal effect. Provided that such a reduction is feasible, the causal effect is identifiable.

Let X, Y and Z be disjoint sets of nodes in a causal DAG G. Denote by $G_{\bar{X}}$ the graph obtained by eliminating from G all edges pointing to nodes in X. Similarly, denote by $G_{\underline{X}}$ the graph obtained by eliminating from G all the outgoing edges of the nodes in X. To represent the elimination of both incoming and outgoing edges, $G_{\bar{X}\underline{Z}}$ is used, see below.

[52] Pearl, Judea (2000). Causality: Models, Reasoning and Inference. Cambridge University Press. isbn:978-0-521-89560-6.



Subgraphs of G used in the derivation of causal effects

Theorem 2.1.5. (Rules of the do-Calculus). Let G be a directed acyclic graph associated with a causal model, and let P() be the probability distribution induced by that model. For any disjoint subsets of variables X, Y , Z and W , we have the following rules:

Rule 1 Insertion/suppression of observations.

$$P(y|do(x), z, w) = P(y|do(x), w) \ si \ (Y \perp\!\!\!\perp Z|X; W)_{G_{\bar{X}}} \tag{3.12}$$

Rule 2 Exchange of actions/observations.

$$P(y|do(x), do(z), w) = P(y|do(x), z, w) \ si \ (Y \perp\!\!\!\perp Z|X; W)_{G_{\bar{X}\underline{Z}}} \tag{3.13}$$

Rule 3 Insertion/deletion of actions

$$P(y|do(x), do(z), w) = P(y|do(x), w) \ si \ (Y \perp\!\!\!\perp Z|X; W)_{G_{\bar{X}\bar{Z}(W)}} \tag{3.14}$$

where Z(W) is the set of Z-nodes that are not ancestors of any W-node in $G_{\bar{X}}$.

Rule 1 restates d-separation as a valid test for conditional independence in the distribution resulting from the intervention do(X = x), hence the graph $G_{\bar{X}}$. This rule follows from the fact that the elimination of the equations of the system does not introduce any dependence between the remaining disturbance terms.

Rule 2 provides a condition for an external intervention do(Z = z) to have the same effect on Y as the passive observation Z = z. The condition is equivalent to {X ∪ W} blocking all backdoor paths from Z to Y (in $G_{\bar{X}}$), since $G_{\bar{X}\underline{Z}}$ preserves all and exclusively those paths.

Rule 3 establishes the conditions for introducing, or eliminating, an external intervention do(Z = z) without affecting the probability of Y = y. The validity of this rule derives, again, from simulating the intervention do(Z = z) by suppressing all the equations corresponding to the variables of Z, hence the graph $G_{\bar{X}\bar{Z}}$.

Corollary 2.1.5.1. A causal effect q = P (yl, ..., yk)|do(x1), ..., do(x_m) is identifiable in a model characterised by a graph G if there exists a finite sequence of transformations, each conforming to one of the inference rules of Theorem 3.1.5, which reduces q to a standard probability expression involving observed quantities.

Theorem 2.1.6. Rules 1-3 are complete.

That these rules are complete means that they are sufficient to derive all identifiable causal effects. The proof of Theorem 2.1.6 can be found in the literature[53].

The task of deciding whether a sequence of rules exists to reduce an arbitrary causal effect expression can be a very complex job. This is why different software is used for causal analysis. The following section presents the tasks that causal models must provide to be useful and classifies the libraries available to build these models according to these tasks.

11.1.8. The Seven Tools of Causal Inference

According to Pearl[54], causal models need to provide seven tasks to be useful. The following is an overview of these tasks in the SCM framework, the tools used in each, and the unique contribution each tool makes to the art of automated reasoning.

- **Coding Causal Assumptions - Transparency and Verifiability**. Transparency allows analysts to discern whether the coded assumptions are plausible or whether additional assumptions are warranted. Testability allows one to determine whether the coded assumptions are compatible with the available data and, if not, to identify those that need to be repaired. Testability is facilitated by the graphical criterion d-separation, which provides the fundamental connection between causes and probabilities[55].
- **The do-Calculus and Confounding Control**. For models where the backdoor criterion is not met, the do-Calculus is available, which predicts the effect of interventions whenever possible[56].
- **The Algorithmisation of Counterfactuals**. This task formalises the counterfactual reasoning within the graphical representation. Each structural equation model determines the truth value of each counterfactual statement.
- **Mediation Analysis and Evaluation of Direct and Indirect Effects**. This task refers to the mechanisms that transmit changes from a cause to its effects, which is essential for generating explanations, and counterfactual analysis must be used to facilitate the identification of these.
- **Adaptability, External Validity and Sample Selection Bias**. Robustness is recognised by AI researchers as a lack of adaptability that comes to the fore when environmental conditions change. The do-Calculus offers a comprehensive methodology to overcome biases due to changes in the environment.

[53] Shpitser, Ilya y Judea Pearl (2006). «Identification of Joint Interventional Distributions in Recursive Semi-Markovian Causal Models». En: Proceedings of the Twenty-Second Conference on Uncertainty in Artificial Intelligence, págs. 437-444.
[54] Pearl, Judea y Dana Mackenzie (2018). The Book of Why. Penguin Books. isbn: 978-0-141-98241-0.
[55] Pearl, Judea (1988). Probabilistic reasoning in intelligent systems: networks of plausible inference. Morgan Kaufmann. isbn: 978-0-934613-73-6.
[56] Shpitser, Ilya y Judea Pearl (2008). «Complete Identification Methods for the Causal Hierarchy». En: Journal of Machine learning Research 9.9, págs. 1941-1979. url: https://www.jmlr.org/papers/volume9/shpitser08a/shpitser08a.pdf.

It can be used to readjust learned policies, to circumvent changes in the environment and to control for disparities between non-representative samples and a target population[57].

- **Recovery of Missing Data.** The use of causal models can formalise the conditions under which causal and probabilistic relationships can be recovered from incomplete data and, provided the conditions are met, produce a consistent estimate of the desired relationship.
- **Causal Discovery.** The d-separation criterion detects and lists testable implications of a given causal model. This opens up the possibility of inferring, with mild assumptions, the set of models that are compatible with the data, and of representing this set in a compact form. Under certain circumstances, the set of compatible models can be significantly pruned to the extent that causal questions can be estimated directly from that set[58].

In addition to these seven tasks, certain implementation aspects have been taken into account for the selection of the library:

Licensing. The licence that the library and the rest of the environment (IDE) have. Only open source models have been found.

- **Programming language.** The programming language used to build the models. All the libraries considered are implemented in R or Python, some of them accept both.
- **Documentation and Support Channels.** In all cases there is good written documentation (tutorials, API descriptions, examples and Q&A guides).
- **Tools for writing Causal Diagrams.** Availability of support tools for writing from scratch, uploading and modifying and converting from different file formats the causal diagram.

Table 10 presents the different libraries considered, as well as their main features based on the seven tasks and implementation requirements detailed above. As can be seen, DoWhy (Sharma, Kiciman et al., 2019 and Sharma and Kiciman, 2020) is the only library that covers all the tasks. Moreover, it has a very permissive licence, has several bindings to different programming languages and has one of the most active communities. For all these reasons, DoWhy, implemented through the Python programming language, will be the library used to implement the Causal Model that will be developed in the project.

Features	DAGitty	DoWhy	Causal Graph Models	Causality	Causal Inference
Codification of assumptions causality, Transparency and Verifiability	✔	✔	✔	✔	✔
do-Calculus and Confusion control	✔	✔	✔	✔	✔
Algorithmization of Counterfactuals	✔	✔		✔	✔
Mediation analysis and Evaluation of	✔	✔	✔	✔	✔

[57] Bareinboim, Elias y Judea Pearl (2016). «Causal inference and the data-fusion problem». En: Proc Natl Acad Sci 113(27). doi: 10.1073/pnas.1510507113.

[58] Jaber, A., J.J. Zhang y E. Bareinboim (2018). «Causal Identification under Markov Equivalence''. En: Proceedings of the Thirty Fourth Conference on Uncertainty in Artificial Intelligence, 978–987.

direct and indirect effects					
Adaptability, External validity and Sample selection bias	✔	✔			
Lost data recovery		✔			
Discovery of the cause	✔	✔	✔	✔	
Tools for generating causal diagrams	✔	✔	✔	✔	✔
Licence	GNU	MIT	MIT	Open	BSD
Programming language	R	R/Python	Python	Python	Python
Documentation and support	✔	✔	✔	✔	✔

Table 10: Main features of the different libraries available to implement the Causal Model

11.2. Psychological theories

11.2.1. Social Cognitive Theory and Agency

The concept of collective agency and self-determination (understood as empowerment) is closely linked to the theories of Human Development and the capabilities approach originally proposed by Amartya Sen (2000)[59]. This approach, also known as the capabilities approach, is based on Sen's revision of Rawls' theory of justice[60] in terms of primary goods, which translates into a theoretical approach to assess various aspects of individual, group and societal well-being, such as inequality, poverty, lack of development and quality of life. This capabilities approach has a highly evaluative and normative dimension and this is where the concept of agency comes in. According to Sen, agency is the ability to define one's own goals autonomously and to act on them: "*that which a person is free to do and achieve in pursuit of goals or values that he or she considers important*" (Sen, 1985, p. 203). In subsequent literature this definition has been complemented as a way of explaining aspects of autonomous human functioning (Alkire, 2008[61]; Archer, 2000[62]; Bandura, 1996[63]; Kagitcibasi, 2005[64]) by referring to personal competence, placing the main focus on the individual as an actor operating in a social context. As a concept with a strong evaluative dimension, the Personal Agency and Empowerment Scale (ESAGE) developed by Pck et al. (2007)[65], which incorporated items grouped into the following variables: 1) Self-efficacy, 2) Self-determination, 3) Control over my behaviours, 4) Independent thinking, 5) Identification of need for change, 6) Fear of success, 7) Recognition of my learning, 8) Perception of my context and 9) Control over my environment, seems particularly relevant to us. Fig. 21 graphically represents this.

[59] Sen, A. (2000). A decade of human development. Journal of human development, 1(1), 17-23
[60] Rawls, J. (2020). A theory of justice. Harvard university press.
[61] Alkire, S. (2008). Concepts and measures of agency (p. 2). OPHI Working Paper 9, University of Oxford.
[62] Archer, M. S., & Archer, M. S. (2000). Being human: The problem of agency. Cambridge University Press.
[63] Bandura, A. (1989). Human agency in social cognitive theory. American psychologist, 44(9), 1175.
[64] Kagitcibasi, C. (2005). Autonomy and relatedness in cultural context: Implications for self and family. Journal of cross-cultural psychology, 36(4), 403-422.
[65] Pick, S., Sirkin, J., Ortega, I., Osorio, P., Martínez, R., Xocolotzin, U., & Givaudan, M. (2007). Scale for the Measurement of Personal Agency and Empowerment (ESAGE). Interamerican Journal of Psychology, 41(3), 295-304.

