PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE

SCHOOL OF ENGINEERING

UNDERSTANDING THE POTENTIAL DEMAND FOR GREYWATER REUSE IN URBAN ENVIRONMENTS: BEHAVIOURAL MODELS FOR POLICY DESIGN

GLORIA ESTEFANY AMARIS CASTRO

Thesis submitted to the Office of Graduate Studies in partial fulfilment of the requirements for the Degree of Doctor in Engineering Sciences

Advisors:

JORGE GIRONAS

JUAN DE DIOS ORTUZAR

Santiago de Chile, January 2021

PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE

SCHOOL OF ENGINEERING

UNDERSTANDING THE POTENTIAL DEMAND FOR GREYWATER REUSE IN URBAN ENVIRONMENTS: BEHAVIOURAL MODELS FOR POLICY DESIGN

GLORIA ESTEFANY AMARIS CASTRO

Members of the Committee:

JORGE GIRONAS	DocuSigned by: Jorge Gironás 6A08AD2D3F494C9...
JUAN DE DIOS ORTUZAR	DocuSigned by: Juan de Dios Ortúzar 376BE4D3F7A24BE...
ALEX GODOY	DocuSigned by: Alex Godoy Faundez E90D7E941FA349E...
STEPHANE HESS	DocuSigned by: Stephane Hess E37CBEC7ADD04E7...
MARIA MOLINOS	DocuSigned by: MARIA MOLINOS SENANTE 7ED38C94E67544B...
SEBASTIAN VICUÑA	DocuSigned by: SEBASTIAN VICUNA DIAZ 34405F892012491...
GUSTAVO LAGOS	DocuSigned by: Gustavo Lagos C. B558E6FD3B4641F...

Thesis submitted to the Office of Graduate Studies in partial fulfilment of the requirements for the Degree Doctor in Engineering Sciences

Santiago de Chile, January 2021

To the infinite improbability

ACKNOWLEDGMENTS

I want to thank all the people who accompanied me in the development of this research, and to each of the professors who were part of this thesis to whom I want to express my admiration and respect.

In a special way I want to thank:

My *Mother and my Brother*, who motivate me to be better every day. Thank you for giving me unconditional support and encouraging me to seek my dreams.

Thomas Guerrero, for motivating me to take on the PhD challenge and for being the best partner along the way. Thank you for encouraging me to go ahead in difficult times, for giving me the strength and courage to continue this path. Thank you for always supporting me, even when you do not agree with my decisions. Thank you for teaching me the value of being strong and courageous. All my admiration for you.

Jorge Gironás, my advisor and professor during my doctorate, who has contributed in all this time his experience, his guidance and his advice. These have and will be of great value in the present and also for my future challenges. Thank you for creating an additional space on your research team and thank you for believing in me and in this project.

Juan de Dios Ortúzar, my advisor, who decided to support me unconditionally. Thank you for sharing your knowledge and experience, which were key for the success of this research. Thank you for your time, patience, and encouragement to work in this amazing area of choice modelling. Thanks for being a motivator at times when I had problems. Thank you for your valuable advices and for believing in my work.

Richard Dawson, who received me in my first experience abroad. My time in Newcastle is probably the best experience I have ever had, and a key factor was our fluid and pleasant relationship. I admire your work very much, and I hope we can continue collaborating in the future.

Stephane Hess, I have no words to express all my gratitude to you. Thank you for your unconditional support, guidance and encouragement. Thank you for the opportunities you provided me with, and for the trust you have placed in me. Thank you for all the time and effort you have put into this project. Thanks for the countless discussions that allowed us to make a perfect mix of numbers and applicability. Thank you for being part of this project and for motivating me to keep going. I admire your work very much, and I hope we can continue collaborating in the future.

Alex Godoy. Thank you for the advice you have given me throughout this process. Your advice has been very valuable for the direction that I took in the thesis and also for the development during my doctorate. I want to thank you for always following my progress and for always having the time to advise me.

I also want to thanks to ***Oscar Melo, Sebastián Vicuña, María Molinos*** *and* ***Margareth Gutierrez*** for their advice on the survey development and the experimental design.

This research was funded by the Centre for Sustainable Urban Development, CEDEUS (grant CEDEUS/FONDAP/15110020). The research team also thanks additional funding from Centro UC de Cambio Global (FONDECYT grant 171133) and Colegio de Programas Doctorales y Vicerrectoría de investigación (VRI). Jorge Gironás also acknowledges grant CONICYT/FONDAP/15110017. Stephane Hess acknowledges the financial support by the European Research Council through the consolidator grant 615596-DECISIONS, which also funded my internship in Leeds. Juan de Dios Ortúzar acknowledges the Instituto Sistemas Complejos de Ingeniería (ISCI) through grant CONICYT PIA/BASAL AFB180003, and Richard Dawson acknowledges the UKRI GCRF Water Security and Sustainable Development Hub (Grant No: ES/S008179/1). Finally, I am grateful for the insightful comments of the unknown referees who helped me and my co-authors to produce much better papers.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE

ESCUELA DE INGENIERIA

UNDERSTANDING THE POTENTIAL DEMAND FOR GREYWATER REUSE IN URBAN ENVIRONMENTS: BEHAVIOURAL MODELS FOR POLICY DESIGN

Thesis submitted to the Office of Graduate Studies in partial fulfilment of the requirements for the Degree of Doctor in Engineering Sciences

GLORIA ESTEFANY AMARIS CASTRO

ABSTRACT

Numerous experiences around the world have revealed that treated greywater reuse in cities can reduce the demand for water in the mains system by 30% to 80% (depending on the applications), among other indirect benefits (e.g., environmental benefits, water security, autonomy). However, these experiences have also shown that the success of this management strategy depends on its acceptability by individuals, since users can associate treated greywater with impure water, even though it is technically possible to remove all pollutants from it at an acceptable cost. Therefore, it is relevant to know the users' acceptability of this type of practice. The ideal scenario would be to acquire this knowledge from real experiences in the field; however, much time and money would be required in the implementation and monitoring of pilot experiences.

In general, cities with no prior experience with residential greywater reuse base their regulations on the results of these practices in other locations. This can lead to unsuccessful initiatives since individuals have different perceptions about reuse, which are strongly influenced by their mental, physical and/or cultural associations, as well as by geographic differences. This thesis offers an alternative method for the understanding and quantitative characterisation of the acceptability of residential greywater reuse, through the study of the decision-making of individuals. In particular, the study focuses on understanding the demographic, psychological and environmental factors that

influence an individual's perceptions of residential greywater reuse for different potential uses. Additionally, it seeks to recognise the importance of the particular characteristics of greywater treated as a parallel service to that of drinking water from the mains network. The study area is the city of Santiago (Chile), where despite the existence of a law that regulates the collection, reuse and disposal of greywater (Law 21,075 of 2018), these practices have not been widely adopted.

Given that the residential water reuse conditions studied in this thesis are still unknown, we based the work on the study of choices in hypothetical scenarios. For this, we used a technique known as *stated preference elicitation*, where each respondent faces a set of scenarios in which a choice must be made between mutually exclusive alternatives. The characteristics of these alternatives vary between scenarios based on a carefully constructed experimental design, intended to provide information that allows relating the influence of different characteristics on the choice. To achieve our research objectives, an analysis framework was employed that integrates advanced discrete-choice methods, including a Mixed Logit model with Error Components, a Hybrid Choice model with latent variables (LV), and a latent classes (LC) model, with a spatial analysis of the forecasts. This set of methods allowed us to identify the different factors that can influence acceptability, among which are included: (1) the sociodemographic characteristics of the individuals, (2) psychological constructs of the individuals given by their pro-grey water reuse attitudes, (3) similarities of the individual sensitivities to greywater reuse, and (4) their spatial geolocation.

The results of this research show that the aesthetics of the treated water (colour, odour) and the potential savings in the water bill, influence different measures for different residential uses. The most accepted uses for treated greywater are those that require less direct contact with the skin. In the best case, where treated greywater has the same appearance as drinking water in terms of odour, colour and quality, the individuals' valuation of treated greywater is positive for all uses except drinking, and they would even accept increases in their water bill (ranging from 1.7% to 18.7% of the value of the water bill according to use). Therefore, we can infer that not only economic reasons influence the decision to use greywater, but also the reduction in water use *per se*. On the other hand, for reusing greywater for drinking to be as acceptable as using mains water, a compensation of 18.9% would be required in the water bill. Something similar applies when the appearance of the treated water is below the standard of the mains water. It was also found that preferences vary widely between sociodemographic groups, mainly influenced by characteristics of the individual such as gender, age, educational level, level of water expenditure, and previous level of knowledge about reusing treated water, as well as their pro-greywater reuse attitudes and geolocation. Additionally, according to the preferences for the different types of indoor greywater reuse and the appearance of the treated greywater, individuals could be classified into four classes: enthusiasts, greywater sceptics, appearance-conscious, and water consumption conscious.

The results obtained may be an important contribution to the city of Santiago in terms of a better understanding of individual behaviour based on the sociodemographic composition of households and their attitudes and choices. It would allow the creation of more effective strategies to increase the acceptability of residential greywater reuse and, thus, the number of users. But it may also be an important contribution to other communities that want to start establishing water reuse within cities together with new regulations.

Also, a contribution to knowledge is made concerning the potential impact on public policies and water resources management in urban environments, motivating strategies that integrate social and economic components, as well as technical ones. The differentiating elements of this work are mainly: (1) the generation of a set of models that integrate needs and acceptability strategies according to the conditions of the case-study city, and (2) the comparison of results concerning the effectiveness of current and future measures on acceptability, including detailed cartographic analysis and scenario testing. This work should allow the identification of measures from an academic-theoretical perspective, aimed at generating solid bases to motivate the prompt implementation of residential greywater reuse as a water management strategy. Additionally, initial steps are taken to predict the potential effectiveness of the current greywater laws, contrast them with alternative rules, and thus determine the potential of the city to implement a new parallel integrated system of greywater and drinking water.

Members of the Doctoral Thesis Commission:

Jorge Gironás
Juan de Dios Ortúzar
Alex Godoy
Stephane Hess
María Molinos
Sebastián Vicuña
Gustavo Lagos

Santiago, January 2021

PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE

ESCUELA DE INGENIERIA

ENTENDIENDO LA DEMANDA POTENCIAL POR REUTILIZAR AGUAS GRISES EN AMBIENTES URBANOS: MODELOS DE COMPORTAMIENTO PARA EL DISEÑO DE POLITICAS

Tesis enviada a la Dirección de Postgrado en cumplimiento parcial de los requisitos para el grado de Doctor en Ciencias de la Ingeniería.

GLORIA ESTEFANY AMARIS CASTRO

RESUMEN

Numerosas experiencias en todo el mundo han revelado que la reutilización de aguas grises en ciudades puede reducir la demanda por agua en el sistema principal, entre un 30 y un 80% (según las aplicaciones), entre otros beneficios indirectos (e.g., beneficios ambientales, seguridad hídrica, autonomía). Sin embargo, estas experiencias también han demostrado que el éxito de esta estrategia de gestión está ligado a su aceptabilidad por parte de los individuos, ya que los usuarios suelen asociar aguas grises tratadas con aguas impuras, aunque técnicamente hoy es posible eliminar todas las partículas microscópicas contaminadas del agua a un costo aceptable. Por tanto, es relevante conocer la aceptabilidad por parte del usuario de este tipo de práctica. El escenario ideal sería adquirir este conocimiento a partir de experiencias reales en el campo; sin embargo, se necesitaría mucho tiempo y dinero para la implementación y el seguimiento de numerosas experiencias piloto.

En general, las ciudades sin experiencia previa con la reutilización residencial de aguas grises basan sus regulaciones en los resultados de estas prácticas en otros lugares. Esto puede conducir a experiencias infructuosas, ya que los individuos tienen diferentes percepciones sobre la reutilización, las cuales están fuertemente influenciadas por sus asociaciones mentales, físicas y/o culturales, así como por las diferencias geográficas. Esta tesis ofrece un método alternativo para la comprensión y caracterización cuantitativa de

la aceptabilidad de la reutilización residencial de aguas grises a través del estudio de la toma de decisiones de los individuos. En particular, el estudio se centra en comprender los factores demográficos, psicológicos y del entorno que influyen en las percepciones de un individuo sobre la reutilización residencial de aguas grises para diferentes usos potenciales. Adicionalmente, busca reconocer la importancia de las características particulares de las aguas grises tratadas como un servicio paralelo al del agua potable de la red principal. El área de estudio es la ciudad de Santiago (Chile), donde a pesar de la existencia de una ley que regula la recolección, reutilización y disposición de aguas grises (Ley 21,075 de 2018), estas prácticas no han sido ampliamente adoptadas.

Dado que las condiciones de reúso de agua residencial estudiada en esta tesis todavía son desconocidas, basamos el trabajo en el estudio de elecciones en escenarios hipotéticos. Para esto, utilizamos una técnica conocida como enfoque de *preferencias declaradas*, en que cada encuestado se enfrenta a un conjunto de escenarios en los que se debe elegir entre un conjunto de alternativas mutuamente excluyentes. Las características de estas alternativas varían entre los escenarios que se basan en un diseño experimental cuidadosamente construido, destinado a brindar información que permita relacionar la influencia de diferentes características en la elección. Para lograr nuestros objetivos de investigación, se empleó un marco de análisis que integra métodos avanzados de elección discreta, incluyendo un modelo logit mixto con componentes de error, un modelo híbrido con variables latentes (LV),un modelo de clases latentes (LC), y un análisis espacial de las predicciones. Este conjunto de métodos permite identificar los diferentes factores que pueden influir en la aceptabilidad, entre los que se incluyen (1) las características sociodemográficas de los individuos, (2) constructos psicológicos de los individuos dados por sus actitudes pro-reutilización de aguas grises, (3) similitudes de las sensibilidades individuales a la reutilización de aguas grises y (4) su geolocalización espacial.

Los resultados de esta investigación muestran que la estética del agua tratada (color, olor) y el potencial ahorro en la boleta de agua, influyen en distintas medidas para diferentes usos residenciales. Los usos más aceptados de las aguas grises tratadas, son aquellos que requieren un contacto menos directo con la piel. En el mejor de los casos, cuando las aguas grises tratadas tienen la misma apariencia que el agua potable en términos de olor, color y calidad, su valoración individual es positiva para todos los usos excepto para beber. Incluso, las personas aceptarían aumentos en su cuenta del agua (que van desde el 1,7% al 18,7% del valor de la cuenta, según uso). Por tanto, podemos inferir que no solo las razones económicas influyen en la decisión de utilizar aguas grises, sino también la reducción del uso de agua per se. Por otro lado, para que la reutilización de aguas grises para beber sea tan aceptable como el uso de agua corriente, se requeriría una compensación del 18,9% en la cuenta de agua. Algo similar sucede cuando la apariencia del agua tratada está por debajo del estándar del agua de la red. También se encontró que las preferencias varían ampliamente entre grupos sociodemográficos, influenciadas principalmente por características del individuo como género, edad, nivel educativo, nivel de gasto de agua y nivel previo de conocimiento sobre la reutilización de agua tratada, así como su pro-reutilización, actitudes de reutilización del agua y geolocalización. Además, de acuerdo con las preferencias por los diferentes tipos de reutilización de aguas grises en interiores y la apariencia de las aguas grises tratadas, los individuos podrían clasificarse en cuatro clases: entusiastas, escépticos de las aguas grises, conscientes de la apariencia y conscientes del consumo de agua.

Los resultados obtenidos pueden ser un aporte importante para la ciudad de Santiago en términos de una mejor comprensión del comportamiento individual, a partir de la composición sociodemográfica de los hogares y sus actitudes y elecciones. Esto posibilitaría la creación de estrategias más efectivas para aumentar la aceptabilidad de la reutilización residencial de aguas grises y, por ende, un mayor número de usuarios. Pero también, es un importante aporte a otras comunidades que quieran comenzar a establecer el reúso de agua dentro de las ciudades y deseen establecer nuevas regulaciones.

Asimismo, se hace un aporte al conocimiento sobre el impacto potencial en política pública y la gestión de recursos hídricos en entornos urbanos, motivando estrategias que integren componentes sociales y económicas, así como técnicas. Los elementos diferenciadores de este trabajo son principalmente: (1) la generación de un conjunto de modelos que integren necesidades y estrategias de aceptabilidad de acuerdo con las condiciones de la ciudad estudio de caso, y (2) la comparación de resultados en cuanto a la efectividad de actuales y futuras medidas de aceptabilidad, incluido un análisis cartográfico detallado y pruebas de escenarios. Este trabajo debe permitir la identificación de medidas desde una perspectiva académico-teórica, orientadas a generar bases sólidas para motivar la pronta implementación de la reutilización residencial de aguas grises como una estrategia de gestión del agua. Además, se toman los pasos iniciales para predecir la efectividad potencial de la normativa actual de aguas grises, contrastarlas con reglas alternativas, y así determinar el potencial de la ciudad para implementar un nuevo sistema integrado paralelo de aguas grises y agua potable.

Miembros de la Comisión de Tesis Doctoral:

Jorge Gironás
Juan de Dios Ortúzar
Alex Godoy
Stephane Hess
María Molinos
Sebastián Vicuña
Gustavo Lagos

Santiago, Enero 2021

1. INTRODUCTION

1.1. Water Security

Water security, in terms of access to and availability of water, is a reality of global concern that will worsen over time and as a function of spatial conditions (Distefano & Kelly, 2017). One of its most influential causes is the vulnerability of water supply systems due to factors that cannot be controlled, at least at the local level, such as increasing temperature, decreasing rainfall, the overall alteration of the natural hydrological cycle, and the overexploitation of the resource (OECD, 2012). UNESCO (2015) estimates that the global water deficit forecast will be 40% by 2030 and could reach 55% in 2050. The implication is mainly that the supply of water will decrease, while at the same time the demand will increase, due to natural population growth and other migratory phenomena including the densification of cities (Wang et al., 2017). Hence, the progressive deterioration of water both in quantity and quality (Carpenter et al., 1998), may lead to severe impacts on the wellbeing and financial situation of the population in the short term (Pedro-Monzonís et al., 2015), as well as to the overexploitation of water sources in the medium term.

Many countries currently face challenges in terms of water security around the world. Freshwater scarcity is not uniform and affects each country in different ways, scales and magnitudes (Mekonnen & Hoekstra, 2016). For example, areas such as the Western part of the United States, Southern Europe, Central Asia, and North China, suffer moderate to severe water scarcity in the spring-summer seasons. While other sectors in North Mexico, North of Argentina, North of Africa, Somalia, Southern Africa, the Middle East, Pakistan and Australia, may go from moderate to severe water scarcity during more than half of the year (Mekonnen & Hoekstra, 2016). Chile is a good example of a country that is not immune to this problem, but where the consequences vary extensively across areas. Given the heterogeneity of the Chilean territory, the water deficit conditions do not affect all zones (Meza et al., 2014). For example, in the South of the country, the availability of surface flows are higher than water demand, while in sectors from the *Metropolitan Region* to the North, the opposite occurs (Valdés-Pineda et al., 2014).

1.2.Greywater Reuse as an Alternative Solution

1.2.1. Generalities of water reuse

The reuse of water, worldwide, has evolved over time. In ancient civilizations (e.g., Roman, Greek), residential wastewater was used mainly for irrigation, land fertilization and aquaculture (Angelakis et al., 2018). However, in more recent times, the regeneration and subsequent reuse of water has been implemented for a variety of purposes around the world, including potable use (Harris-Lovett et al., 2015).

Water that can be reused comes from three different sources:

- **rainwater**: while rainwater constitutes the primary source of the mains water supply (i.e., the centralised system), it can also be used in more localised settings, including residential contexts (i.e., capturing rainfall on site). However, this depends on the climatic and geographical characteristics of the cities, and as rainwater can only be stored for a short time, it may not be a "reliable" source on a daily basis.
- **sewage**: as water collected in the sanitary sewer has been in contact with faeces, it contains harmful bacteria and pathogens that may cause diseases. This type of pollutant load in the water does not dissipate easily, so its treatment must be more specialized. This precludes a decentralised approach. In addition, given the *source* of this type of water, even after treatment, generally it does not re-enter directly in the water supply system. For example, while the Chilean *Metropolitan Region* (MR) currently treats 100% of the wastewater reaching the wastewater treatment plants, more than 95% of that water is returned to water bodies, and less than 5% is reused (Aguas Andinas, 2016).
- **greywater**: this water comes from household sinks, showers, tubs and washing machines, and, unlike sewage, has not been in contact with human waste. This characteristic of greywater dramatically decreases the risk of disease and increases the rate at which it can be safely broken down and reused with basic treatments. Greywater corresponds to 50 - 70% of the residential water that today is discharged through the sewer system; in this water, 30% represents the organic fraction and 9-

20% the nutrients (Fountoulakis et al., 2016). Unlike mains water, greywater can generally contain soap particles, grease, hair and even scales from human skin.

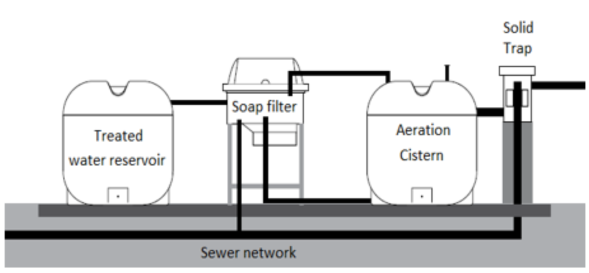
Worldwide, at least 60 countries are already reusing their water (AIDIS & UNESCO, 2016). There are multiple successful experiences of water reuse to partially meet the water demand (WD) in urban areas, among which Egypt (11% of WD), Singapore (10% of WD), Australia (23% of WD), Saudi Arabia (10% WD) and the United Arab Emirates (6% WD) stand out (Y. Chen et al., 2017; Khan & Anderson, 2018; Lefebvre, 2018; Woltersdorf, et al., 2018). Likewise, some countries' urban sectors (Saudi Arabia, Africa, Australia, China, Japan, the United States, Israel, Kuwait and Qatar) have already integrated water recycling and reuse in their action plans for urban water management (Bahri et al., 2016; Guthrie et al., 2017; Jiménez & Asano, 2008; Yi et al., 2011). As a result of the experiences in these various countries, the following is available: (1) guidelines for the control of water quality depending on the type of water source (grey or residual) and projected use; (2) protocols for regulating the performance of technologies; (3) technology improvement needs in terms of efficiency, performance and cost minimization; and (4) guidelines for planning management systems that integrate urban waters (rainwater, waste and/or grey).

1.2.2. The emergence of decentralised greywater treatment and reuse

Given the shortage of fresh water around the world, as well as the densification of urban areas, reconfiguring the conventional drinking water system has become more common, allowing cities to use water treatment for residential purposes through decentralized systems. This new way of recovering water in cities runs in parallel to the mains supply network, and requires households to manage part of their water used in sinks, showers, tubs and washing machines (i.e., greywater onwards) by themselves. Decentralized systems should allow a more efficient water use, as mains water might be used only when strictly needed (drinking, cooking), while treated greywater - from a parallel decentralized system - can be used when a high-quality standard is not essential (e.g., toilet flushing, garden irrigation).

While greywater has long been used informally in some areas for garden irrigation and toilet flushing *without treatment* (Kotzé, 2018), appropriate treatment allows for wider use of the water and also to reduce the risk of contracting diseases. Treated greywater can be suitable for different uses, ranging from toilet flushing all the way to drinking, as long as it is properly treated considering the level of human contact (direct or indirect) for the desired use (Fielding et al., 2019; Jefferson et al., 2004), and according to the quality of greywater collected (Shaikh & Ahammed, 2020). In general, greywater treatment mainly seeks to remove suspended solids, organic matter and microorganisms (Li et al, 2009). Several investigations carried out in the last two decades (Fountoulakis et al., 2016; Jefferson et al., 2004; Li et al., 2009; Wu, 2019), suggest that biological processes combined with solids separation, filtration and disinfection practices, configure the most appropriate approaches to greywater treatment, allowing its reuse even for drinking purposes. These processes are considered, for example, in *Hydro4*, an existing equipment in Latin America considered for reference purposes in this study (Figure 1-1).