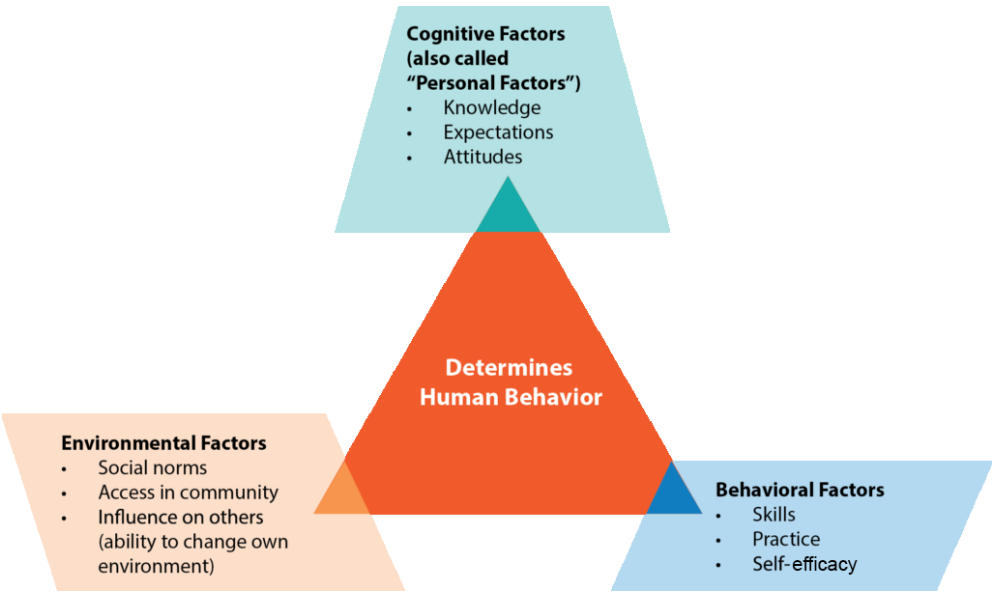


Figure 21: Main components of the Social Cognitive Theory

Very tightly coupled with the agency concepts, the Social Cognitive Theory is a theory about how humans learn behaviour by observing it in our environment, proposed by Albert Bandura in 1977. This theory models the interaction that occurs between an individual and the environment. For this reason, it is supported by three main aspects: Environmental Factors, Behavioural Factors, and Cognitive Factors, also called Personal Factors. In the Social Cognitive Theory, a key concept developed by Bandura was reciprocal determinism, which states that a person's behaviour both influences and is influenced by personal factors and the social environment. This concept was born in contrast to previous theories of learning that argued that people's behaviour was always controlled by the environment or the rewards that were given to them[66]. Observational learning is then the main concept of the Social Cognitive Theory. Bandura argued that learning can occur even in the absence of reinforcement and punishment and people can learn by simply observing others or collaborating with others as in the CoP. Besides, Social Cognitive Theory advocates for fostering people's expectations. This refers to the anticipated consequences of a person's behaviour. People anticipate the consequences of their actions before engaging in the behaviour, and these anticipated consequences can influence successful completion of the behaviour or enrollment. Finally, Social Cognitive Theory fosters the Self-efficacy which refers to the level of a person's confidence in his or her ability to successfully perform a behaviour. Self-efficacy is influenced by a person's specific capabilities and other individual factors, as well as by environmental factors (barriers and facilitators). The collective dimension of the Social Cognitive Theory was proposed by the same author in 2002[67] proposing three levels of agency: 1) personal agency exercised individually; 2) proxy agency in which people secure desired outcomes by influencing others to act on their behalf; and 3) collective agency in which people act in concert to shape their future. This final level is also encompassed by the perceived collective efficiency representing shared beliefs in the power to produce desired effects by collective action. Perceived collective efficiency is not simply the sum of the efficiency beliefs of individual members. Rather, it is an emergent group-level property that

[66] Skinner, B. F. (1988). The selection of behavior: The operant behaviorism of BF Skinner: Comments and consequences. CUP Archive.
[67] Bandura, A. (2002). Social cognitive theory in cultural context. Applied psychology, 51(2), 269-290.

embodies the coordinative and interactive dynamics of group functioning. In essence, according to this theory, interventions should:

- Promote role models who practise the desired behaviours and experience resulting benefits. This can be done through education activities, and through community events in which people performing the desired behaviours are celebrated so others can be influenced by them.
- Promote the intrinsic and extrinsic rewards and benefits that can be expected from engaging in the desired behaviours.
- Provide information, tools and skills to increase people's perceived ability to engage in the desired behaviours.

Finally, it is worth mentioning that the collective efficacy pathway proposed by Bandura is only one of the options for the people to take collective action. Other models reviewed by Bamberg, S., Rees, J., & Seebauer, S. (2015)[68] are: 1) The cost-benefit pathway; 2) The group-based emotions pathway; and 3) The social identity pathway. The emerging model will be fed by the collective efficacy pathway, though.

11.2.2. Self-determination Theory, Social practice and Basic Psychological needs

Shove et al.[69] already explored how practices are constructed through Social Practice theory. Shove and colleagues contextualise practices as units of analysis, understanding them like an entity composed of three main elements. These elements are human competencies (i.e., skills and knowledge needed to perform a practice), meaning (i.e., emotions and feelings emerged from the practice) and materials (e.g., artefacts, tools, and infrastructures). This framework considers these elements as linked, and thus, any changes will have an impact on the entire practice. Following this rationale, any variation in materials will influence the meaning of the practice. Pre-defining the meaning of a practice will not get people to engage in it. The question of why people engage in some practices and not others is based on their motivation. Hence, an effective, sustainable practice is both motivating and pro-environmental. Considering the motivation to perform a practice, Klapperich et al. propose an approach that links the fulfilment of basic psychological needs (e.g., competence, relatedness, autonomy) with the meaning of practices. Based on Experience Design by Hassenzahl et al.[70][71], the approach describes that the design of the technology forms the meaning of a practice. However, people are more likely to perform a practice if it fulfils a psychological need (i.e., is motivating). Thus, if an individual feels genuinely motivated when performing a specific practice, she will find it enjoyable and, therefore, will engage with it. Thus, the following work aims at finding the motivations and pleasures of being sustainable to improve the individuals' wellbeing while developing Pro-Environmental actions.

[68] Bamberg, S., Rees, J., & Seebauer, S. (2015). Collective climate action: Determinants of participation intention in community-based pro-environmental initiatives. Journal of Environmental Psychology, 43, 155-165.

[69] Elizabeth Shove, Mika Pantzar, and Matt Watson. 2012. The Dynamics[1] Elizabeth Shove, Mika Pantzar, and Matt Watson. 2012. The Dynamics of Social Practice: Everyday Life and how it Changes.

[70] Marc Hassenzahl, Sarah Diefenbach, and Anja Göritz. 2010. Needs, affect, and interactive products - Facets of user experience. Interact. Comput. 22, 5 (2010), 353–362. DOI:https://doi.org/10.1016/j.intcom.2010.04.002

[71] Marc Hassenzahl, Kai Eckoldt, Sarah Diefenbach, Matthias Laschke, Eva Lenz, and Joonhwan Kim. 2013. Designing moments of meaning and pleasure. Experience design and happiness. Int. J. Des. 7, 3 (2013), 21–31

Furthermore, among the most influential models in contemporary behavioural science, self-determination theory offers a broad framework for understanding the factors that promote human motivation and psychological flourishing. In this authoritative work, SDT co-founders Richard M. Ryan and Edward L. Deci systematically review the theory's conceptual underpinnings, empirical evidence base, and practical applications across the lifespan[72]. Ryan and Deci demonstrate that supporting people's basic needs for competence, relatedness, and autonomy is critically important for virtually all aspects of individual and societal functioning as can be seen in Fig. 22. In their manuscript, beginning with theoretical foundations, they explored how self-determination theory was developed and how it diverges from other major approaches to human motivation and self-regulation.

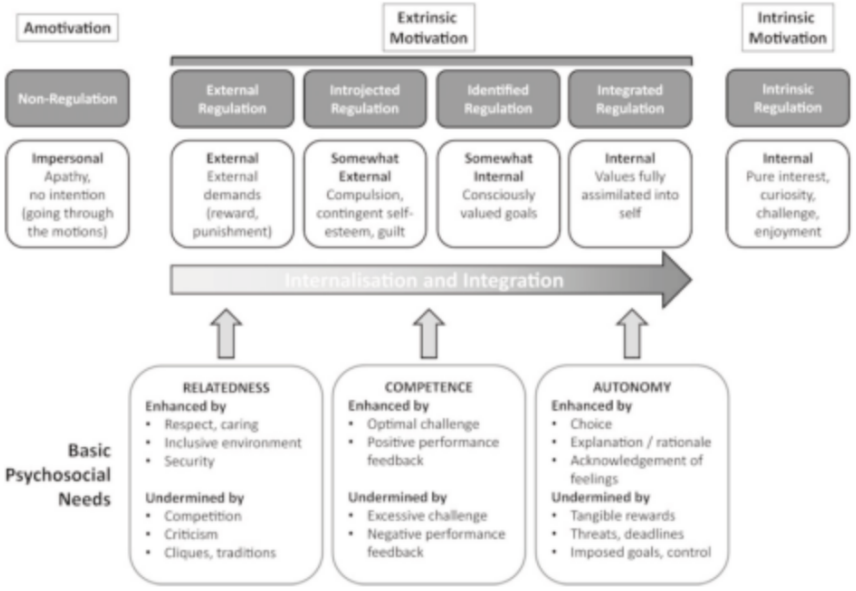


Figure 22: Main components of the self-determination theory

11.3. Transtheoretical model

The Transtheoretical Model (TTM) uses a temporal dimension, the stages of change, to integrate the processes and principles of change from the major intervention theories. This model emerged from a comparative analysis of the major theories of psychotherapy and behaviour change in an effort to integrate a field that had become fragmented into over 300 theories[73].

This impetus for the model emerged when Prochaska conducted a comparative analysis of people who quit smoking independently with those who undergo professional treatment[74]. Ten processes of change were identified as preceding successful smoking cessation, including awareness from Freud's theory, contingency management from Skinner's theory, and helping relationships from Rogers' theory (Prochaska, Redding and Evers, 2008):

[72] Ryan, R. M., & Deci, E. L. (2017). Self-determination theory: Basic psychological needs in motivation, development, and wellness. Guilford Publications.
[73] Prochaska, James y Wayne Velicer (sep. de 1997). «The Transtheoretical Model of Health Behavior Change». En: American journal of health promotion : AJHP 12, págs. 38-48. doi: 10.4278/0890-1171-12.1.38.
[74] Prochaska, James y Carlo Diclemente (ene. de 1982). «Trans-Theoretical Therapy - Toward A More Integrative Model of Change». En: Psychotherapy: Theory, Research and Practice 19, págs. 276-288. doi: 10.1037/h0088437

- **Awareness**. Finding and learning new facts, ideas and advice that support behaviour change.
- **Meaningful relief**. Experiencing the negative consequences of engaging in a certain behaviour.
- **Self-re-evaluation**. Realising that behaviour change is an important part of one's identity as a person.
- **Environmental reappraisal**. Realising the impact of behaviour change on the immediate environment.
- **Self-liberation** - making a firm commitment to change.
- **Helping relationships**. Seeking and using social support for behaviour change.
- **Counter-conditioning**. Substitution of the behaviour with a more appropriate alternative.
- **Reinforcement management**. Increasing rewards for positive behaviour change and decreasing rewards for negative behaviour change.
- **Stimulus control**. Adding cues or reminders to perform the more appropriate behaviour.
- **Reinforcement management**. Increasing rewards for positive behaviour change and decreasing rewards for negative behaviour change.
- **Stimulus control**. Adding cues or reminders to perform the most appropriate behaviour.
- **Social release**. Realising that social norms are changing in the direction of supporting appropriate behaviour change.

Participants used different processes at different times in their struggle with addiction. These individuals revealed to the researchers that behaviour change develops through a series of stages, a phenomenon that was not captured in any therapeutic theory and which led to the development of TMD.