The potential benefits of treated greywater are clear when looking at water consumption at the household level. An average citizen of the Metropolitan Region (RM) of Chile consumes between 167 l/day in winter and 230 l/day in summer (Aguas Andinas, 2016), out of which 100 - 140 l/day are greywater (free of faeces), which could be treated at a lower cost and reused in uses that do not require direct skin contact. Cities are gradually recognising this and seeking to facilitate the practice.



Equivalent inhabitants	Daily flow [L/day]	Electrical consumption [kWh/day]
30 max.	3000	22
60 max.	6000	35
120 max.	12000	70

	Guiding Values	
Control in treated water	**Greywater entry**	**Greywater recovered exit**
Turbidity [NTU]	22 - 100 NTU	< 2
E. Coli [CFU / 100 ml]	10-10000 UFC/100 ml	No detected
DBO5 [mg/Lt]	90 - 100	< 20
pH if chlorine is added		7.0 - 8.0

Figure 1-1. Technical specifications of water recycling technology (Hydro4)

1.3. Acceptability by consumers

Developing and promoting water reuse laws and policies for better resource management requires an understanding of the degree of people's acceptability. End consumers are the party most affected by new water services, as they will perceive changes in their well-being and make decisions that can contribute to the operation of a management measure. Gaining an understanding of consumer preferences is essential to assess the effectiveness of greywater reuse strategies, as well as to foresee the potential impacts of laws and policies.

The previous experience of other cities in the implementation and use of greywater reuse systems is a key input for cities that want to integrate greywater reuse as part of their supply sources. However, acceptability has been demonstrated to be heterogeneous among individuals (Ilemobade et al., 2013; Wester et al., 2015), that is, two individuals may perceive reusing water differently, which directly impacts the acceptability of uses and therefore, the success of the management measures. This heterogeneity may exist between individuals that have different characteristics (e.g., young *vs* old), but also between two individuals that fall into the same socio-demographic group. In addition, there is clearly scope for geographic differences.

The understanding of behaviour has been studied extensively in psychology (Laland & Brown, 2013; Wallsten & Budescu, 1983). However, since many aspects of human life require individual decision-making, the study of behaviour has transcended to other areas (e.g., environmental sciences, transport), where there is a focus on understanding preferences to promote policies, products and services. Until now, insights into individuals' responses to water reuse schemes have been based on social and psychological interpretations of the individual (Dolnicar et al., 2011; Fielding et al., 2019; Goodwin, Raffin et al., 2018; Hartley, 2006) and different approaches have been used to understand these public responses towards reuse. In an extensive review, Smith et al. (2018) classified the different studies focused on water reuse according to their approach, as follows:

1. The first approach seeks to identify the characteristics of the product and consumer that influence public reactions to water reuse and to understand associations between different factors (Hartley, 2006);
2. The second approach is more oriented to socio-psychological principles, supported by the theory of planned behaviour (Ajzen, 1985);
3. The third approach is more associated with trust and emotional reactions.
4. The fourth approach is associated with constructivist social perspectives and the theory of socio-technical systems, which considers 'subjective norms' - characterized as "the influence a person feels from other people".

While the first approach focusses on observable characteristics, the latter three focus on factors that mainly involve psychological constructs. These approaches are clearly not mutually exclusive, that is, it is possible to evaluate the role of the characteristics of a water reuse system and the influence of various types of factors (e.g., demographic, psychological associations and emotional reactions) at the same time.

To quantitatively understand and then to predict the potential demand for the reuse of greywater in urban settings, where that practice is not widely implemented, it is necessary to develop a model of consumer behaviour. Initially, a model is formulated and parameters explaining behaviour are estimated using data collected specifically for that purpose. Subsequently, the model can be applied to new scenarios to obtain the answers of interest. The data is the basis for modelling, and therefore the design of the data collection tool (usually surveys) must be carried out with great care. The information collected by the survey can be obtained either from what decision-makers have been observed to choose in real-world settings (Revealed Preference), or what they say they would do or prefer in hypothetical settings (Stated Choice or Stated Preference). Given that greywater reuse is not a common practice in Santiago, the second technique fits better our study, as explained in detail in chapter 2 of this manuscript.

Disentangling the different sources affecting choices, requires a careful mathematical modelling process to quantify the impact of the different factors. However, caution must be exercised in selecting the appropriate measurement and estimation method since each assumption adds a different level of complexity to the models (Train, 2009), and potentially also has implications for how the results of the analysis can be used in policy design. In the last decade, researchers have proposed new efficient modelling strategies, based on the discovery of new attributes and the establishment of the water needs of their cities (Bach, et al., 2014). The principles followed by Integrated Urban Water Management (IUWM) systems should be based on: (1) the modelling of factors (e.g. climatological, socioeconomic) and interactions between them, (2) the evaluation of impacts related to water quantity and quality, and (3) the dissemination of the results from both an individual and a global perspective (Bach, et al., 2014).

The type of models selected for the present thesis belong to the field of *discrete choice modelling,* and in particular *random utility models*. These have become a useful tool for understanding the importance of individual characteristics of products or services and facilitate the evaluation of the heterogeneity in individuals' choices. They form advanced analytical tools, with a majority of applications now relying on some form of mixture models (as shown in the various contributions in Hess & Daly, 2014), that explain complex heterogeneity patterns. Much of the work in this area makes use of experimental techniques rather than "real world" decisions, especially for choices involving new products and/or services. The same applies when seeking to understand the response to characteristics that are difficult or impossible to measure in real choices, such as risk, or characteristics with insufficient real-world variation to capture changes in behaviour, such as key qualitative attributes like noise and smell.

A major unaddressed issue in this context arises in the presence of potentially significant differences in perception across individual decision makers. If people react differently to attributes with a clear and objective quantitative scale, such as time or money, then it is relatively uncontroversial to attribute this to actual differences in sensitivities, notwithstanding the possibility that this heterogeneity may be smaller or larger in experimental settings. However, the same is not the case with attributes that have a more subjective angle of interpretation, such as risk, smell, or colour. An analyst needs to make a decision on how to describe these attributes in an experimental context, and any differences in interpretation will likely exacerbate the estimated differences in sensitivities. This issue is addressed carefully in this thesis by explaining the attributes and descriptions to individuals prior to the experiment.

In the context of evaluating the potential demand for a new greywater service, the analytic toolkit should ideally meet three different requirements. First, it needs to be suitable for understanding the process by which consumers make decisions, so that we can get insights into why consumers accept greywater in some settings while they reject it in others. Second, in the context where a *market* does not yet exist, the toolkit needs to work with data from hypothetical choice scenarios. Third, the model should be suitable for making predictions of how demand might evolve in the future, if the attributes of the product/service or the consumer change. This can also involve understanding what changes are required to achieve a desired change in behaviour (e.g., increased uptake of greywater reuse). This thesis puts forward the use of a combination of stated choice methods and advanced discrete choice models for this purpose (Ortúzar and Willumsen, 2011, Chapters 3, 7, 8 and 9), and these approaches are discussed in detail in chapters 3, 4 and 5.

1.4.Motivation

As with any innovation, the extent to which evidence is transferable is unclear. In the present context, this relates both to spatial transferability as well as to the source of water that is reused. In terms of spatial effects, while there is growing experience in some areas, this is not universal. For example, despite the potentially substantial benefits that come from water reuse, the practice is not yet widespread in South America. Indeed, while countries such as Colombia, Perú, Argentina, Brazil and Chile reuse part of the treated water, most of it is destined for reuse in agriculture or is discharged into water bodies (AIDIS & UNESCO, 2016). Secondly, the source of water for reuse and the type of technology used may have an impact on consumer acceptability, which is key to the success of any system. This applies, in particular, in the case of relatively novel approaches, where our focus is on treating greywater for reuse in a residential setting.

Regulations on greywater reuse in cities without previous experience on the subject may act as a demotivating element on its acceptability. In the case of the current Chilean law, only two residential uses are allowed: garden irrigation and toilet flushing, but not all houses have gardens. Further, those that do have gardens would not use that water in wet seasons, which could make the installation of greywater systems unattractive as they could not be used to their full capacity. Thus, if the choice behaviour of individuals, which is based on their sociodemographic composition and attitudes, was better understood, more effective strategies for increasing the acceptability of urban greywater reuse by consumers would be possible.

1.5.Hypotheses

The key overarching hypothesis of this research is that there is not a single homogeneous willingness, or otherwise, in the population to reuse treated greywater. There is extensive heterogeneity in the level of acceptability, depending on both the product and the consumer. This would imply that the success of any greywater policy depends on recognising and accommodating such heterogeneity. This overarching hypothesis can be divided into several individual hypotheses.

- **H1:** The acceptability and willingness to reuse greywater are not independent of the characteristics of the treated greywater and vary as a function of the projected use and appearance of the water to be reused.

- **H2:** Observable characteristics of individual consumers (e.g., age, education) as well as past exposure to greywater reuse, are key drivers of heterogeneity in the willingness to use treated greywater.

- **H3:** There are additional variations in preferences that cannot be linked to socio-demographic attributes, but which are driven by unobserved factors.

- **H4:** Such idiosyncratic differences in preferences could be linked in part to underlying attitudes of individuals, and/or to the existence of different segments of the population with very distinct preference structures.

1.6. Objectives

The main aim of this research is to study residential greywater reuse preferences, and understand which quantitative and qualitative characteristics would increase the acceptability of water reuse as an additional source of water supply in cities, and how this could differ across consumers.

The work is based on a carefully constructed survey of preferences, which is detailed in chapter 2. Four separate chapters form the key contribution of the thesis, and between them address the four following specific objectives:

- **O1:** Understand the willingness to use greywater for different residential uses, considering the variation in observable consumer characteristics across households, as well as the properties of the greywater service, in terms of qualitative appearance and monetary implications.

- **O2:** Evaluate the role of individuals' attitudes to explain the heterogeneity in greywater reuse preferences and establish which consumer characteristics contribute to the formation of these attitudes.

- **O3:** Establish whether there are specific subgroups of the population with clearly distinct preferences, how the preferences vary across these groups, and how individuals are split across these groups, both through observable differences between consumers and through idiosyncratic variation.

- **O4:** Develop insights for policy design, including understanding geographic differences in preferences and predicting the potential uptake of greywater reuse under different future scenarios, by using the results from quantitative modelling analyses.

Chapters 3-5 address **O1-O3** in turn, while chapter 6 distils and further processes the results from chapters 3-5 to address **O4**.

The interrelation between objectives is shown in Figure 1-2. At the top we can see a summary version of the aspects considered for the acceptability assessment. For example, in this study the scenarios consider variations in qualitative characteristics of the treated greywater service (colour, odour) and quantitative characteristics such as water savings due to lower consumption from the mains network.

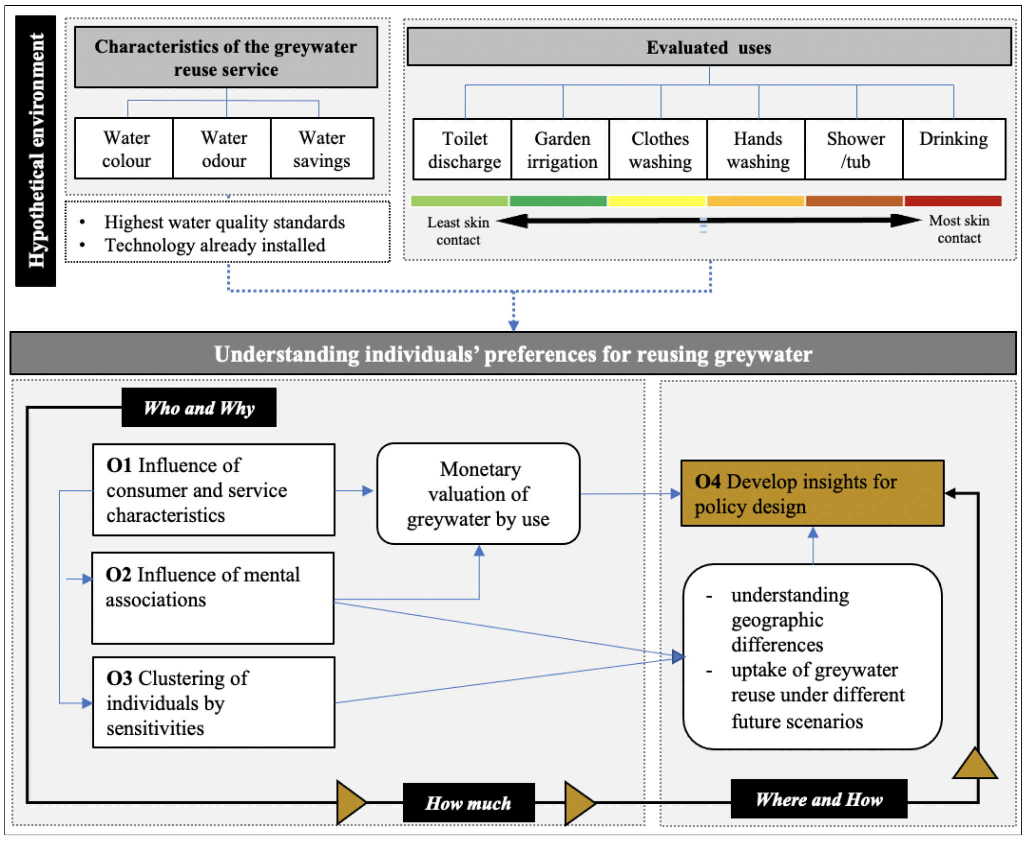


Figure 1-2. Topics and objectives of the dissertation

The uses evaluated are residential uses that require different levels of contact with the skin. A better detail of this can be read in chapter 2. Figure 1-2 also presents, in a summarized form, the objectives and how they relate with each other. Note that these objectives seek to understand individual water reuse preferences based on knowledge of the *who*, *why*, *when*, *where* and *how* of acceptability. Once these questions are answered, it should be possible to better understand the behaviour of individuals and evaluate viable management strategies to increase the acceptability of greywater reuse.

1.7.Study Area

The study zone is the urban area of Santiago located in the *Metropolitan Region* of Chile. Santiago is the most populated urban centre in Chile (40% of the Chilean population), with some 7.1 million inhabitants (INE, 2017). It is administratively divided into 37 municipalities (Figure 1-3). A key motivation for developing the study in Santiago is the fact that the new law of greywater sets out the mandatory installation of greywater reuse systems for new buildings. Three other characteristics were also highly relevant in choosing this city to assess the willingness to reuse greywater, namely that it is an area with i) water security risks, ii) growing and changing population and iii) residential greywater reuse is allowed by law.

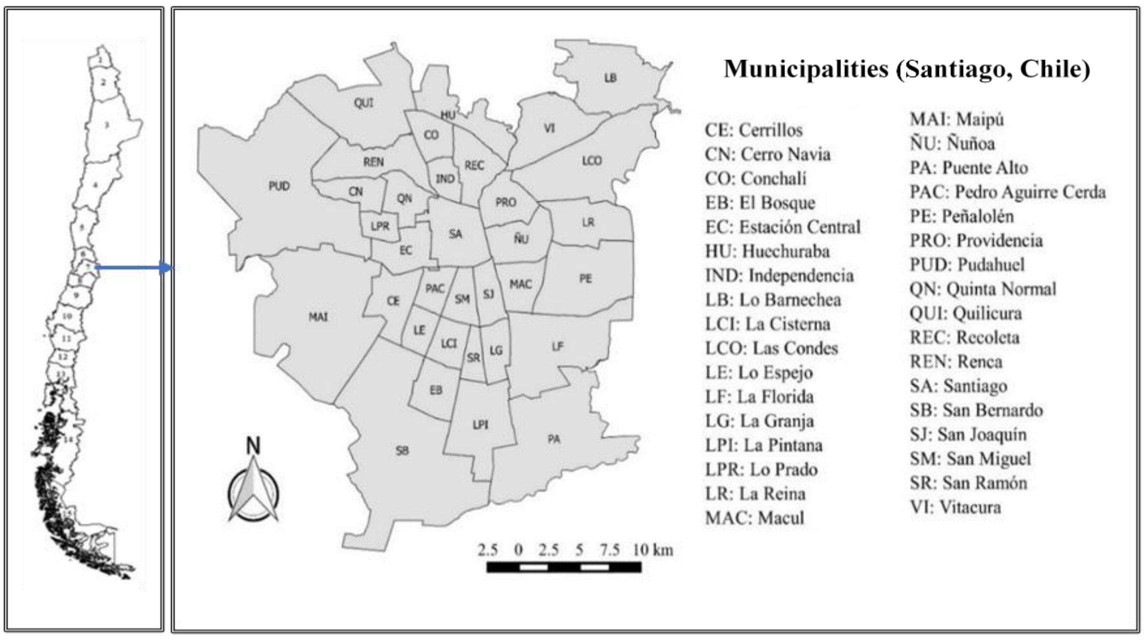


Figure 1-3. Study area

A more detailed description is presented below:

(i) Water security risks.

The potable water supply comes predominantly from the *Maipo River,* supported by the *Mapocho River*, the *Yeso reservoir* and some groundwater wells (Meza et al., 2014). Almost 90% of the population receives its water supply and sewage services from a private company called *Aguas Andinas*. Currently, residential water demand per capita averages 150 l/day, but can be as high as 600 l/day in some neighbourhoods, depending on the presence and size of gardens (Bonelli et al., 2014). Water losses due to pipe leaks in the mains water system are around 30% (Aguas Andinas, 2019).

The *Metropolitana* Region has severe water deficit problems and is predicted to become the area with the highest deficit in Chile by 2025 (Valdés-Pineda et al., 2014), with periods between one to four weeks of very low flows (Vicuña et al., 2018). Evidence of Santiago's vulnerability towards extreme events are the water service cuts in the main water system. Historical records about extreme water events show that in 2014, for example, 102 districts across Chile were declared in a state of water emergency for four consecutive years because of droughts (Fundación Chile - FCH, 2017; Ministerio del Interior y Seguridad Publica, 2014). Despite the efforts of *Aguas Andinas* to strengthen the main drinking water system, it continues to be fragile in the face of significant threats due to climate variability, climate change and population growth (Vicuña et al., 2018).

(ii) Growing and changing population.

Approximately 40.5% of the Chilean population lives in the Metropolitan Region, and the large majority of these (93%) are inside the urban area. The overall population is growing, although the rate is low (1%), and the socio-demographic characteristics are changing. Furthermore, growth of private homes between 2002-2017 in the Metropolitan Region is 44.9%, while increaseing population density has led to 8% of households having five or more inhabitants per room, and are considered to be critically overcrowded (Sintesis de resultados INE, 2018).

(iii) Regulation to allow greywater reuse.

Given the extent and severity of the 2014 drought in Chile, Law 21,075 was published in 2015 to allow for the regulation, collection and reuse of greywater in urban and rural areas of the *Metropolitan* Region. The law has three key components.

- It sets out the requirements to request authorization for the operation of a greywater system.
- It determines which urban uses are permitted (sanitary devices and garden irrigation - Article 8), and which are not permitted (human consumption, swimming pools, or any other use that the health authority considers risky for health - Article 9). The permitted uses require prior approval, and depending on this, the authorities are required to establish the quality that the water should have according to the projected use. The owner is required to meet certain quality levels for the requested use and, in turn, is responsible for the operation and maintenance of the technology (Article 12).
- It sets out the mandatory installation of greywater reuse systems for new buildings.

Although there are still challenges to carry out the implementation of these systems associated with economic viability, technological adaptation and institutional capacities, there is a greater challenge related with the willingness of individuals to use greywater.

The norm demands a great responsibility on the part of the owners in charge of the operation of the system, and it is unknown whether the people would be willing to assume the responsibility of treating their own water.

1.8.Methodology

To achieve the thesis's goals, a methodology has been developed that is comprised of three phases: (i) Preliminary work, (ii) Modelling, and (iii) Analysis of results. An overview of the methodology can be seen in Figure 1-4.

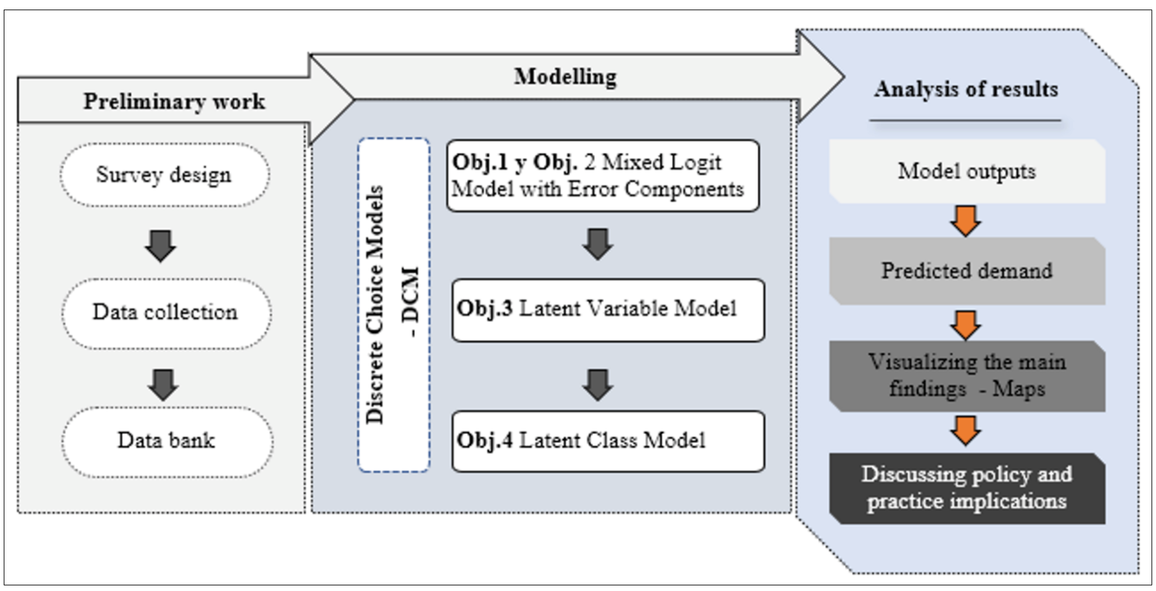


Figure 1-4. Methodology

Preliminary work was associated with the design of a survey about hypothetical choices in a greywater context, and the collection of data from potential consumers using that survey. The aim of the data collection work is to allow us to analytically evaluate the acceptability of residential reuse of treated greywater in settings where this is not common practice. The surveys were randomly taken in the *Gran Santiago* urban area, and later the information was processed in a databank. Details on the survey and data collection stage are given in Chapter 2.

In the *Modelling* phase, three analytical models associated with the proposed objectives were developed. Several models of the discrete choice family were implemented. We started with a Mixed Logit model with error components, which allowed us to evaluate the influence that socioeconomic characteristics of consumers and characteristics of the greywater have on the acceptability of individuals for residential reuse of greywater. The second approach corresponded to a Latent Variable model, which helped us to disentangle the heterogeneity of choices and to understand the role of individuals' attitudes. The final structure corresponded to a Latent Class model, which helped us to classify the individuals in categories according to their sensitivities toward the attributes of greywater services. Detailed information about each of these approaches, along with the appropriate background on choice models, is given in the respective chapters (chapters 3-5).

Once the models had been estimated, we proceeded to make predictions about the possible acceptability by individuals of greywater in the expected scenarios of the water reuse service. This was possible because we had already evaluated the behaviour of individuals under variations of the attributes chosen to characterize the greywater service (based on the results of chapters 3 to 5). Importantly, in the *Analysis of results* phase, we also reweighted the sample population to make it representative of the overall population of Santiago. Next, a GIS tool was implemented to integrate the acceptability forecasts with the geographic location of the respondents and, finally, forecasts were made allowing us to evaluate various policy scenarios, including the expected reductions in water demand given the acceptability forecasts. These different contributions are reported in Chapter 6 of this document.

1.9.Contents and Contributions

This thesis describes the most relevant findings of five years of research through four different articles, each one presented in a different chapter (Chapter 3 to Chapter 6), briefly described in the next subsections. This document contains six additional chapters. Chapter 2 is concerned with the data collection work, where the choice context, sampling and instrument design for the data collection exercise are explained in detail. Chapters 3 to 6 correspond to the development of the specific research objectives and their respective conclusions. Finally, Chapter 7 presents our general conclusions.