11.3.1. Stages of change

In the past, behaviour change was understood as a discrete event, such as quitting smoking. TTM characterises behaviour change as a process that unfolds over time, a non-linear transition through a sequence of qualitatively distinct stages. At each stage there are individual, stage-specific sources of resistance to change that can keep people stuck at an early stage for a long period of time, so specific skills and strategies are needed. Successful transition through the stages is reflected in increasing readiness to change. The TTM is based on six stages of change:

- **Precontemplation**: a stage where people do not intend to act for a short period of time, usually measured as the next six months. People may be in this stage because they are not well informed about the consequences of their behaviour or they may have tried to change several times and have become demoralised.
- **Contemplation**: A stage where people are trying to change their behaviour over the next six months. They are more aware of the pros of change, but are also very conscious of the cons. This balancing of pros and cons can produce deep ambivalence and keeps people stuck in contemplation for long periods of time.
- **Preparation**: a stage where people intend to act soon, usually within the next six months. Usually they have already taken some significant step towards the behaviour in the last year and have a plan of action.

- **Action**: stage where people have made concrete and overt lifestyle changes in the last six months. Not all behavioural changes count as action in this model, certain criteria that scientists and practitioners consider sufficient must be met.
- **Maintenance**: stage where people have made specific and overt lifestyle modifications and work to avoid relapse, they do not apply the change processes as frequently as people in action. They are increasingly confident that they can continue with the changes.
- **Completion**: stage where people have zero temptation to relapse and 100% self-efficacy. It is as if the behaviour never existed in the first place or their new behaviour has become automatic. This criterion may be too strict, being an ideal goal for most people.

11.3.2. Evolution of the Transtheoretical Model

Originally the TTM was developed to understand the adoption of personal health behaviours, however, this model has been transferred to other fields. Bamberg proposed the Stages Model of Self-Regulated Behaviour Change[75], a model that assumes that environmental behaviour change can be characterised as a transition through an orderly sequence over time through four qualitatively different stages, the name of which is borrowed from the Transtheoretical Model.

The TTM has been criticised for being a mainly descriptive model, which does not provide clear answers to important questions such as the separation of the stages and the processes that trigger the transition between them. For this reason, the Stages Model of Self-Regulated Behaviour Change integrates the stage concept with well-established constructs taken from the TPB[76] and the NAM[77], giving a detailed description of the tasks that a person has to solve in the four stages considered, as well as the specific cognitive mindset that people adopt to solve them. The model assumes that the transition through the stages is marked by three critical transition points, goal intention, behavioural intention and performance intention, which reflect the successful solution of the specific tasks of each stage:

- **Precontemplation**: the process of change begins when people start to consciously reflect on their current behaviour, realising that it causes negative social and environmental effects. If the person accepts their individual responsibility, they will experience negative effects such as guilt and feel concerned about what others expect them to do (social norms), feeling obliged to change this behaviour (personal norm).

  If the personal norms and the positive emotions for meeting them are strong and the perceived feasibility of changing the current behaviour is high, a goal intention is formed which indicates the transition to the second stage.

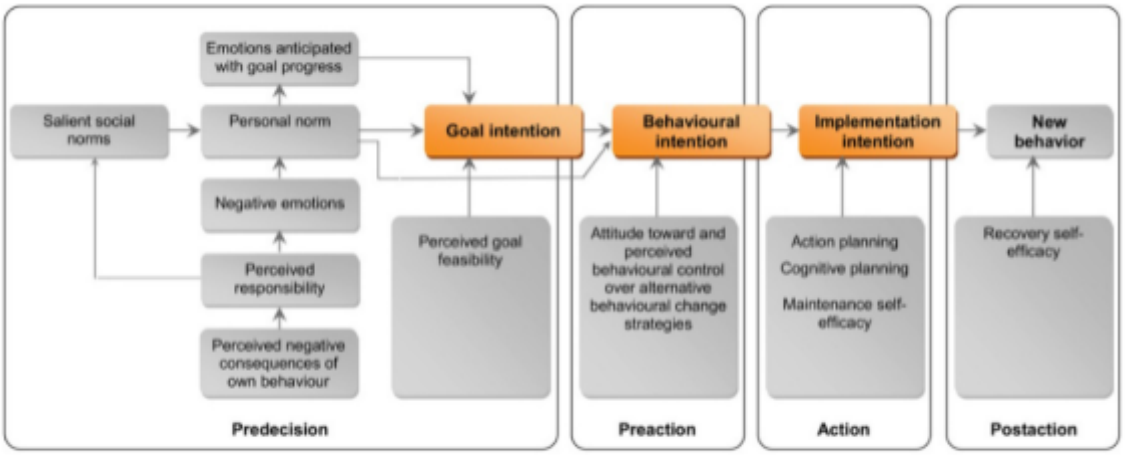
[75] Bamberg, Sebastian (jun. de 2013a). «Changing environmentally harmful behaviors: A stage model of self-regulated behavioral change». En: Journal of Environmental Psychology 34, págs. 151-159. doi: 10.1016/j.jenvp.2013.01.002.
— (2013b). «Environmental psychology: An introduction». En: BPS textbooks in psycho logy. Cap. Processes of change, págs. 267-279

[76] Theory of planned behaviour (Ajzen, 1991) assumes that attitude, perceived behavioural control (PBC) and subjective norms are central socio-cognitive factors that promote the formation of behavioural intention.

[77] Norm activation model (Onwezen, Antonides, & Bartels, 2013) assumes that when an individual becomes aware that their current behaviour has harmful consequences for other people and/or the environment (consequence awareness) and accepts personal responsibility for causing this harm (attribution of responsibility), this can lead to negative feelings such as guilt. It also assumes that activation of a personal norm leads to anticipation of positive emotions (pride, satisfaction) associated with behaviour more in line with the personal norm.

- **Contemplation**: the person values the personal consequences associated with alternative behavioural options (reflected in their attitude), as well as that of carrying it out (reflected in perceived behavioural control). Behavioural intention, which marks the transition between the contemplation stage and the preparation/action stage, is the result of the person's weighing of the pros and cons of different behavioural options to achieve the goal, as well as the perceived difficulty of carrying out these options.
- **Preparation/action**: The main task of this stage is to initiate the actions necessary to implement the new behavioural intentions. This is done by planning when and where to act in order to achieve the intended goal by performing the intended behaviour. Here, cognitive planning abilities and skills to cope with actual or anticipated performance problems are important variables. At the end of this phase, an implementation intention is established and the behaviour is carried out.
- **Maintenance**: involves the stabilisation of the modified behaviour and the implementation of new routines or behavioural habits based on the modified behaviour. The task at this stage is to cope with unpleasant experiences with the new behaviour and the consequent temptation to return to the previous behaviour.

This requires the skills to resist this temptation and, if a relapse occurs, the skills to recover and re-establish the new behaviour.



El Modelo de Etapas de Cambio de Comportamiento Autorregulado

This model is used in the systematic development of interventions aimed at promoting environmentally relevant behaviour change. Christian Klöckner, using a variation of the Stages of Self-Regulated Behaviour Change Model, tested the specific effect of 24 barriers and drivers at different stages of decision-making on energy efficiency improvement in private households. In his study, he proposes the use of four distinct stages. The first stage is "not being in decision mode", which corresponds to the mindset of the precontemplation stage in Bamberg's model. The second he called "deciding what to do", which has a clear link to the contemplation stage.

The third, "deciding how to do it" would be positioned between contemplation and action. And finally, the fourth stage, "deciding how to implement it" corresponds to Bamberg's action stage. The figure below shows the most relevant barriers and drivers for progression through the different stages.

The analysis of barriers and drivers for energy efficiency improvement decisions at each stage provides information that would be lost if the barriers and drivers were analysed without taking into account how far the decision-maker has gone in the decision making process. In this study, the non-linearity of the process is not sufficiently represented and the last stage of the decision process, i.e. whether the measures decided upon were actually implemented at some point in time, was not taken into account.

At the same time, the correlations between stages 2-4 are high, indicating that they are probably not sufficiently distinct or that the measurement instrument was not good enough.

Despite these drawbacks, these results could be used to find ways to promote the adoption of energy efficiency measures in residential buildings and other high-cost pro-environmental investments. They can also be used to adapt communication and support schemes, both public and private, to get stakeholders over the threshold to implement this technology.

Undoubtedly, this is one of the main objectives of the WHY project, to find the causes that lead to the adoption of measures for the decarbonisation of the residential sector in order to be able to intervene on them through different policies. This is why the different Causal Models that are built for the different aspects of the energy transition are based on the Transtheoretical Model described in this section, and in particular, the model described in Klöckner and Nayum, 2016[78]. This is intended to provide the Causal Models with a faithful representation of human behaviour, and with the main drivers that lead to positive change in it.

[78] Klöckner, Christian A. y Alim Nayum (sep. de 2016). «Specific Barriers and Drivers in Different Stages of Decision Making about Energy Efficiency Upgrades in Private Homes». En: Frontiers in Psychology 7. doi: 10.3389/fpsyg.2016.01362.

12. ANNEX C: Documentation shared with the panel of experts

Buildings

Introduction

We have created four speculative scenarios in order to obtain, from you as an expert, a set of **specific determinants or factors that may cause an investment decision by family units, either monetary or behavioural, to make their home more energy efficient**.

Each scenario describes a different reality for each of the aspects analysed. Please remember, the scenarios described here do not reflect a specific individual building, but are rather a representation of the majority of households in a city.

Introduction

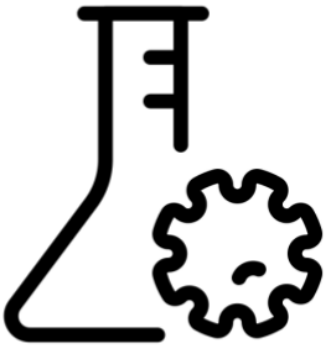
Please consider first that your property is a single-family house (SFH) in each scenario. Then, what drivers would change in the scenarios if you were the owner of a multifamily residential unit (multi-dwelling unit, MDU) instead of a SFH? Finally, considering you are a tenant of the property instead of being an owner, what would change in the scenarios?

We will start from the baseline scenario and we build on it throughout this jamboard.
Thanks a lot for your time!

Base Scenario

You live in an old house (please consider the different possibilities mentioned in the introduction) built between the 1970s and 1980s that has either poor or no insulation (depending on country-level standards) and a heating system based on fossil fuels. It has no renewable energy generation and limited storage mechanisms (for instance a thermal storage tank for domestic hot water, DHW). The appliances in the house have a low to medium energy efficiency, and the house does not have an energy management system. Your electricity tariff for the dwelling is a standard tariff with a fixed energy price. In addition, there is no time-of-use (ToU) scheme, therefore you do not usually worry about what time you switch your appliances on. Thus, you plug them in and use them when needed.

Dry run!



In the following slides, we will provide an example of what we are expecting from you in each of the four scenarios. We will start with the dry run.

Just relax and see :)

Dry run - This is a (test) example of a speculative scenario on top the baseline provided before

You start looking for information to help determine whether or not to invest in energy efficiency at your home *[from the baseline scenario]*. You ask advice from friends who are relatively knowledgeable on energy efficiency. **You conclude that you should make some improvements and repairs in your home**.