1.9.1. Chapter 3: Understanding the preferences for different types of urban greywater uses and the impact of qualitative attributes

Abstract: Greywater reuse can allow substantial improvements in the efficiency of potable water systems. However, widespread uptake of greywater reuse depends on its acceptability by the population. Previous studies have assessed the implementation costs of greywater reuse technology and considered its acceptability in principle. Although cost is clearly very important in terms of adopting/installing the technology, the actual perception of greywater reuse is crucial in driving the acceptability of use and the long-term success of the technology. This study uses discrete choice models to quantify, for the first time, the preferences of different socio-economic groups for greywater of different quality (colour, odour) and for different uses inside homes. A stated choice survey that removed the influence of installation costs was developed, and implemented in Santiago, Chile. Although legislation allows greywater use in Santiago, it does not take place at any meaningful scale. Results show that, in decreasing order of preference, there is an overall acceptance for using high quality treated greywater for toilet flushing, laundry, garden irrigation, hand washing and, shower/bathtub use, but not for drinking. When the quality of appearance in terms of colour and odour gets worse, monetary incentives could be needed even for those uses that do not involve human contact. Gender, age, educational level, water expenditure level, and in particular previous knowledge about greywater reuse, are important determinants of acceptability and thus willingness to pay for greywater use; however, their importance varies according to the type of use. Our results provide important insights for understanding the conditions that would precipitate rapid and wide uptake of greywater reuse in cities, and thereby make better use of limited water resources.

This chapter has already been published:
Amaris, G., Dawson, R., Gironás, J., Hess, S. & Ortúzar, J. de D. (2020). Understanding the preferences for different types of urban greywater uses and the impact of qualitative attributes. *Water Research*, 116007. https://doi.org/10.1016/j.watres.2020.116007

Contributors:
Gloria Amaris: study concept, survey work, model specification work, modelling work, manuscript writing
Richard Dawson and Jorge Gironás: policy implications, manuscript editing
Stephane Hess: model specification work, manuscript editing
Juan de Dios Ortúzar*:* study concept, advice on survey and modelling, manuscript editing.

1.9.2. Chapter 4: Using hybrid choice models to capture the impact of attitudes on residential greywater reuse preferences

Abstract: The reuse of treated greywater in a residential setting could contribute substantially to easing problems with water scarcity. This chapter argues that preferences in relation to reusing greywater for different uses within the home vary across households and can be driven at least in part by psychological constructs, such as attitudes and perceptions, which might appear irrational at face value from an economic perspective. To better understand heterogeneity in behaviour in a greywater reuse context, data from a stated choice survey were analysed using a hybrid choice model with latent variables, allowing us to incorporate measurable characteristics of the decision makers as well as other elements that cannot be measured directly (e.g. attitudes towards greywater reuse). Our results provide evidence on the preferences for different uses of treated greywater, and about the heterogeneity of choices among individuals and uses. The model suggests that heterogeneity in the acceptance of greywater reuse can be linked back mainly to underlying attitudes, for all uses except drinking. This knowledge can be used as an input to evaluate diffusion strategies to increase greywater reuse acceptability focused on messages about its direct (i.e. water bill savings) and indirect benefits (environmental benefits, water security, autonomy).

This chapter has already been published:
Amaris, G., Hess, S., Gironás, J. & Ortúzar, J. de D. (2021a). Using hybrid choice models to capture the impact of attitudes on residential greywater reuse preferences. *Resources, Conservation and Recycling*, **164**, 105171. https://doi.org/10.1016/j.resconrec.2020.105171
https://www.sciencedirect.com/science/article/pii/S0921344920304882

Contributors
Gloria Amaris: study concept, survey work, model specification work, modelling work, manuscript writing
Stephane Hess: model specification work, manuscript editing
Jorge Gironás: policy implications, manuscript editing
Juan de Dios Ortúzar: study concept, advice on survey and modelling, manuscript editing.

1.9.3. Chapter 5: Capturing and analysing heterogeneity in residential greywater reuse preferences using a latent class model

Abstract: To legally permit greywater reuse as a management strategy, it is necessary to establish allowed uses, as well as guarantee legitimacy, safety and maintain public trust. Cities with previous experience in greywater reuse have reconfigured their regulations according to their own evidence with decentralized water reuse systems. This has allowed them to encourage or restrict certain indoor uses of treated greywater. However, cities starting to use these residential schemes lack the experience to reconfigure their water and sanitation regulation, and thus need "blindly" decide on the type of greywater uses to allow to achieve a balance between users' acceptability and avoiding public health problems. In this section, we analyse hypothetical situations of greywater reuse based on real evidence related to decentralized water systems. The main objective of this study is to evaluate the heterogeneity of individuals' preferences regarding residential greywater reuse for six intended indoor uses, using stated choice experiments and a latent class model. Hence, we obtain preliminary evidence about the direction that the regulation or pilot tests should take. We use the context of Santiago (Chile) as a reference, where although allowed, greywater reuse is not taking place widely. Our results show that survey respondents can be classified into four classes (enthusiasts, greywater sceptics, appearance conscious and water expenditure conscious), according to the preferences for the different types of indoor greywater reuse and the appearance of the treated greywater. From a policy perspective, our results show differences across classes as a function of socioeconomic characteristics and previous greywater reuse knowledge, as well as wider household characteristics, including the presence of sensitive individuals (under 15 and over 74 years old), number of residents, number of sanitary devices, and location and type of garden.

This chapter has already been accepted for publication:
Amaris, G., Gironás, J. Hess, S. & Ortúzar, J. de D. (2021b). Capturing and analysing heterogeneity in residential greywater reuse preferences using a latent class model. *Journal of Environmental Management* (in press).

Contributors
Gloria Amaris: study concept, survey work, model specification work, modelling work, manuscript writing
Jorge Gironás: policy implications, manuscript editing
Stephane Hess: model specification work, manuscript editing
Juan de Dios Ortúzar: study concept, advice on survey and modelling, manuscript editing.

1.9.4. Chapter 6: From mathematical models to policy design: a multi-component assessment framework to analyse residential greywater reuse preferences

Abstract: Residential reuse of treated greywater is emerging as an appealing option to better manage water in cities with scarcity. However, while some cities have successfully implemented schemes, problems can arise when cities with no prior experience with residential greywater reuse implement regulations based on those from other locations, potentially leading to unsuccessful policy schemes. This is a result of different local circumstances as well as potential differences in consumer preferences, and this heterogeneity has the potential to impact the use and success of water efficiency measures. The present chapter presents a framework for such studies, going from study area selection through data collection and modelling, to the use of results in application. While the data collection and modelling work follows established practice from choice modelling, our key contribution comes in developing guidance from these results, including a key focus on understanding geographical differences through cartographic representation. In a case study application to the city of Santiago de Chile, we show how public willingness to reuse greywater could be increased through targeted education campaigns or monetary incentives. We highlight how the extensive heterogeneity in preferences across consumers and uses of greywater could affect the potential success of greywater reuse schemes. Finally, we show how allowing for an additional permitted use of greywater could save several hundred litres of water per month per household.

This chapter is under review as follows;

Amaris, G., Dawson, R., Gironás, J., Hess, S. & Ortúzar, J. de D. (2021). A spatial assessment framework to analyse greywater residential reuse preferences in cities without previous reuse experience. *Sustainable Cities and Society*. Submitted.

Contributors:

Gloria Amaris: study concept, survey work, model specification work, modelling work, manuscript writing
Richard Dawson and Jorge Gironás: policy implications, manuscript editing
Stephane Hess: model specification work, manuscript editing
Juan de Dios Ortúzar*:* study concept, advice on survey and modelling, manuscript editing

2. SURVEY WORK

2.1. Overview

A carefully designed survey was designed and applied to understand how the acceptability of GWR could be associated with qualitative and quantitative attributes of greywater after treatment, and how acceptability could vary as a function of characteristics of the individuals, their attitudes, and their sensibilities to changes in the greywater appearance and its intended uses.

Considering that greywater reuse is not widely implemented at present in Chile, the survey first presented individuals with a schematic representation to explain the concepts of greywater and sewage, and showed them how a greywater reuse technology system would work inside their homes. Given the interest of this study in qualitative attributes and currently inexistent reuse situations, we relied on a stated choice (SC) experiment, a widely used tool across different research areas – for a comprehensive introduction, see Louviere et al., (2000).

The survey form was divided into four sections:

- *Greywater reuse.* Six questions with predefined possible answers/ratings were asked to gather information related to the respondent's attitudes (e.g., reactions to the concept of greywater reuse, confidence in a greywater reuse system).

- *Choice experiment.* First, a hypothetical environment of greywater reuse was showed to the respondent and then six different scenarios was presented (stated choice experiment).

- *Perceptual indicators*. Questions about attitudes and confidence in treated greywater reuse within the home.

- *Characterization of dwelling and household.* This section had 15 questions related with the number of household members, their socioeconomic characteristics and their dwelling facilities (e.g. age, gender, house size, presence of garden and coverage percentage, kind of coverage – grass or another kind of vegetation).

2.1.1. Hypothetical environment

In SC surveys, respondents make hypothetical choices between mutually exclusive options, requiring an analyst to decide on the choice setting, alternatives, and attributes of these alternatives. The situations scenarios that were based on real experiences in Spain, South Africa and the USA (Domnech & Saurí, 2010; Ilemobade et al., 2013; Wester et al. , , 2016), arriving at the following setup.

The choice options were framed around a hypothetical scenario where respondents had to assume that the technology is already installed in their property, is as easy to use as a standard appliance (e.g., washing machine) and the water after treatment has high quality standards as is shown in Figure 2-1. In this way, the implementation costs of the greywater reuse technology were intentionally eliminated to remove their biasing impacts on acceptability, allowing the focus on the characteristics of the water as these could impact respondents' likes and dislikes, net of the impact of installing the technology *per se*. Such a focus on use rather than acquisition is a common application of stated preference (SP) across different fields of research. For example, one of the most common uses of SP looks at the choice of mode of transport, say between private car and public transport. In that context, the focus is on the cost of travel per journey, rather than on the cost of purchasing a car.

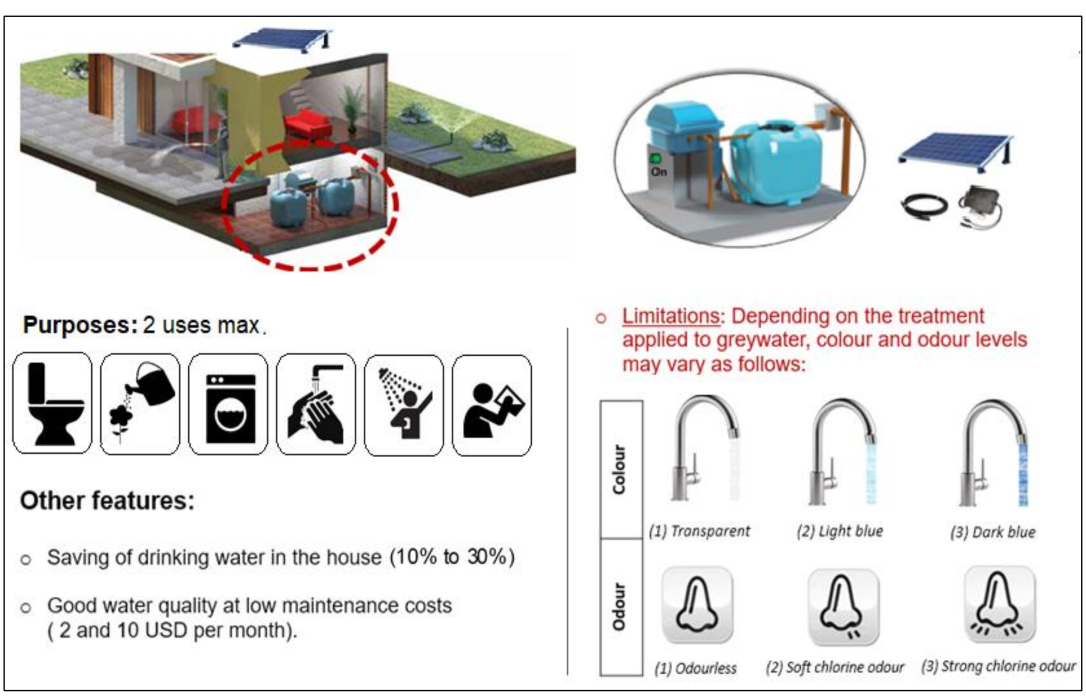


Figure 2-1. Hypothetical environment

Of course, it is important to ensure that respondents can relate to the choice context presented and make decisions that are in line with real world preferences. To this extent, the hypothetical setting was described as follows:

"Assume that in your home there is a device to treat greywater with a simple power button to start using it. The technology will not increase your electricity cost as a solar panel provides power. After the greywater treatment is completed, the quality of the treated water is good enough for use inside the home. However, due to treatment, it might not be as visually clear or smell-free as mains water".

It should be noted that this setting is not unrealistic. Indeed, the solar power generated by a single panel (between 1kWh/day and 5kWh/day, see Jäger-Waldau, (2019) will exceed the operating needs of the greywater treatment for a one family unit (less than 1kWh/day, cf. Matos et al., 2014). Chile is increasing its deployment of solar energy, where law 20.571 came in force in 2013 to encourage uptake of solar panels in households, and there is a growing sustainable housing industry (Cáceres, et al., 2015; Serpellet al., 2013).

2.1.2. Stated choice

A general idea about how the Stated Choice (SC) survey was developed, and how the fundamentals were developed is schematically represented in Figure 2-2.

A key issue in the development of a SC survey is the selection of the attributes used to describe the alternatives. Following the findings of Ilemobade et al. (2013), greywater reuse alternatives were characterized by three level-of-service attributes: *colour*, *odour* and *type of use*, and an economic attribute, the *savings.* In the choice scenarios, the first two alternatives implied greywater reuse for a single purpose within the home (and mains water for all other uses), while the third was a *status quo* option, implying the use of mains water for all purposes.

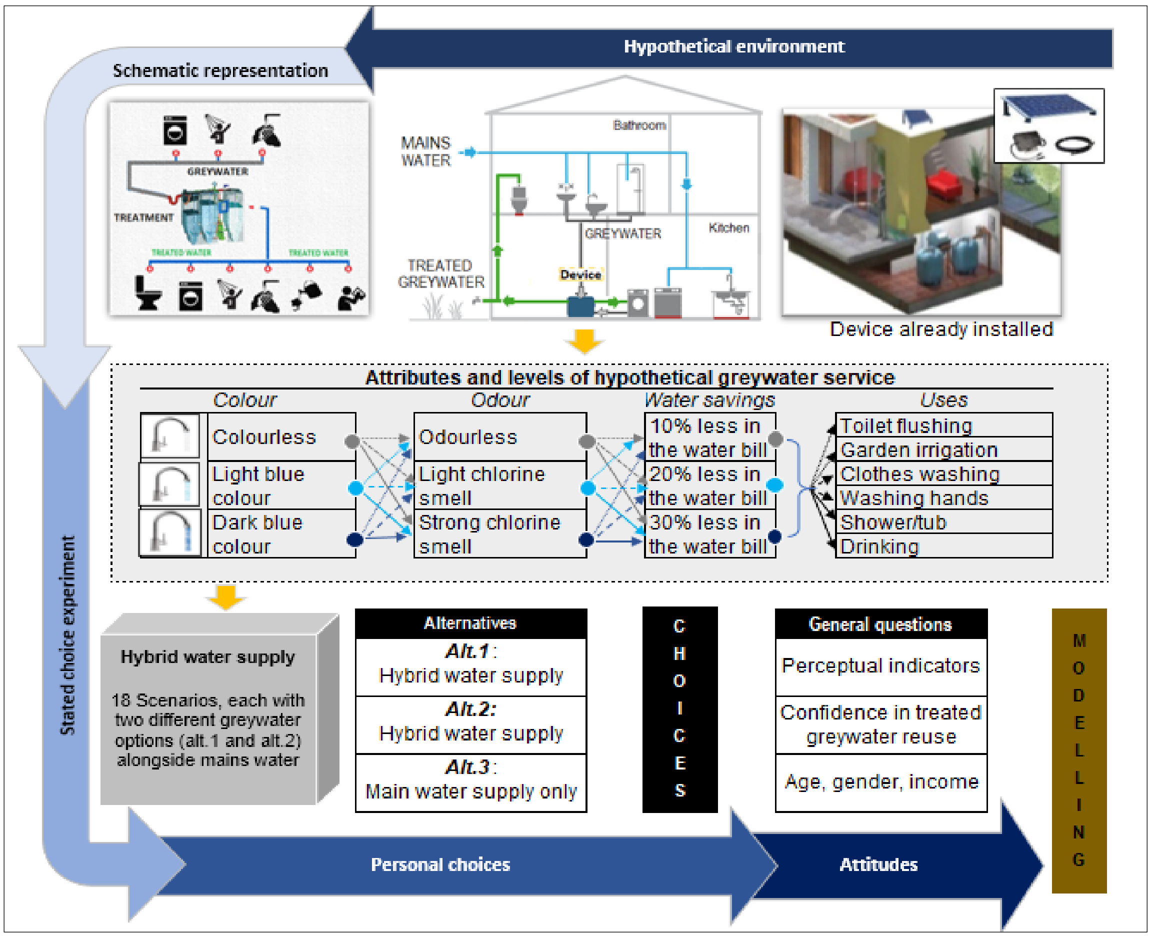


Figure 2-2. Context of the modelling process

The greywater options were described on the basis of usage, quality, and also water bill savings, with the following levels:

- **Usage**: six different types of reuse, namely *Toilet flushing*, *Garden irrigation*, *Washing clothes*, *Washing hands*, *Shower/tub*, and *Drinking*.
- **Quality**: quality was considered in terms of water appearance through three levels of colour (*Transparent*, *Light blue* and *Dark blue*) and three levels of odour caused by the treatment (*No odour*, *light chlorine odour* and *Strong chlorine odour*). Such a difference in the appearance of greywater (compared to mains water) could be caused by the type of device[1], and treatment (e.g. water purification tablets), or could be introduced deliberately to indicate to users that the removal of contaminants had been successful, in line with reuse laws (Domnech & Saurí, 2010).

- **Savings**: a mains water savings attribute was included to reflect the lower use of mains water at home due to the reuse of greywater. Previous experiences show that water savings can vary between 10 and 50% (Z. Chen, et al., 2017; Fountoulakis et al., 2016; Guthrie et al., 2017; Lambert & Lee, 2018). In the

[1] https://www.theguardian.com/lifeandstyle/2014/jul/21/greywater-systems-can-they-really-reduce-your-bills

absence of local experience, an intermediate range were used, with levels of savings of 10%, 20%, and 30% of the current mains water consumption. In the choice scenarios the savings attribute was monetised as a function of current consumption, with two reference groups: (i) group 1 (T1, with 290 households) having a monthly water consumption bill below 20,000 Chilean Pesos (CLP) (approximately US $ 28.8 at the time of data collection) and (ii) group 2 (T2, with 220 households) having a monthly water bill above CLP 20,000.

A core point of SC surveys is that the scenarios force respondents to make trade-offs (i.e., there is not a clear dominant option). This is illustrated in the example scenario shown in Figure 2-3.

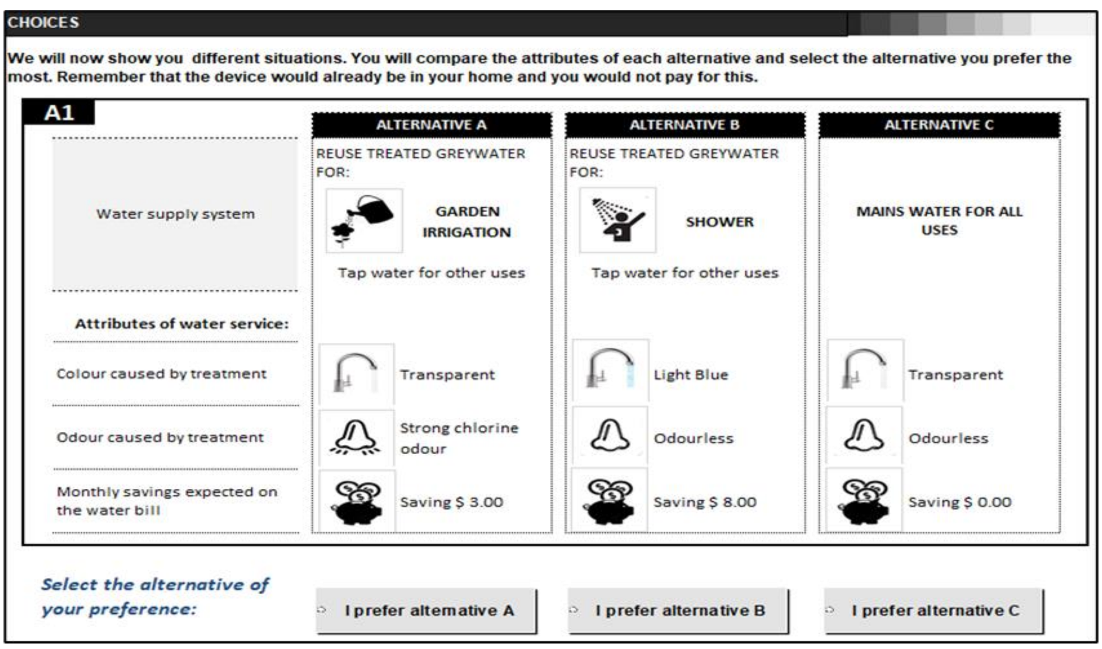


Figure 2-3. Example choice scenario 1.

Note that while alternative C has the best qualitative levels in terms of colour and odour, it has a disadvantage compared to the other two options in terms of savings. Similarly, there is no dominance between alternatives A and B. One of them has better colour but worse odour and lower savings. Alternatives 1 and 2 differed from each other in their attributes (colour, smell and use of treated greywater), in such a way that respondents had to make trade-offs between the different characteristics to select the alternative of their preference.

2.1.3. Experimental design

The second stage of the experimental design process relates to selecting the combinations of attribute levels (Table 2-1) for each given choice scenario, for example leading to the scenario presented in Figure 2-3. For a detailed introduction to experimental design see Bliemer & Rose (2010). Initially, 60 respondents answered a pilot survey that used an orthogonal design produced in NGENE (ChoiceMetrics, 2012), with 27 individual choice scenarios, subdivided into three blocks, such that, to avoid fatigue, each respondent answered only nine choice situations. Previous experiences had demonstrated that 10 or fewer choice scenarios work well with Chilean respondents (Caussade *et al*., 2005; Rose *et al*., 2009).

Table 2-1. Attributes and levels of treated greywater alternatives in the SC survey

Level	Colour	Odour	Use of treated greywater	Monthly expected savings in water bill	
				Group 1 (T_1) $N_1 = 290$	Group 2 (T_2) $N_2 = 220$
1	Transparent	Odourless	Toilet flushing	US$ 3.00	US$ 8.00
2	Light blue	Soft chlorine odour	Garden irrigation	US$ 6.00	US$ 12.00
3	Dark blue	Strong chlorine odour	Washing clothes	US$ 8.00	US$ 18.00
4			Washing hands		
5			Shower/Tub		
6			Drinking		

Subsequently, using the results of models (cf. Section 3.2) estimated on the pilot survey data as priors, a D-optimal (also known as D-efficient) design was generated with the aim of minimizing the standard errors of the parameters to be estimated with the resulting data. This final design comprised 18 hypothetical choice scenarios that were also subdivided into three blocks of six scenarios each, as we noted in the pilot that even nine choice scenarios increased the respondent’s burden in this case. Therefore, each respondent only answered six choice scenarios in the final survey. A core aim of the design process is the lack of dominance, hence requiring respondents to make trade-offs, where this is a characteristic of all 18 scenarios used in the survey (six per respondent, split into three blocks).

2.1.4. Questions on attitudes and acceptability

The calibration of the role of the attitudinal constructs required additional information at the level of each respondent. For this purpose, respondents were first asked to indicate their level of agreement with eleven statements (Table 4-1), which were in part informed by previous studies on environmental attitudes carried out by Hoyos et al. (2015). To reduce the risk of fatigue and potentially biased responses (Ampt, 2003), the number of these "indicators" of underlying attitudes was limited. The survey also collected (1) six binary responses (yes/no scale) to questions about willingness-to-accept greywater reuse for different uses inside the house, and (2) three sequential questions about willingness-to-install technology for greywater reuse in a respondents' dwelling if: (a) they should cover for the costs themselves, (b) the costs were partially covered by someone else, and (c) the costs were fully covered by someone else. Note that as the questions were sequential, question (b) was only asked if the respondents answered no to question (a), and question (c) was only asked if they answered no to question (b). Before the last set of questions, respondents were shown the dimension of the device (i.e. 1.1 m^2, similar to the space occupied by a washing machine) and its cost (i.e. one million CLP, equivalent to 1170 US$). This information was taken from Ferguson, (2014) and the Hydro4 web page[2].