Dry run - after reading the scenario…

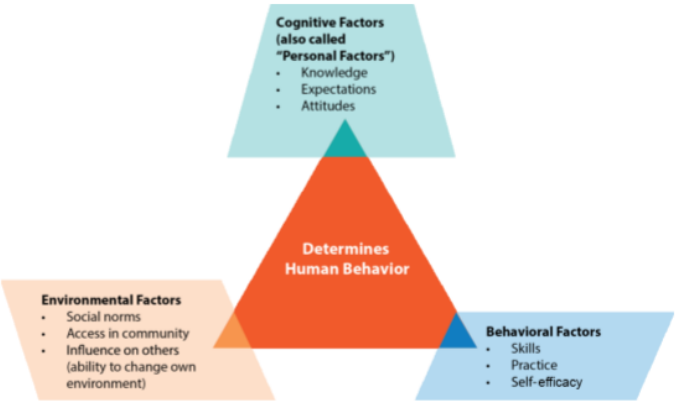
...You will be provided with a canvas/framework in which you will have to fill determinants **(i.e., intrinsic and extrinsic factors that causes an investment decision)**. We will also ask you about barriers and rebound effects for each scenario.

But before, we will be always offering you some tips to provide these determinants. See the next slide.

Social Cognitive Theory can help you understand better the type of determinants we expect

The Social Cognitive Learning Theory acknowledges the constant interaction that exists between the individual and his or her environment, both structural and social, to shape behavior. Three personal cognitive factors that are affected by the environment influence behavior:

- **Observational learning:** Individuals are more likely to perform a desired behavior if they observe others modeling that behavior and experiencing the subsequent positive rewards.
- **Outcome expectations:** Individuals are more likely to practice a desired behavior if they believe the benefits of performing that behavior and outweigh the costs.
- **Self-efficacy:** Individuals are more likely to practice a desired behavior if they perceive that they have the necessary skills and capacity to do so (Bandura, 2001; Glanz & Rimer, 2005).



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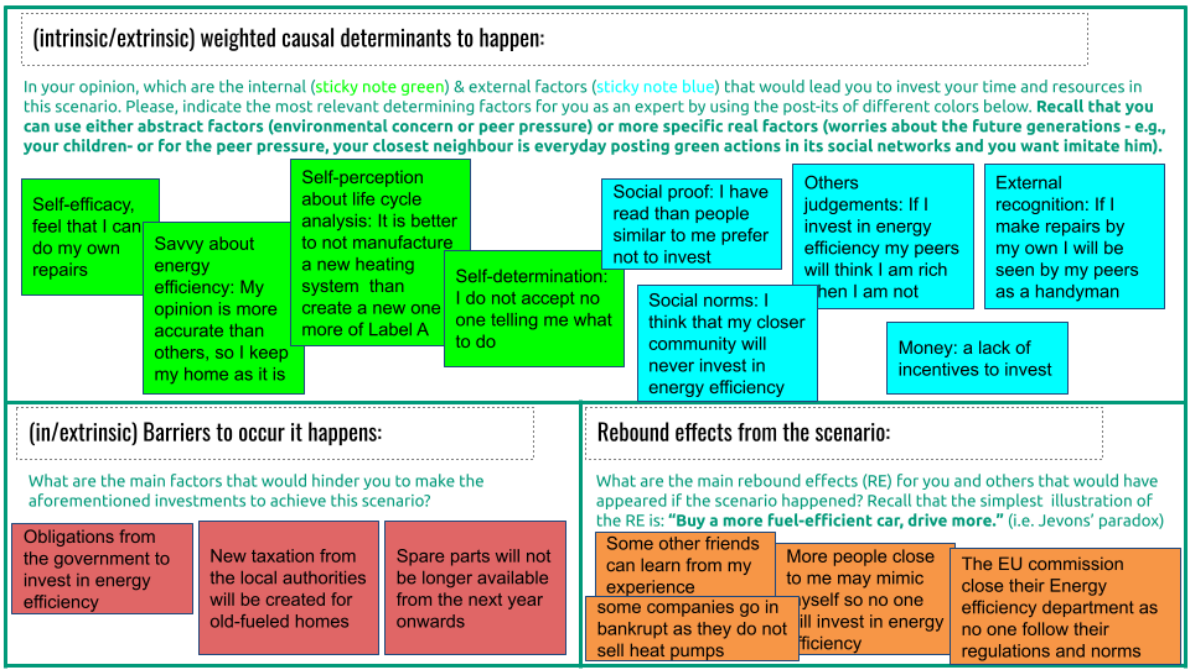


Hands on in the real scenarios (your turn)!

Please read the four speculative scenarios and **provide a comprehensive list of relevant factors for the decision-making determinants. Your input will be structured as the example in the dry run.**

Therefore, we ask you to **provide as many determinants, which cause an investment decision by family units in each scenario, as possible (we will provide some references after each scenario to inspire you).**

Please, recall the baseline scenario on slide **4** and **Let's start with the minimum scenario!**

Minimum Scenario

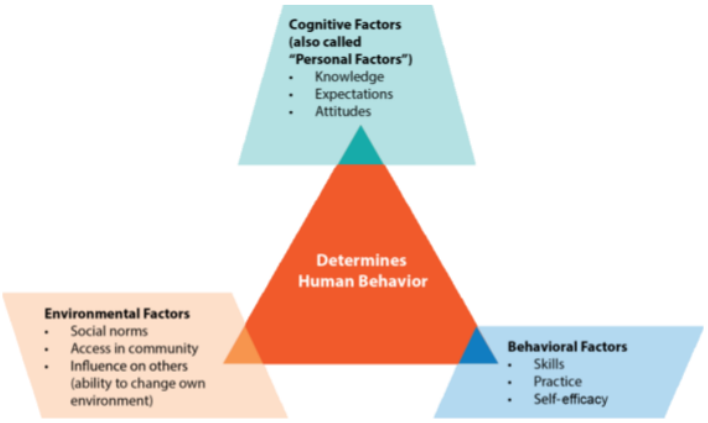
After reading about decarbonisation targets in the newspaper, you decide to find out what measures you need to take to ensure your comfort while reaching those targets. Consequently, you set the thermostat following your utility recommendation that the ideal temperature for a home ranges between 20 and 21°C during the day, and between 15 and 17°C at night; your clothing is suitable to the weather (for instance, in winter you wear different layers), you have checked your windows and doors for air leaks, replaced the seals on doors and windows, fixed any cracks inside and weather-stripped the windows, among others. Please, consider the different possibilities mentioned above.

Remember!

According to the existing literature, it seems that internal factors such **as personal beliefs, values or environmental concern (e.g. someone may feel we, as society, are not doing enough against climate change)** are the prominent drivers that foster a change in people's daily behaviour to invest time and effort in reducing the carbon and energy footprint in their personal dwelling.

Besides, the dominant external factors for such pro-environmental behaviour to occur seem to be **peer pressure (e.g. your partner is already doing energy efficiency actions), social comparison (e.g. your neighbours do green actions and exhibit them openly) and social norms (e.g. doing energy efficiency actions is well recognised in your community and may enhance your social capital)**.

Tip or helping guide: Clusters of factors that affects someone's behaviour



(intrinsic/extrinsic) weighted causal determinants to happen: Minimum Scenario

In your opinion, which are the internal (sticky note green) & external factors (sticky note blue) that would lead you to invest your time and resources in this scenario. Please, indicate the most relevant determining factors for you as an expert by using the post-its of different colors below. **Recall that you can use either abstract factors (environmental concern or peer pressure) or more specific real factors (worries about the future generations - e.g., your children- or for the peer pressure, your closest neighbour is everyday posting green actions in its social networks and you want imitate him).**

(in/extrinsic) Barriers to occur it happens:	Rebound effects from the scenario:
What are the main factors that would hinder you to make the aforementioned investments to achieve this scenario?	What are the main rebound effects (RE) for you and others that would have appeared if the scenario happened? Recall that the simplest illustration of the RE is: **"Buy a more fuel-efficient car, drive more."** (i.e. Jevons' paradox)

Minimum Scenario is completed!

Minimum **Probable** **Plausible** **Ideal**

13. ANNEX D: Full distribution of codes across aspects

		Flexibility				Appliances				Buildings				Mobility					
Code	Concept	Minimum	Probable	Plausible	Ideal	Minimum	Probable	Plausible	Ideal	Minimum	Probable	Plausible	Ideal	Minimum	Probable	Plausible	Ideal	TOTALES	
Financial	Profits	7	5	6	4	6	0	4	5	6	9	3	4	2	1	1	1	64	7%
	Credit Score	1	4	3	4	0	10	0	1	0	10	7	6	5	0	0	1	52	6%
	Risk Profile	1	2	4	2	2	1	0	0	0	3	5	0	2	1	0	0	23	3%
	Added Value	0	0	0	2	0	1	2	0	0	5	6	3	2	2	1	0	24	3%
	Frugality	0	0	0	0	3	0	3	0	2	0	0	1	2	2	1	0	14	2%
Security	Legal	0	3	1	2	1	0	2	1	0	2	1	1	4	6	7	3	34	4%
	Trust	1	2	3	3	2	0	5	7	0	1	0	3	2	2	3	1	35	4%
	Safety	0	1	0	3	1	0	2	4	1	3	1	0	0	3	1	1	21	2%
Security + Meaning	Climate Protection	2	1	0	1	6	3	0	0	1	0	1	0	0	0	0	0	15	2%
Competence	Cost-Efficiency	7	3	4	3	3	5	12	5	2	0	2	2	2	0	1	0	51	6%
	Knowledge	10	6	6	7	9	8	1	3	3	1	1	3	0	1	1	1	61	7%
	Own Competence	5	2	1	0	1	4	1	3	1	3	3	4	1	1	0	1	31	3%
	Technical Fit	2	1	2	2	2	14	3	4	1	2	1	0	6	8	3	10	61	7%
Competence + Meaning	Environmental Concerns	1	1	2	2	3	3	2	1	3	1	3	2	3	2	2	0	31	3%
Autonomy	Self-Satisfaction	0	0	1	3	1	0	0	0	2	0	0	3	0	1	0	0	11	1%
	Commitment	0	1	3	1	0	0	1	2	1	0	0	0	0	0	1	2	12	1%
	Adherence	4	0	0	0	8	2	2	0	2	0	1	0	0	1	1	0	21	2%
Security + Autonomy	Autarky	0	2	2	3	0	0	0	0	0	0	0	0	2	0	1	0	10	1%
Physicalness + Security	Wellbeing	0	0	1	0	2	0	1	0	4	5	4	1	0	1	2	4	25	3%
Physicalness + Relatedness	Cozyness	0	0	0	0	0	0	0	0	2	3	0	1	1	3	0	3	13	1%
Relatedness	Rights and Duties	0	2	1	1	0	0	0	2	1	3	1	1	0	0	1	0	13	1%
	Peer-Pressure	5	6	6	2	5	2	4	0	2	1	0	1	2	4	1	0	41	5%
	Support	4	1	1	2	2	1	3	1	1	3	0	0	1	2	0	0	22	2%
	Socialising	1	1	3	0	0	0	7	6	1	0	0	1	0	0	1	0	21	2%
	Agreement	3	5	5	2	2	0	2	11	2	3	7	0	2	0	0	0	44	5%
Stimulation	Novelty	1	0	1	1	0	3	0	2	1	0	0	1	0	0	0	0	10	1%
	Fun	2	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	4	0%
Stimulation + Popularity	Brag	1	1	2	1	1	5	1	1	1	0	3	3	2	1	1	0	24	3%
Popularity	Trends	5	2	0	0	8	5	1	0	0	2	1	1	3	3	1	1	33	4%
Popularity + Relateness	Authority	5	4	1	4	7	6	4	6	5	2	2	6	1	0	0	1	54	6%
Meaning	Own Significance	3	2	3	0	3	2	1	1	3	0	1	2	3	0	1	0	25	3%
Meaning + Popularity	Poseur	0	0	0	0	0	0	0	0	0	2	0	2	1	0	0	0	5	1%