2.2. Sample

The analysis and modelling were based on the results of a *face-to-face* survey conducted on a random sample of 606 households in 29 of the 37 municipalities within the Santiago, and only household heads or their partners over 18 years of age were interviewed. The information was collected by a private survey company with experience in this type of tasks. Municipalities were selected from the areas of the city with drinking water and sanitation services provided by *Aguas Andinas*. In each municipality, the survey was carried out in different non-neighbouring blocks and the households participating in the survey were randomly selected. After data cleaning, a sample of 510 households were retained for the analysis, of which 290 households (N_1) and 220 households (N_2),

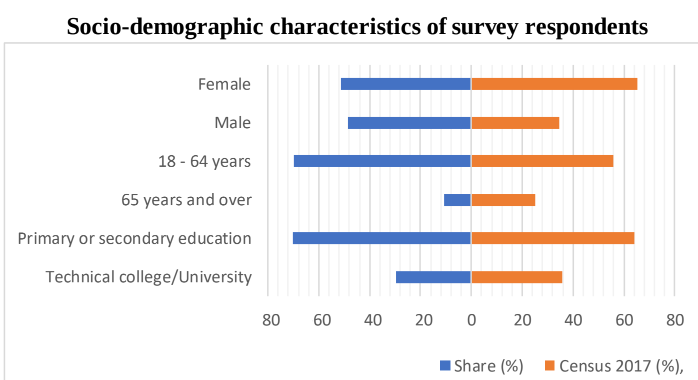
[2] http://hydro4.com.ar/linea-ingenieria/reciclado-de-aguas-grises/

respectively, belonged to the low and high water expenditure groups previously defined (Table 2-1). Table 2-2 shows a summary of the data according to the socio-demographic characteristics used in our analysis.

Table 2-2. Overview of socio-demographic characteristics of survey respondents

Characteristic	**Level**	**Share (%)**	**Census 2017 (%), *taken from INE (2018)***
Gender	Female	65.3	51.3
	Male	34.7	48.7
Age	18 - 54 years	55.9	69.8
	55-64 years	19.0	
	65 years and over	25.1	10.8
Education	Primary or secondary education	64.1	70.2
	Technical college	15.5	29.8
	University	20.4	
Water expenditure level	Below 20,000 CLP/month	56.7	N/A
	Above 20,000 CLP/month	43.3	N/A
Previous grey-water knowledge	None or low	71.4	N/A
	Middle or high	28.6	N/A

It is important to highlight that although more women participated in the survey, characteristics in the survey still replicate partially those reported by INE (2018) for the actual population how is shown in the Figure 2-4.



Life expectancy (Census 2017)	
Women	*Men*
80-90 years old	75 - 85 years old

Average people per household	
Sample	*Census 2017*
3.4	3.1

Type of house: Apartment	
Sample	*Census 2017*
11%	30%
Type of house: House	
89%	67%

Figure 2-4. Overview of socio-demographic characteristics INE (2017)

3. UNDERSTANDING THE PREFERENCES FOR DIFFERENT TYPES OF URBAN GREYWATER USES AND THE IMPACT OF QUALITATIVE ATTRIBUTES

3.1.Introduction

In recent years, greywater reuse has emerged as a viable and sustainable water management strategy, because: (i) the volume of water that can be recovered presents a significant share of water consumption (Tello *et al*., 2016; Z. Chen *et al*., 2017; Guthrie *et al*., 2017); (ii) the greywater characteristics have reached higher quality standards (Fountoulakis *et al*., 2016); (iii) there are important benefits associated with lower water demand, lower losses in potable water systems and improvements in water allocation (Walsh et al., 2016; Wilcox *et al*., 2016); and (iv) there is a reduction in the energy required for the treatment and distribution of potable water (Lu et al., 2019). However, to become a non-niche water management strategy, greywater reuse needs to be widely accepted by the population, and its welfare benefits for residences and the overall community recognised (Smith *et al*., 2018; Fielding *et al*., 2018).

Several authors have studied the willingness of the population to reuse water (e.g. Adapa, 2018; Fielding et al., 2018; Khan & Anderson, 2018), as well as the characteristics that can influence choices in this area (Hartley, 2006; Hurlimann & Dolnicar, 2016; Smith *et al*., 2018). However, understanding the psychology of the individual is difficult (Dolnicar *et al*., 2011), and that is why studies often rely on aggregate analysis of choices (Fielding *et al*., 2019; Hurlimann & Dolnicar, 2016). Their main limitation is that it is not generally possible to a) understand the specific influence of households' characteristics on the uses projected for the reused water, b) measure the influence of different characteristics of the greywater on acceptability, and c) make predictions about acceptability with changes in water or population characteristics. This highlights the need for improved data collection and econometric analysis methods.

To understand the acceptability of individuals and their choices for water reuse, there are two elementary sources of information: (i) successful local experiences and the population perception of the system (Z. Chen *et al*., 2017; Woltersdorf *et al*., 2018; Lefebvre, 2018; Khan & Anderson, 2018), and (ii) previous studies related with the acceptability of water reuse (Baumann, 1983; Fielding *et al*., 2019; Gu *et al*., 2015; Smith *et al*., 2018; Wilcox *et al*., 2016). The first source generates new opportunities to create instruments for collecting information about water reuse perceptions (Khan & Anderson, 2018; Lefebvre, 2018). The second is a valuable academic source to understand where policies should focus to achieve greater acceptability of these measures.

Most previous studies have focused attention on attributes associated with the cost of implementing the technologies (Gu *et al*., 2015; Massoud *et al*., 2018; Oh *et al*., 2018), and found that this could predispose individuals to reject water reuse due to the economic cost involved, especially in the case of individuals who have no previous knowledge or experience about water reuse (Wilcox *et al*., 2016). This is a relevant issue, as negative individual perceptions can affect the implementation of policies oriented to provide alternative water sources and reduce water security problems. Work that seeks to understand acceptability of greywater reuse thus needs to be careful to avoid the influence of the upfront monetary component. Hence, there is a need for studies where this economic issue is controlled, to better characterize and understand individuals' response to other attributes related to the quality of the treated greywater, given past findings about feelings of "disgust" towards greywater (Garcia-Cuerva et al., 2016; Leong, 2016). In this way, although both the cost and disgust are key factors, we want to highlight that while the former is very important in terms of adopting/installing the technology, the disgust factor is crucial in terms of driving the acceptability of use and the long-term success of the technology.

Given the above, the aim of the present chapter is to study the potential preferences for greywater reuse, considering specifically which characteristics of greywater are desirable and which are undesirable, net of the impact of installing the technology *per se*. In particular, we address two specific objectives: (1) to determine the willingness to use residential greywater considering the variation in observable consumer characteristics (e.g. age, education) across households, and (2) to determine if compensation would be required so that the alternatives for reusing greywater are accepted by the population, and how this varies as a function of the appearance of the treated greywater. Given our interest in qualitative attributes and currently inexistent reuse situations, the use of *stated choice* (SC) experiments emerge as a potentially ideal tool for modelling; the SC approach stands out from other methods due to its success and robustness over time when new alternatives are considered under hypothetical scenarios of choice (Bennett & Blamey, 2001; Ortúzar & Willumsen, 2011; Schaafsma *et al*., 2014). SC techniques are used widely across different research areas – for a comprehensive introduction, see Louviere et al., (2000) and Rose & Bliemer, (2014). Examples in water research include the work of Rungie *et al* (2014) and Scarpa *et al*. (2012). In our study we make use of SC techniques that allow us to study the preferences of households in carefully constructed hypothetical scenarios, and analyse the resulting data using advanced econometric structures belonging to the family of discrete choice models. The study area is the Metropolitan Region of Santiago, Chile, a location where greywater use, although legally allowed, does not take place at present. The characteristics of the study area plus the uniqueness of the modelling approach and attributes under consideration, make our results potentially valuable not just for this region but also for areas with similar characteristics.

3.2.Overall model structure

Our survey aimed to study the impact of a variety of characteristics on preferences, including qualitative attributes, the type of use, and the monetary implications. We employed econometric methods belonging to the family of discrete choice models, and specifically those based on random utility theory, to help us disentangle these different influences on choice. In these models, the probability of choosing a specific option amongst mutually exclusive alternatives increases in the presence of desirable characteristics and decreases in the presence of undesirable characteristics. The extent to which individual characteristics are desirable/undesirable is determined during model estimation. For an in-depth overview of choice modelling techniques, see the theoretical discussions in Ortúzar & Willumsen, (2011, Chapters 7–9) and Train (2009), while a coverage of application areas is available in (Hess & Daly, 2014).

Our modelling work considered the estimation of progressively more flexible specifications, especially in terms of socio-demographic effects. The final specification was an Error Components Mixed Logit model (Train, 2009), capturing the correlation across choices made by the same respondent (i.e. the so-called pseudo panel effect). The models used a detailed utility function with numerous socio-demographic and water use interactions (Ortúzar & Willumsen, 2011, chapter 8, pp. 279).

In random utility models, each alternative has an associated "utility function", which is a latent construct describing the appeal of the alternative to the individuals; these functions have two components: (i) a systematic or representative utility, which is typically a linear function of the attributes weighted by unknown parameters that represent marginal utilities; (ii) an error term that serves to treat data deficiencies, the effect of unknown variables, etc. This error term can have different forms yielding different model specifications (Ortúzar & Willumsen, 2011; Train, 2009). The higher the utility, the more likely the alternative is to be chosen. Undesirable attributes (e.g. darker colour in our case) decrease the utility of an alternative while desirable attributes (e.g. higher savings) increase it. The impact of each attribute is captured through its associated parameter. The values for these parameters are estimated through a maximum likelihood process. The expectation is that negative parameter values are obtained for undesirable attributes and positive parameter values for desirable attributes. The absolute size of the parameters gives an indication of the importance of the various individual attributes in shaping the decision-making process. As mentioned above, these parameters were allowed to vary across decision makers as a function of their socio-demographic characteristics.

In our models, the utility for alternative j (where $j = 1,..3$) for respondent n in choice scenario t ($U_{j,n,t}$) is given by:

$$U_{j,n,t} = \delta_j + \underline{\beta}_n \underline{X}_{j,n,t} + \xi_{j,n} + \varepsilon_{j,n,t} \qquad (3.1)$$

This utility function contains two error terms. The first, $\xi_{j,n}$, is identically and independently distributed (IID) across alternatives and respondents according to a normal $N(0,\sigma)$ distribution, where σ is estimated, and serves to treat the pseudo panel effect. The second term, $\varepsilon_{j,n,t}$, is IID across alternatives and observations, and follows a type I extreme value distribution. In the absence of the first error component, this specification would be a simple Multinomial Logit model (Train, 2009). For both error terms, the variance is the same across alternatives (σ^2 for $\xi_{j,n}$, and $\frac{\pi^2}{6}$ for $\varepsilon_{j,n,t}$), but while $\varepsilon_{j,n,t}$ varies across all choices, $\xi_{j,n}$ is kept constant across the choices for the same respondent, thus capturing the potential correlation among them.