	Flexibility				Appliances				Buildings				Mobility			
Concept	Minimum	Probable	Plausible	Ideal	Minimum	Probable	Plausible	Ideal	Minimum	Probable	Plausible	Ideal	Minimum	Probable	Plausible	Ideal
Financial	9	11	13	12	11	12	9	6	8	27	21	14	13	6	3	2
Security	2	7,5	5,5	10	8	1,5	9,5	12	3,5	8,5	4,5	4,5	7	11,5	12,5	7
Competence	24,5	12,5	14	13	16,5	32,5	18	15,5	8,5	6,5	8,5	10	10,5	11	6	12
Autonomy	4	2	5	5,5	9	2	3	2	5	0	1	3	1	2	2,5	2
Physicalness	0	0	0,5	0	1	0	0,5	0	3	4	2	1	0,5	2	1	3,5
Relatedness	15,5	17	16,5	9	12,5	6	18	23	10,5	12,5	9	6,5	6	7,5	3	2
Stimulation	3,5	0,5	2	1,5	0,5	5,5	1,5	2,5	1,5	0	1,5	3,5	1	0,5	0,5	0
Popularity	8	4,5	1,5	2,5	12	10,5	3,5	3,5	3	4	3,5	6,5	5	3,5	1,5	1,5
Meaning	4,5	3	4	1,5	7,5	5	2	1,5	5	1,5	3	4	5	1	2	0

TOTALES	
177	20%
115	13%
219,5	24%
49	5%
19	2%
174,5	19%
26	3%
74,5	8%
50,5	6%

Financial	13%	19%	21%	22%	14%	16%	14%	9%	17%	42%	39%	26%	27%	13%	9%	7%
Security	3%	13%	9%	18%	10%	2%	15%	18%	7%	13%	8%	8%	14%	26%	39%	23%
Competence	35%	22%	23%	24%	21%	43%	28%	23%	18%	10%	16%	19%	21%	24%	19%	40%
Autonomy	6%	3%	8%	10%	12%	3%	5%	3%	10%	0%	2%	6%	2%	4%	8%	7%
Physicalness	0%	0%	1%	0%	1%	0%	1%	0%	6%	6%	4%	2%	1%	4%	3%	12%
Relatedness	22%	29%	27%	16%	16%	8%	28%	35%	22%	20%	17%	12%	12%	17%	9%	7%
Stimulation	5%	1%	3%	3%	1%	7%	2%	4%	3%	0%	3%	7%	2%	1%	2%	0%
Popularity	11%	8%	2%	5%	15%	14%	5%	5%	6%	6%	6%	12%	10%	8%	5%	5%
Meaning	6%	5%	6%	3%	10%	7%	3%	2%	10%	2%	6%	8%	10%	2%	6%	0%

	Flexibility	Appliances	Building	Mobility
Financial	18%	13%	32%	15%
Security	10%	11%	10%	24%
Competence	26%	29%	15%	25%
Autonomy	7%	6%	4%	5%
Physicalness	0%	1%	5%	4%
Relatedness	24%	21%	18%	12%
Stimulation	3%	4%	3%	1%
Popularity	7%	10%	8%	7%
Meaning	5%	6%	6%	5%

14. ANNEX E: Validation of the scenarios with stakeholders

The first session of the workshop was dedicated to the technical aspects of the demand side modelling. The main objective was to discuss with invited energy experts, which components relevant to household energy consumption should be included and prioritised in the WHY-toolkit, considering the European Use Case. We grouped these components into four different discussion themes: in round 1 we focused on elements related to Building Performance and Mobility, whereas in round 2 we discussed aspects concerning Flexibility and Smart Appliances.

The proceedings underpinning the exchange on those themes were the same in each round. First, we introduced the concept of scenarios, divided into: a base, a minimum, a probable, a plausible and an ideal scenario. FigureD-1. illustrates the main features of the scenarios mentioned above, which were presented to the stakeholders, and provides their general description.

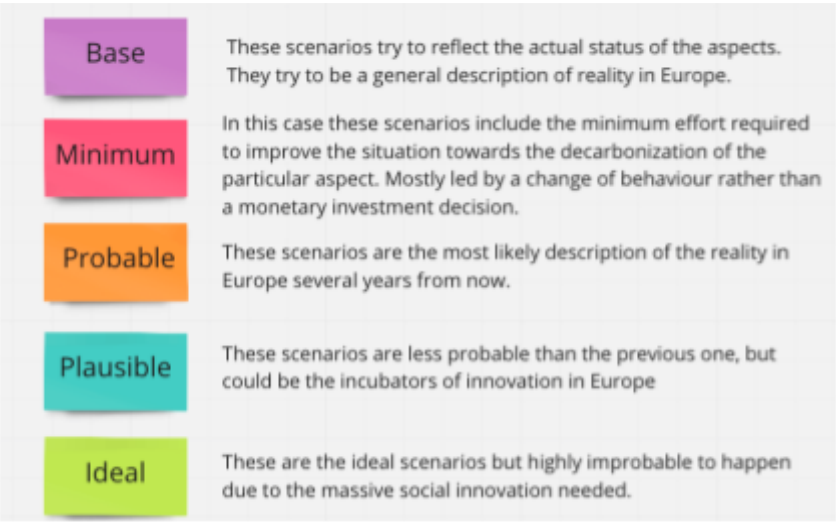


Figure D-1: The scenarios applied in Session 1 one of the workshop – "Energy Transition: Things to Consider when Modelling the Demand Side"

As the next step, the stakeholders read five different scenarios related to the Building Performance aspects (a similar task concerned also other main themes), to get acquainted with the visions of the potential developments in the European demand sector (section 4.2.). Afterwards, the participants of this session were asked to classify those scenarios as a base, minimum, probable, plausible, and ideal (as introduced in the previous step). Each evaluation was supposed to be done in the context of the three next decades (covering the 2020-2050 period). This is depicted in Figure D-2

Decades	Scenarios	Flexibility determinants					Appliances determinants					Buildings determinants					Mobility determinants				
		A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	Fossil fuel	Electric Vehicle	Public transport	Robotaxis	15' cities
2030	Base	2							3			3	1	1		1	1	1			
	Minimum		3				3			1			2				1	1			
	Probable													2		2	1				
	Plausible			2							1			1	2			2			
	Ideal			1	3			2			1		1	1	2		1		1		1
	Not Applicable	1				2							2		1		1		1	3	2
2040	Base	1					1			2						1			1		
	Minimum		3				1			1		2	2	1							
	Probable			1										1	2			1			
	Plausible			2	1			1			2	1	1	1		1	1	2	1		
	Ideal				1	1		1			3				1		1		2	2	2
	Not Applicable	2							3								2				
2050	Base						1			3				2							
	Minimum		2	1			1								1			1			
	Probable				2						1				1			1	1		
	Plausible			2									2	1	1	2	1		1	1	1
	Ideal				1	1		3			1				1		1	1		1	2
	Not Applicable	3							3			3				1	2				

Figura D-2 Evaluation during the three next decades

At first, the realisation of this task brought ambiguous results. Stakeholders were not unanimous in estimating the character of possible scenarios to be taking place in the upcoming decades, resulting in different colours of the dots placed in the matrix. The strongest unanimity considered the fact that the weakest decarbonisation scenarios would not be sufficient at the household level in 2040 and 2050. In general, the overall trend showed that the longer-oriented time perspective, the more agreeable stakeholders were.

In the next task, we asked the participants to write down specific technologies on the sticky notes, which, in their opinion, will be essential in implementing the aforementioned scenarios. the above mentioned scenarios. Importantly, under "technologies" we have not only understood technical solutions, but also those related to social innovation. This task is visualised in Figure D-3.

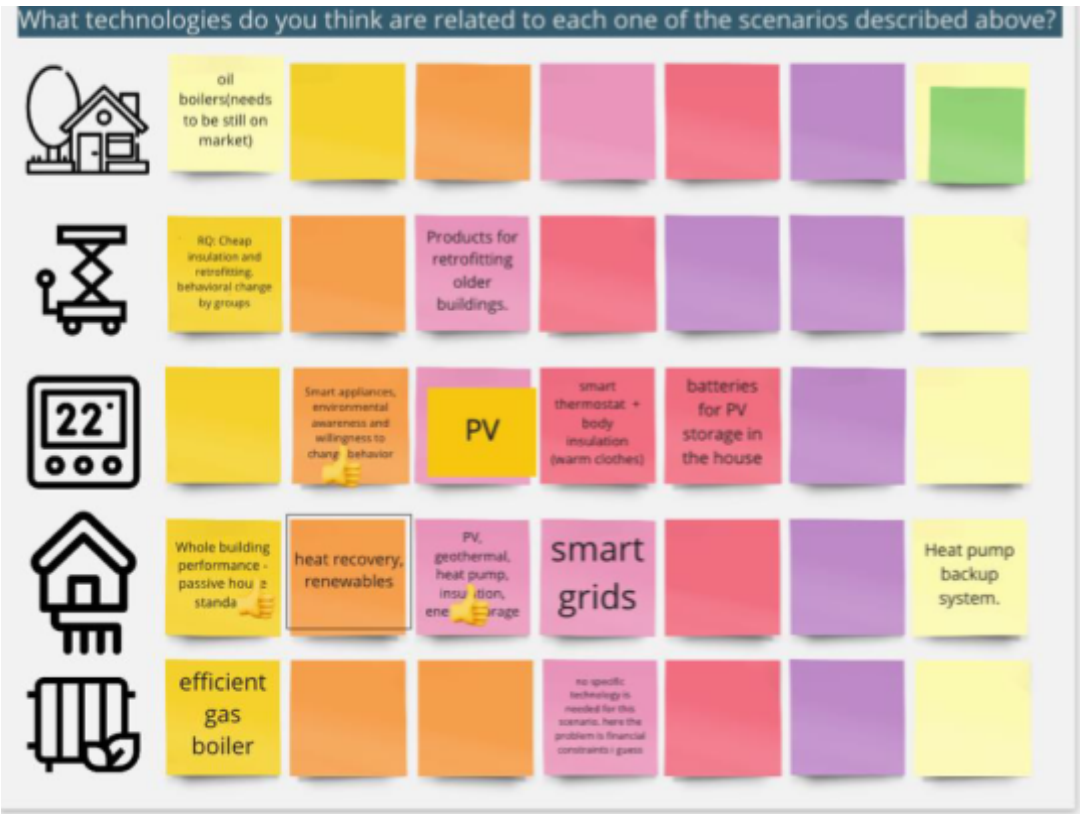


Figure D-3: A set of technologies anticipated by stakeholders as relevant for the first set of the scenarios.

The last task was linked to the previous one – we asked the stakeholders to indicate, which of the previously mentioned technologies they would prioritise in the modelling of the Building Performance aspects. The range of answers varied considering two dimensions: the degree of detail (low vs. high) and the answer time (fast vs. slow). We assumed that both dimensions are interrelated – the fast answer time also means a low level of detail, and vice-versa. In that context, the participants indicated that, e.g., the gas boilers should not be given a lot of attention in the modelling runs, in contrast to renewable and renewable-related technologies, such as PV or smart grids. The results of this exercise are presented in Figure D-4.

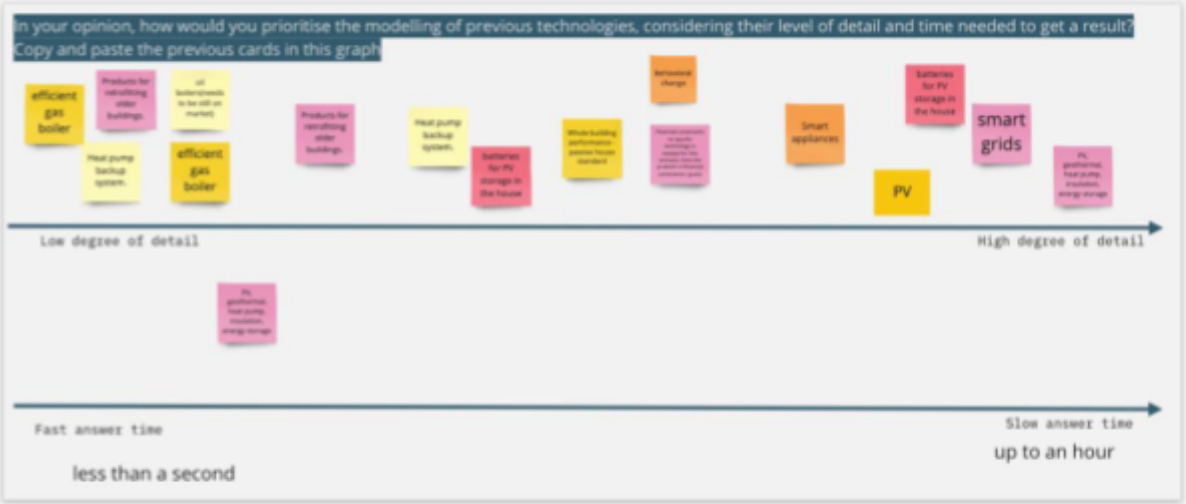


Figure D-4: Technologies related to Building Performance, classified according to the level of detail and the answer time.

After completing the last task related to the Building Performance aspects, the stakeholders undertook similar exercises in relation to the Mobility aspects. First, the participants read potential future scenarios dealing with mobility (section 4.4.) and afterwards they indicated, which of them were referring to a required minimum, which of them were most probable, plausible, ideal, not applicable or presented the actual situation. The scenarios classification are shown in Figure D-2.

In case of the Mobility aspects, the participants indicated mixed assessments of the presented scenarios, being, however, in some cases unanimous. For example, stakeholders were sure that a scenario assuming a broad use of the electro taxis will not be applicable until the end of this decade. Similarly, they assessed that it would be an ideal solution, if by 2040 the cities are planned in a way that the private vehicles are not needed.

In the following task, the workshop's participants listed numerous technologies relevant to presented mobility scenarios. Noticeably, as Figure D-5. shows, they mentioned not only technological developments needed for the transformation of the mobility system, such as reliable artificial intelligence or batteries, but they have also emphasised the importance of the behavioural change and the emergence of new business models.

Figure D-5: Technologies related to the Mobility sector as indicated by the stakeholders.

Against this backdrop, stakeholders claimed that most of those aspects should be characterised by moderate levels of detail and answering time. A visible deviation from this outcome concerned e-waste recycling facilities (low level of detail/ fast answer time) and reliable artificial intelligence (rather/ high level of details/ slow answer time). There was no clear agreement regarding the behavioural change. Figure D-6 presents these results.

Figure D-6: Technologies related to Mobility, classified according to the level of detail and the answer time.

This task finished round 1 of the parallel thematic sessions and after coffee break and re-shuffling of the stakeholders' groups, further energy demand aspects were discussed. At the beginning stakeholders read five scenarios related to Flexibility aspects (section 4.3).

Subsequently, they classified these scenarios as minimum required, most probable, plausible, ideal, not applicable or presenting the actual situation. The experts participating in the workshop were rather consistent in their answers – they categorised

the Flexibility scenarios considering the time perspective by using mostly the same colour coding. More detailed results of this exercise are presented in Figure D-2.

Within the following task, stakeholders did not have problems with indicating numerous technologies related to Flexibility. Interestingly, they did not mention any technologies related to the first scenario. It resulted from the fact that this scenario did not present any progressive decarbonisation measures and, therefore, the stakeholders recognised this scenario mostly as not applicable in the future and, hence, as a reality that will not require any technologies. Other results are depicted by Figure D-7.

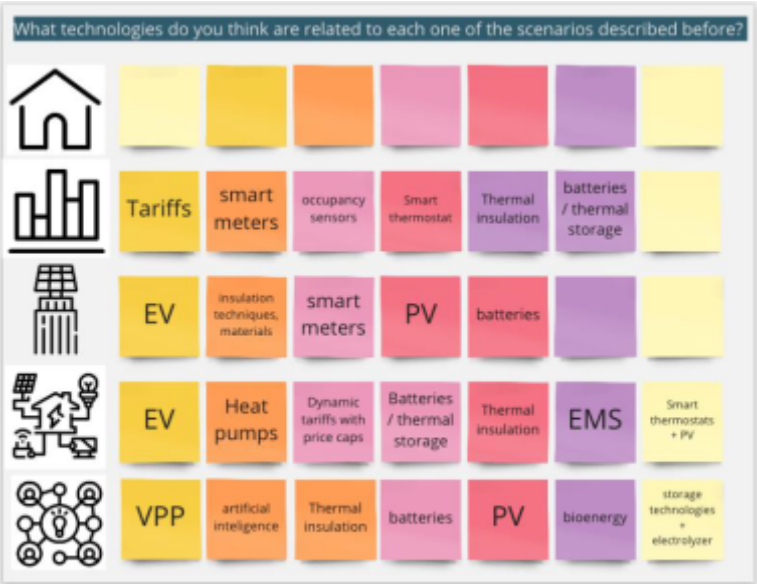


Figure D-7: Technologies related to the Flexibility aspects as indicated by the stakeholders.

Finally, the stakeholders classified the previous technologies according to their preferences regarding the level of modelling detail and time for receiving the modelling result. According to their input, the most desirable in terms of high detail degree are the results of the Virtual Power Plant's (VPP) modelling. On the opposite side of this axis the workshop's participants placed smart meters. Full results of this exercise are visualised in Figure D-8.

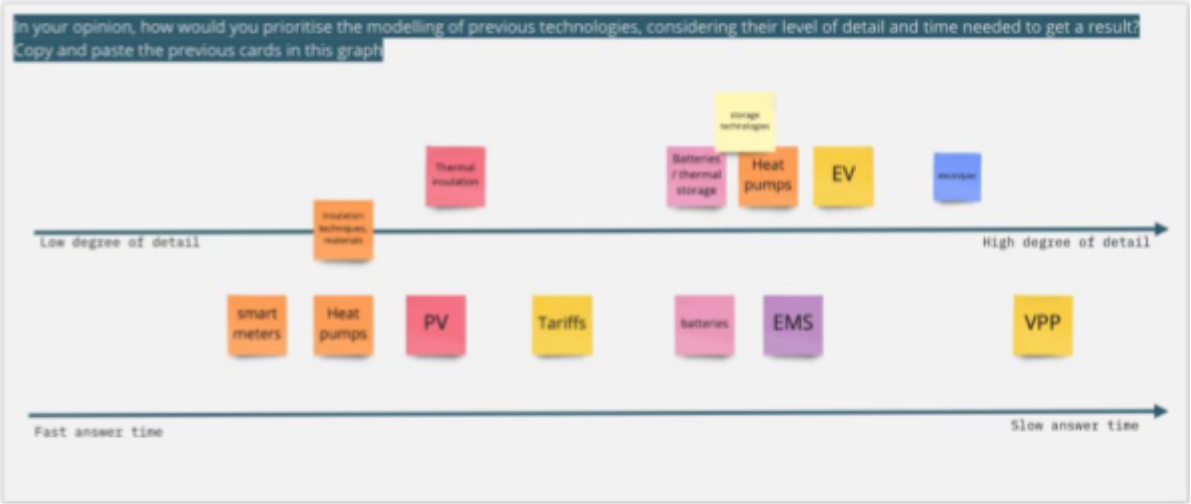


Figure D-8: Technologies related to Flexibility, classified according to the level of detail and the answer time.

The last group of aspects discussed with the stakeholders concerned Smart Appliances. Similarly like in previous themes, the participants first read the descriptions of the possible future scenarios and afterwards, they categorised them as minimum required, most probable, plausible, ideal, not applicable (section 4.1.)or presenting the actual situation. This is illustrated in the figure D-2.

Again, stakeholders were quite consistent in their assessments – in most of the scenarios they agreed on their character in the context of the decades to come. The most visible discrepancy of the answers occurred in case of a scenario foreseeing a communal use of some of the appliances.

In the next exercise, the invited experts indicated few technologies related to the Smart Appliances scenarios, but clearly less as in case of previous scenarios. Additionally, all of those technologies were assessed as requiring rather a low level of detail (but delivered fast) while modelling. This is depicted in Figure D-9.

Figure D-9: Technologies related to Smart Appliances, classified according to the level of detail and the answer time.

15. ANNEX F: Composition of the Panel of Experts

Partner	Description	Keywords		
		Position	Country	Company
Mobility				
Grzegorz Sierpinski	Expert in Transport engineering, Green economy, Transport economics, Civil engineering, Civil engineering	Head of Department	Poland	Silesian Technology University
Chris Merveille	Coordinated the EU-funded research and innovation effort to promote a citizen-centred sustainable energy transition at GoiEner.	European Projects Coordinator	Spain	GoiEner
Javier Goikoetxea	Professional with more than 18 years of experience in business development and expertise in start-ups, technology and industry services.	CEO of NEXT Group	Spain	NEXT Group
Merit Tatar	Doctor in Public Administration, she is also a consultant in the development of EU-funded projects for local authorities, companies and NGOs in Estonia and abroad.	Director of Development	Estonia	Institute of Baltic Studies
Buildings				
Thomas Nacht	Doctor of Engineering, Senior Researcher at 4ward Energy Research GmbH	Senior Researcher	Austria	4ward Energy
Sebastian Seebauer	Doctor, Research in Science, Technology and Environmental Politics, Applied Psychology, Environmental Psychology and Social Psychology	PostDoc Position	Austria	Joanneum Research Forschungsgesellschaft mbH
Urko Buendia	Public / Private Administration or Civil society	Member of the Tertiary Area	Spain	Energy Agency of the Basque Government
José Manuel Borque	Industrial engineer, Energy techniques, Public / Private, Efficiency and Renewable Energy, Administration or Civil society, Energy	Head of the Tertiary Area	Spain	Energy Agency of the Basque Government
Mirela Panait	Doctor, scientific researcher at the Institute ofNational Economy and PhD advisor at the doctoral school of the RomanianAcademy	PhD Professor at Faculty of Economic Sciences	Romania	Petroleum-Gas University of Ploiesti
Daniel Rodik	MSc, Expert for energy and climate challenges. Advisor for climate change mitigation and adaptation strategies and planning, energy efficiency in households and renewable energy systems	Business Consultant	Croatia	Društvo za oblikovanje održivog razvoja (DOOR)
Jakub Sokołowski	Experience of eight years in the energy sector, dealing mainly with energy poverty. Member of the Management Committee of COST Action dedicated to Energy Poverty in Europe	Doctoral student	Poland	Faculty of Economic Sciences of the University of Warsaw
Flexibility				
Leire Astigarraga Urzelai	Engineer of Renewable Energy, Industry & Energy Department, Electrical Insulation System Engineer, Wind Energy, Demand Response to Energy Communities: the energy transition with a user-centric approach	Market technician	Spain	GoiEner
Guntram Preßmair	MSc in Environmental and Bioresource Management , member of the e7 team as project support and junior consultant.	Consultant	Austria	e7 energy innovation & engineering
Frauke Wiese	Doctor, Energy and Environmental Management (EUM), fluctuating wind energy and inflexible base-load coal-fired power plants, energy	Professor	Germany	Europa-Universität Flensburg

	transition, electricity supply without fossil energies			
Pedro Manuel Sasia Santos	Doctor in Chemical Sciences, 20 years in the environmental and occupational health areas	Senior Lecturer	Spain	University of Deusto
Desislava Asenova	Seven years of experience in Science, Technology and Innovation Policy Programme	Project Manager	Bulgaria	Applied Research and Communica-tions Fund
Oier Etxebarria	Industrial Engineer, Organisation, Energy community promoter	Community creation processes	Spain	GoiEner
Diana Süsser	Doctor, researcher in group Energy Transitions and Public Policy, focuses on socio-technical transitions, energy policy-model interactions and innovations for a sustainable energy transition	Research Associate	Germany	Institute for Advanced Sustainability Studies
Appliances				
Markus Puchegger	PhD candidate, Senior Researcher in Area Energy Transition	Senior Researcher	Austria	Forschung Burgenland Research
Daniel Bell	Research on Urban Climate Adaptation Measures, research into social and environmental science aspects of urban climate adaptation measures	Senior Lecturer & Researcher	Austria	Fachhochschule Technikum Wien
Alvaro Gutiérrez Martín	Doctor in computer science, experience on Artificial intelligence, Automatic and Control Systems, swarm robotics, mobile robotics, control systems, sensor networks, and demand-side management applications.	Associate Professor	Spain	Polytechnic University of Madrid
Christian A. Klöckner	Doctor,leader of the research group for "Citizen, Environment, and Safety" which is focusing on researching individual, social and contextual drivers of environmental decisions. Coordinator of several national and international research projects, among them the H2020 projects ECHOES, SMARTEES, and ENCHANT	Professor	Norway	Norwegian University of Science and Technology.
Apostolos Tsolakis	Electrical Engineer, Ph.D. Experience in the research sector includes a highly diverse scientific and working background on a daily routine. Characterised by strong ideation skills and self-motivation	Senior Project Manager	Greece	Q-PLAN INTERNATIONAL
Edina Vadovics	PhS Manager of GreenDependent's professional work in the European/International research projects. Experience in corporate environmental and sustainability management. External expert for the European Environment Agency and UNEP	Scientific director	Hungary	GreenDependent Institute (GDI)
Karagiorgou Pennyà g	Marketing	Communicati on Trainee	Greece	BSH Home Appliances Group
Paraskevaido u Vickyà	Marketing	Communicati on Assistant	Greece	BSH Home Appliances Group
Piliou Afroditià	Marketing	Digital Trainee	Greece	BSH Home Appliances Group
Vlachos Anastasiosà	Marketing	Mechanical Engineer	Greece	BSH Home Appliances Group
Prassas Vassilisà	Marketing	Mechanical Engineer	Greece	BSH Home Appliances Group
Moraitis Anastasiosà	Marketing	Digital Assistant	Greece	BSH Home Appliances Group
Dedes Vassilisà	Service	Mechanical Assistant	Greece	BSH Home Appliances Group

Giannaklis Spyrosà	Marketing	Mechanical Engineer	Greece	BSH Home Appliances Group
Pattas Ioannis à Head	Marketing	Mechanical Engineer	Greece	BSH Home Appliances Group

16. ANNEX G: Survey to validate the Archetypes

16.1. Personal characterization

1. **In which country do you reside?**
    a. XXXX
    b. No answer

2. **In which type of town do you live?**
    a. Rural
    b. City
    c. Residential area
    d. I prefer not to answer

3. **How old are you?**
    a. 18-30
    b. 31-55
    c. 56+
    d. I prefer not to answer

4. **Which of the following most accurately describes you?**
    a. Male
    b. Female
    c. Non-binary
    d. Other
    e. I prefer not to answer

5. **Do you live alone or do you share your household with others? (Please, check all the answers that apply to you and your personal situation)**
    a. I live alone
    b. I live with friends or other non-family persons
    c. I live with my partner
    d. I live with my childs (or other minors under my responsibility)
    e. I live with other adults under my responsibility
    f. I live with other persons who are either family or relatives
    g. I live with my pet
    h. I prefer not to answer

6. **How many people live in the house?**
    a. Numeric

7. **What is the highest level of education you have completed?**
    a. Primary or no studies
    b. High school
    c. Vocational training/ Trade School
    d. University
    e. I prefer not to answer

8. **What is your approximate individual yearly income (netto)**?
    a. More than 100.000 €
    b. Between 50.000 € and 100.000 €
    c. Between 30.000 € and 50.000 €
    d. Between 15.000 € and 30.000 €
    e. Less than 15.000 €
    f. I prefer not to answer

9. **In a typical month, how much of your salary is saved?**
    a. I manage to save more than 20% of the monthly salary
    b. I manage to save between 10 and 20 % monthly
    c. I manage to save less than 10 % monthly
    d. Nothing, I am using my savings lately
    e. I prefer not to answer

16.2. Household Characterization

10. **In which type of housing do you live?**
    a. Flat / Apartment
    b. Semi-Detached / Townhomes
    c. Single-Family Home / Chalet
    d. In a multi-family house
    e. Others
    f. I prefer not to answer

11. **Do you own the place where you live?**
    a. Yes
    b. No
    c. I prefer not to answer

12. **How much usable area does your house have?**
    a. Less than 80 m²
    b. Between 80 and 120 m²
    c. More than 120 m²
    d. No answer

13. **Is your house properly insulated?**
    a. Yes (it has been built or refurbished with energy efficiency in mind),
    b. No (it has built without energy efficiency in mind and has not been completely refurbished),
    c. I do not know,
    d. I prefer not to answer

14. **In which climate zone do you live?**
    a. Atlantic
    b. Mediterranean

c. Continental
d. Alpine or Nordic
e. Arid or semi-arid
f. I do not know
g. I prefer not to answer

16.3. Behaviour modelling (self-assessment)

15. On a scale of 0-5, where 0 is "Climate change does not exist" and 5 is "I am a climate change expert/activist", how would you assess your level of awareness of climate change?

16. On a scale of 0-5, where 0 is "Climate change does not exist" and 5 is "They are climate change experts/activists", how would you assess the level of awareness of climate change of your peers or relatives?

17. On a scale of 0-5, where 0 is "It is the first time I hear about it" and 5 is "I am an expert or activist", how would you assess your level of awareness about the energy transition?

18. **On a scale of 0-5, where 0 is "It is the first time they hear about it" and 5 is "they are experts or activists", how would you assess the level of awareness about the energy transition of your peers or relatives?**

16.4. Scenarios

19. Rank, in order of priority for you (where 1 is the highest priority and 4 is the lowest) in which scenario you will be willing to live or to contribute/invest to make it possible. Those are ideal scenarios for making the energy transition a reality. We understand that not all may apply to you or that you may think they are futuristic, but please try to rank them according to your personal preference or situation

a. **Scenario #1 - Appliances**: One of the appliances you use occasionally (e.g. the oven for baking, the washing/drying machine, a drill or the vacuum cleaner) breaks down again. In order to contribute to the climate neutrality objectives, you decide not to buy a new piece of equipment for individual use but to propose its purchase to your community for shared and common use (and that way you can buy a top energy efficiency one). To do this, you convince your entire community of your building to share these household appliances for common everyday use. Luckily, you have space in the basement to accommodate them and you propose to your community to adhere to this initiative when they have to replace their equipment and not before.

b. **Scenario #2 - Insulation:** You live in a new or highly refurbished passive house (https://en.wikipedia.org/wiki/Passive_house). In addition to having first-class facade, roof and window insulation, an intelligent and highly efficient heating/air conditioning system supplies the dwelling with your heating, cooling and hot water needs. An energy management system controls the heating/air conditioner system giving to it the potential to share energy with the neighbours building a "distributed district heating".

Moreover, you are very environmentally conscious so you prioritise saving energy with any kind of investment of money or time, and you are always willing to sacrifice some comfort when setting the thermostat temperature.

c. **Scenario #3 - Electricity:** You live in a new or highly refurbished passive house (https://en.wikipedia.org/wiki/Passive_house). You have solar panels integrated into the building and a battery system that allows you to store excess daily energy to consume at night. The generation system is slightly oversized, and in summer, you have a surplus of energy generated that is used at the community electrolyzer that generates and stores hydrogen. This hydrogen is later used in a highly efficient community cogeneration system (a.k.a. technology that produces electricity and thermal energy) to power a low-temperature district heating that provides the heating/cooling and hot water demand of the community. All these components could be controlled by an energy management system in which you can invest, not only to optimise its performance but also to allow you to trade energy between neighbours or with the energy provider.

d. **Scenario #4 - Mobility:** The city where you live has been re-designed in a way that all services are at foot distance (for example, following the idea of *15 mins cities - https://en.wikipedia.org/wiki/15_minute_city*). A series of agreements between the government and companies, aligned with investments in behaviour change from the citizens' side, ensures that teleworking is mandatory at least three days a week. In your city, the number of vehicles is drastically reduced due to several incentives to embrace low-emissions mobility vehicles (e.g., bikes, e-bikes, e-scooters, etc.) and facilities to take public transport. Indeed, a combination of public or private personal mobility, robotaxis (a.k.a. self-driving taxi or a driverless taxi) and electric public transport supply the rest of travel needs (inter and intra city). For these reasons, traffic jams are something from the past and the air is again breathable. Long distance transport of passengers and goods is only made using trains and the amount of travel by plane is drastically reduced to intercontinental travel.

16.4.1. Determinants

20. As you can see, these ideal yet futuristic scenarios would only be possible if citizens, enterprises, and public authorities collaborate. In the following, you will be presented with a list of factors that may influence your decision making when it comes to contributing to make this scenario possible (e.g., change your daily behaviour, take investment decisions with money or time or decide who to vote for to make the scenarios a reality). Please rate each of them, THINKING ON THE SCENARIO YOU HAVE SELECTED AS THE PRIORITY FOR YOU**, in a scale being the left-side of the slider "**Not at all relevant for you" **and the right-side of the slider "**drastically important to you"**.**

a. **Profits:** Profits are what guide my decision making, I always prefer to earn or save money with every decision I take.
b. **Credit Score**: Access to funding (my own savings, deductions, exemptions, and/or credits) is the main factor that allows/hinders me to make an investment decision.
c. **Risk Profile:** The evaluation of the risks of my investment(s) is what will always guide my final decision.
d. **Added value**: I will only do an investment if my actions have an impact beyond the monetary gain/losses.
e. **Frugality**: I am a thrifty person, so I only invest in actions that allow me to reduce my cost/impact/expenditures.
f. **Climate Protection**: Every decision I take serves to foster the planet's preservation. If my choice might harm the environment, I will always avoid taking this action.
g. **Legal**: Having a complete certainty that my actions comply with the legal, tax and administrative regulations is what guide my actions.
h. **Trust**: I only make decisions if I trust all the parties involved (e.g., public administration, neighbours) and on the technology that is needed to accomplish my goal.
i. **Safety**: I only make decisions if the outcome of them ensures or improves my safety or the ones of my relatives.
j. **Cost-Efficiency**: I always review and assess the pros and cons of my decisions looking for the most cost-effective one.
k. **Knowledge**: I do not make a decision if I do not have enough knowledge of the subject of matter.
l. **Own Competence**: Feeling that I am competent to make an investment is what guides my decision making.
m. **Technical Fit**: I carefully check that the technology, the equipment or the goods fits my lifestyle or the technical requirements before making an investment decision.
n. **Environmental Concerns**: I always review and assess the pros and cons of my decisions in relation to the environment before taking one.
o. **Self-Satisfaction**: I will only take a decision if I feel satisfied with the action and the expected outcome.
p. **Commitment**: I only take a decision if I feel personally committed with the action and the expected outcome.
q. **Adherence**: I will only take a decision if I feel that I can sustain it throughout time.
r. **Autarky**: Self-sufficiency and individual sovereignty is what guide my decisions. I will only make a decision if I feel that the investment will improve my control of all circumstances and potential outcomes.
s. **Wellbeing**: I will only make a decision if it improves my well-being or the well-being of my relatives.
t. **Cosiness**: I will only make a decision if it improves my comfort or the comfort of my relatives.

u. **Rights and Duties**: I firmly believe that we live in a society where we have to adhere to regulations, laws and community agreements by all means, so my investment decision has to agree with this vision.
v. **Peer-Pressure**: My investment decisions are influenced by the opinions of others (such as my peers, relatives or family).
w. **Support**: I will only make an investment decision if it has the approval or support of the community I belong to.
x. **Socialising**: I will only make an investment decision if it improves my possibilities to socialise with my peers and relatives.
y. **Agreement**: I will only make an investment decision if it has the agreement of the people affected by it (for example, my relatives, peers or the community).
z. **Novelty**: I love to test new ideas and cutting-edge technology so novelty is what drives my investment decisions.
aa. **Fun**: Having fun is important to me. Therefore, I will only make a decision if it would be enjoyable and amusing for me.
bb. **Brag**: I am interested in that my decisions lead to increased status for me and I can show others what I achieved.
cc. **Trends**: I usually follow the trends when making a decision. In particular, I usually find myself sticking to the ads I see, the recommendations of people I admire, or what I read in magazines or blogs I follow.
dd. **Authority**: I only take a decision if it helps me to improve my position as an expert on the subject matter.
ee. **Poseur**: I only take a decision if it helps me to improve the opinion of others about me even if this decision is not always what I would do if it was only for myself.
ff. **Own Significance**: I only take a decision if the action has a personal and inner meaning for me (beyond any economic gain).

16.4.2. Self-assessment

21. In Scenario 1: How much money will you be willing to invest deploying a fair booking system for the shared appliances that can be inclusively used for all the neighbours irrespective of their digital literacy?

a. Number in €
b. No answer

22. What is the maximum time of return on investment (ROI) you are willing to accept for this scenario?

a. Number in years
b. No answer

23. In Scenario 2: How much green taxes will you be willing to invest in deploying a public incentivisation scheme that allows neighbours to perform deep refurbishings of their house or buildings to drastically reduce their energy consumption?

a. Number in €

b. No answer

24. What is the maximum time of return on investment (ROI) you are willing to accept for this scenario?

a. Number in years
b. No answer

25. In Scenario 3: How much money will you be willing to invest deploying an energy management system that allows neighbours to sell and buy energy that each can generate?

a. Number in €
b. No answer

26. What is the maximum time of return on investment (ROI) you are willing to accept for this scenario?

a. Number in years
b. No answer

27. In Scenario 4: How much green taxes will you be willing to invest per year to help local governments to make the scenario a reality (e.g., maintain the robotaxis and e-vehicles fleet)?

a. Number in €
b. No answer

28. What is the maximum time of return on investment (ROI) you are willing to accept for this scenario?

a. Number in years
b. No answer

29. Select the statement that best represent yourself when you are taking a decision related to this scenario:

a. I prefer to not make a decision. I rather try to continue doing the same every time without thinking and prioritise following my daily routines.
b. I prefer to do things with the lowest physical and mental effort. I am concerned about the environment, but I am usually too busy to think twice before acting.
c. I prefer to think carefully about my decisions overall if they impact the climate. I know what I want and take my time to evaluate my options.
d. I prefer not to answer

30. **Select the statement that best represent yourself when you are taking a decision related to this scenario:**

a. I am an environmentally conscious and a well-informed consumer.
b. I am concerned about the environment, but I always prioritise comfort.
c. I am concerned about the environment, but I lack awareness of my impacts to act differently.
d. I am rather materialist and the impact on the environment of my decisions is beyond my personal responsibility.

e. Society or my peers influence me, so I usually follow what others suggest to me.
f. I am indifferent to environmental concerns.
g. I prefer not to answer

31. **Select the statement that best represent yourself when you are taking a decision related to this scenario:**
    a. I consider myself as an early adopter, so I enjoy following the latest trends even if it means taking some risks or impacts on the environment.
    b. I am not really interested in new equipment, technology or environmental actions, so I just use/do the one that I am used to.
    c. My main interest is taking the most cost-effective decision. I am an informed person and I always make some calculations before making any decision.
    d. I'd only invest in the energy transition if it helps to improve my safety and that of my relatives.
    e. I'd only invest in the energy transition if it helps me to reduce my environmental impact in any form.
    f. I'd only invest in the energy transition if it helps me to increase my social status (i.e., the opinion of others about me) or if it is the social norm of my colleagues, friends and family.
    g. I'd only invest in the energy transition if it helps to maximise my comfort/well-being and that of my relatives.
    h. I prefer not to answer.

17. ANNEX H: Survey to validate the Causal Model per archetype

17.1. Personal characterization

1. **In which country do you reside?**
    a. XXXX
    b. No answer

2. **In which type of town do you live?**
    a. Rural
    b. City
    c. Residential area
    d. I prefer not to answer

3. **How old are you?**
    a. 18-30
    b. 31-55
    c. 56+
    d. I prefer not to answer

4. **Which of the following most accurately describes you?**
    a. Male
    b. Female
    c. Non-binary
    d. Other
    e. I prefer not to answer

5. **Do you live alone or do you share your household with others? (Please, check all the answers that apply to you and your personal situation)**
    a. I live alone
    b. I live with friends or other non-family persons
    c. I live with my partner
    d. I live with my childs (or other minors under my responsibility)
    e. I live with other adults under my responsibility
    f. I live with other persons who are either family or relatives
    g. I live with my pet
    h. I prefer not to answer

6. **How many people live in the house?**
    a. Numeric

7. **What is the highest level of education you have completed?**
    a. Primary or no studies
    b. High school
    c. Vocational training/ Trade School
    d. University
    e. I prefer not to answer

8. **What is your approximate individual yearly income (netto)**?
    a. More than 100.000 €
    b. Between 50.000 € and 100.000 €
    c. Between 30.000 € and 50.000 €
    d. Between 15.000 € and 30.000 €
    e. Less than 15.000 €
    f. I prefer not to answer

9. **In a typical month, how much of your salary is saved?**
    a. I manage to save more than 20% of the monthly salary
    b. I manage to save between 10 and 20 % monthly
    c. I manage to save less than 10 % monthly
    d. Nothing, I am using my savings lately
    e. I prefer not to answer

17.2. Household Characterization

10. **In which type of housing do you live?**
    a. Flat / Apartment
    b. Semi-Detached / Townhomes
    c. Single-Family Home / Chalet
    d. In a multi-family house
    e. Others
    f. I prefer not to answer

11. **Do you own the place where you live?**
    a. Yes
    b. No
    c. I prefer not to answer

12. **How much usable area does your house have?**
    a. Less than 80 m²
    b. Between 80 and 120 m²
    c. More than 120 m²
    d. No answer

13. **Is your house properly insulated?**
    a. Yes (it has been built or refurbished with energy efficiency in mind),
    b. No (it has built without energy efficiency in mind and has not been completely refurbished),
    c. I do not know,
    d. I prefer not to answer

14. **In which climate zone do you live?**
    a. Atlantic
    b. Mediterranean

c. Continental
d. Alpine or Nordic
e. Arid or semi-arid
f. I do not know
g. I prefer not to answer

17.3. Investment scenario

Scenario #1 - Appliances: One of the appliances you use occasionally (e.g. the oven for baking, the washing/drying machine, a drill or the vacuum cleaner) breaks down again. In order to contribute to the climate neutrality objectives, you decide not to buy a new piece of equipment for individual use but to propose its purchase to your community for shared and common use (and that way you can buy a top energy efficiency one). To do this, you convince your entire community of your building to share these household appliances for common everyday use. Luckily, you have space in the basement to accommodate them and you propose to your community to adhere to this initiative when they have to replace their equipment and not before.

Scenario #2 - Insulation: You live in a new or highly refurbished passive house (https://en.wikipedia.org/wiki/Passive_house). In addition to having first-class facade, roof and window insulation, an intelligent and highly efficient heating/air conditioning system supplies the dwelling with your heating, cooling and hot water needs. An energy management system controls the heating/air conditioner system giving to it the potential to share energy with the neighbours building a "distributed district heating". Moreover, you are very environmentally conscious so you prioritise saving energy with any kind of investment of money or time, and you are always willing to sacrifice some comfort when setting the thermostat temperature.

Scenario #3 - Electricity: You live in a new or highly refurbished passive house (https://en.wikipedia.org/wiki/Passive_house). You have solar panels integrated into the building and a battery system that allows you to store excess daily energy to consume at night. The generation system is slightly oversized, and in summer, you have a surplus of energy generated that is used at the community electrolyzer that generates and stores hydrogen. This hydrogen is later used in a highly efficient community cogeneration system (a.k.a. technology that produces electricity and thermal energy) to power a low-temperature district heating that provides the heating/cooling and hot water demand of the community. All these components could be controlled by an energy management system in which you can invest, not only to optimise its performance but also to allow you to trade energy between neighbours or with the energy provider.

Scenario #4 - Mobility: The city where you live has been re-designed in a way that all services are at foot distance (for example, following the idea of *15 mins cities - https://en.wikipedia.org/wiki/15_minute_city*). A series of agreements between the government and companies, aligned with investments in behaviour change from the citizens' side, ensures that teleworking are mandatory at least three days a week. In your city, the number of vehicles is drastically reduced due to several incentives to embrace low-emissions mobility vehicles (e.g., bikes, e-bikes, e-scooters, etc.) and facilities to take public transport. Indeed, a combination of public or private personal mobility, robotaxis (a.k.a. self-driving taxi or a driverless taxi) and electric public transport supply the rest of travel needs (inter and intra city). For these reasons, traffic jams are something from the

past and the air is again breathable. Long distance transport of passengers and goods is only made using trains and the amount of travel by plane is drastically reduced to intercontinental travel.

15. **For each of the scenarios presented before, please select the statement that best represent yourself when you are taking a decision related to this scenario:**
    a. Short description of each of the archetypes found in Survey 1
    b. None of the above
    c. I prefer not to answer
16. **For each of the scenarios presented before, please select the statement that best represent your actual status:**
    a. I do not intend to carry on any action for a short period of time.
    b. I am starting to consider taking action in a short period of time.
    c. I intend to act soon.
    d. I have made an action already.
    e. I have made an action in the past and I am not considering doing them any more.
    f. None of the above
    g. I prefer not to answer
17. **Please rate each one of the following sentences on a scale being the left-side of the slider "Not at all relevant for you" and the right-side of the slider "drastically important to you".**
    a. Present each one of the determinants that are part of the archetype selected in question 15.