Two sets of parameters were estimated. The first was an alternative specific constant (δ_1), which was included in the utility of the left-most alternative with a view to capturing any positional bias in how respondents choose between alternatives; this parameter is associated with a value 1 for the left-most alternative and zero for the others (and $\delta_j = 0$, for $j \neq 1$). The remaining set of parameters ($\underline{\beta}$) capture the influence on utility of the various possible levels of the attributes describing the alternatives. The vector $\underline{X}_{j,n,t}$ groups together the various characteristics (or attributes) of alternative j, as faced by respondent n in choice scenario t:

- The type of water use, which has seven levels; namely, the six types of grey water uses and using mains water for all purposes. As shown in Table 2-1, only the first six levels are possible for the first two alternatives, while only the final level is possible for the third alternative. This attribute is treated as categorical, with mains water use as reference (i.e., its parameter $\beta_{mains\ water}$ is fixed to zero).
- The colour attribute, which has three levels, namely clear, light blue and dark blue. All three levels are possible for the first two alternatives, while only the first level is possible for the third alternative. This attribute is also treated as categorical, and the best level (which also applies to mains water) is used as reference ($\beta_{clear} = 0$).
- The odour attribute, which also has three levels, namely odourless, light chlorine and strong chlorine. Again, all three levels are possible for the first two alternatives, while only the first level is possible for the third alternative. This

attribute is also treated as categorical, and the best level (which also applies to mains water) is used as reference ($\beta_{odourless} = 0$).

- The savings attribute, which is treated as a continuous variable.

We allowed for differences across socio-demographic groups by considering five characteristics, with two levels each. One level was used as reference and an additional parameter was estimated to measure the shift in utility for the other level in each case. The five characteristics were: Gender (male as the base); Age (55 and over as the base); Education (high education as the base); Water expenditure level (low as the base), and Previous knowledge of greywater use (low as the base). The grouping used here were determined after initial testing with a more detailed model specification that showed, for example, negligible differences between the various age groups below 55. Hence, there are 32 different combinations of types or socio-demographic profiles that are summarised in Table 3-1, which also shows the weight for each profile. Each row corresponds to one combination of gender, education, age and previous knowledge, with a further split into low (T_1 profiles 1 to 16) and high (T_2 profiles 17-32) water expenditure groups.

For each model attribute, we tested for differences in sensitivities according to the five socio-economic characteristics described above. In addition, for gender, education, age and previous knowledge, we tested whether the impact of these characteristics on preferences was different for the low (T_1) and high (T_2) water expenditure groups.

Table 3-1. Socio-demographic profiles of respondents

Profile for T_1 respondents	Profile for T_2 respondents	Gender	Education	Age	Previous knowledge	Share of respondents (%)	
						T_1	T_2
1	17	Female	Basic education	Below 55	Low	9.02	7.84
2	18				High	1.57	2.55
3	19			Over 55	Low	11.18	5.88
4	20				High	4.12	2.75
5	21		Higher education (includes technical college and university level)	Below 55	Low	7.06	4.71
6	22				High	2.16	1.76
7	23			Over 55	Low	1.76	0.78
8	24				High	0.59	1.57
9	25	Male	Basic education	Below 55	Low	4.51	3.92
10	26				High	1.37	0.78
11	27			Over 55	Low	3.73	2.35
12	28				High	1.76	0.78
13	29		Higher education (includes technical college and university level)	Below 55	Low	2.94	2.35
14	30				High	2.16	1.18
15	31			Over 55	Low	1.18	2.16
16	32				High	1.57	1.96

Remember that $\underline{\beta_n}$ is a vector of parameters for respondent n, that groups together his/her parameters associated with the impact of the different explanatory variables. In particular, the utility component for respondent n for attribute l (which could be either the continuous *savings* attribute or one of the levels of a categorical variable) is given by one of the elements in $\underline{\beta_n}$, say $\beta_{n,l}$, as follows:

$$\beta_{n,l} = \beta_l + \Delta_{hc,l} z_{n,hc} + \sum_{m=1}^{4} z_{n,m} \left(\Delta_{\mathrm{m,l}} + \Delta_{\mathrm{m,l,hc}} z_{n,hc} \right) \tag{3.2}$$

In this equation, the sum over m refers to the four characteristics other than water expenditure level (gender, age, education and previous greywater experience), as will become clear now. The different terms in Equation (3.2) are as follows:

- β_l captures the value of the parameter for attribute l for a respondent in the base category for all the socio-demographic variables;
- $\Delta_{hc,l}$ captures a shift in this base value for respondents in the high expenditure group (T_2), where the socio-demographic variable $z_{n,hc} = 1$ if respondent n falls into that group (and 0 otherwise);
- The remaining four socio-demographic characteristics are captured by $z_{n,m}$, where, for example, $z_{n,1} = 1$ if respondent n is female (and zero otherwise). $\Delta_{\mathrm{m,l}}$ captures the shift in the sensitivity to attribute l for a respondent who has the socio-demographic characteristic $z_{n,m}$, while $\Delta_{\mathrm{m,l,hc}}$ captures an additional additive shift if that respondent also belongs to the high water expenditure group (T_2).

3.3.Results and discussion

All our models were estimated using Apollo v 0.0.9 (Hess & Palma, 2019), through simulated maximum likelihood and using 500 Halton draws (Ortúzar & Willumsen, 2011, Chapter 8). The estimation process for discrete choice models consists of finding the parameter values that best explain the choices in the data, where this is achieved by maximising the log-likelihood of the model[3].

[3] Each observed choice has a probability in the model, and the log-likelihood is the sum across all observations of the logarithms of the probabilities of the chosen alternatives. Thus, in a purely deterministic model the log-likelihood would

Alongside values for the parameters, estimation of a choice model also produces standard errors. These are related to the steepness of the log-likelihood function around convergence. The value of the standard error for a parameter is approximately double the expected loss in log-likelihood if we move one standard error from the estimate. In line with standard choice modelling practice, we used these standard errors to compute t-ratios for individual parameters, given by the ratio between the estimate and its standard error. They are a single parameter test and are derived from the fact that the maximum likelihood estimates are asymptotically normally distributed (see for example sec. 8.4.1.1 in Ortúzar & Willumsen, 2011). The value for a t-ratio tells us with what confidence level we can reject the null hypothesis that a parameter is equal to zero. This confidence level depends on whether we are conducting one-sided or two-sided tests, where the 95% confidence level for a one-tailed test is 1.64, and 1.95 for a two-tailed test.

Our specification searches tested many different versions of the model, gradually adding additionally socio-demographic effects. The variable selection process in these cases normally considers both formal statistical tests, relating to whether new parameters lead to significant improvements (i.e., t-ratios to test the null hypothesis of the parameter being zero, and likelihood ratio tests for improvements in model fit) and more informal (but even more important) tests such as examining the sign of the estimated coefficient, to judge whether it conforms to *a priori* notions or theory. Given the limited sample sizes available in most analyses, it is good practice to retain parameters that provide important insights (notably for socio-demographic effects) with lower levels of confidence, given that each socio-demographic level will only apply to a smaller set of the data (cf. page 278 in Ortúzar & Willumsen, 2011, and also the more general points on significance in Amrhein et al., 2019).

be 0 (with all choices having a probability of 1), while in a purely random model, the log-likelihood would be $N \cdot \log\left(\frac{1}{J}\right)$, where J is the number of alternatives. The latter is known as the log-likelihood at zero - LL(0). A measure of the goodness of fit of a choice model is given by the adjusted ρ^2 measure (McFadden, 1974), which shows how far estimation has moved from LL(0) towards a perfect model, with $\text{adj.}\,\rho^2 = 1 - \frac{LL(\beta)-K}{LL(0)}$, where $LL(\beta)$ is the log-likelihood at convergence, and K is the number of estimated parameters. While there are no absolute guidelines, values in the range of 0.2 to 0.4 are typically seen as providing a very good fit.

Our final specification includes 40 parameters; 32 have a t-ratio that rejects the null hypothesis of no difference from zero at or above the 95% level of confidence; the remaining eight parameters were retained as they provided valuable insights into socio-demographic effects. Numerous other effects were tested during the specification searches but were not retained due to a lack of statistical importance and behavioural insights. This final specification has a log-likelihood of -2,524.65 and an adjusted ρ^2 of 0.24, offering the best fit of all specifications tested after accounting for the number of parameters.

3.3.1. Overview of results

Before looking at the results in detail, we first provide an overview at the sample level. As the 32 socio-demographic profiles had different levels of representation in our sample, we calculated a weighted average of the different utility components. The weighted average value for the parameter associated with attribute l is given by $\widehat{\beta_l} = \sum_{k=1}^{K} w_k \beta_{k,l}$, where weight $w_k = {N_k}/{N}$, N is the total number of respondents in the sample, N_k is the number of respondents in segment k of our sample, and $\beta_{k,l}$ is the utility associated with attribute l for respondents in segment k. This incorporates any socio-demographic shifts, as described above in Equation (3.2).

The weighted average of the 32 profiles (Table 3-1) for the different components of utility are shown in Table 3-2. The results show that utility decreases with an increase in the colour beyond light blue (which is no different from clear) and/or any odour level, and that the water bill savings have an important positive influence.

Table 3-2. Weighted average of utility function components across socio-demographic groups

General description	Weighted estimate
Light blue (vs. clear)	0.000
Dark blue (vs. clear)	-0.427
Light chlorine (vs. no odour)	-0.399
Strong chlorine (vs. no odour)	-1.064
Toilet flushing (vs. no grey water use)	1.116
Garden irrigation (vs. no grey water use)	0.457
Washing clothes (vs. no grey water use)	0.475
Washing hands (vs. no grey water use)	0.096
Shower/Tub (vs. no grey water use)	0.109
Drinking (vs. no grey water use)	-1.087
Savings	0.106

Furthermore, (i) compared to only using mains water, greywater reuse within the home is perceived positively in most cases; (ii) in contrast with past work, the outdoor use of greywater (i.e. garden irrigation) is not the favourite use for respondents (despite only 17% of respondents having no garden at all), and (iii) reusing water in garden irrigation is valued similarly to reusing water for laundry. On the other hand, it is also important to note that the level of exposure seems to influence reuse preferences, especially in those uses that require most and least human contact (drinking and toilet flushing, respectively); this is consistent with results reported elsewhere (Aitken *et al*., 2014; Fielding *et al*., 2018; Massoud *et al*., 2018; Oh *et al*., 2018).

3.3.2. Detailed estimation results

We now explore the influence of socio-economic characteristics in more detail, with a full breakdown of the discrete choice model results in Table 3-3. The most influential socioeconomic characteristics are gender, age, educational level and level of knowledge about greywater reuse. Among these characteristics, two stood out in all uses: (i) being female, for its strong negative influence (especially in households with high water expenses), and (ii) previous knowledge about reuse for its strong positive influence.

Position of alternative: The constant associated with the left-most alternative received a negative value. Thus, all other things being equal, out of the two reuse alternatives in each choice scenario, the second was chosen more often than the first, despite both having been randomised across choice situations in the survey. So, apparently, the left-most alternative is perceived as less desirable on the basis of its position (given that the third, and right-most alternative, was always the *status quo*), justifying the use of the alternative specific constant.

Water appearance: Concerning colour and odour, an increase in level causes a decrease in the utility for the affected alternative. However for colour, only the change to dark blue matters, while high levels of odour seem to influence utility more than colour. The negative perception of dark blue colour was found to be a bit stronger in the case of respondents whose houses had lower water expenses.

Savings: Water bill reductions increase the utility of respondents, as expected. Also, the marginal utility (i.e. the per unit value) of increases in savings is larger for people whose households had lower water expenses, although this shift is only significant at lower levels of confidence (87 for a one-sided test). In part, this could be due to these respondents being more cost sensitive (and hence also using less water). However, the finding is also in line with much evidence in the choice modelling literature about non-linear sensitivities to money (see Gaudry *et al*, 1989 and a more recent discussions in Hess *et al*., 2017). Indeed, the cost savings presented to respondents in the high expenditure group were larger, and our finding suggests that the per unit value of a saving is smaller in these cases.

Uses: A key interest in the analysis of results lies in the different types of greywater reuse, where there is extensive heterogeneity across socio-demographic groups, as shown in the numerous interactions with socio-demographics in Table 3-3. For all six uses, the values must be interpreted relative to the reference of using mains water for all uses (with a utility fixed to 0 as the base). A detailed investigation of the socio-demographic shifts will follow in our discussion of probabilities and monetary valuations. For now, we only highlight two key findings. Firstly, there is a positive and statistically significant influence of past knowledge for all six types of uses, meaning that the utility of any greywater reuse option, compared to using mains water, is higher for respondents with previous knowledge of greywater reuse. Other characteristics, most notably gender and level of education, have quite differing effects across uses, where this also differs between the low and high consumptions groups. Despite greywater being of notably better quality (i.e. without faecal matter and other pollutants) than wastewater, these findings echo studies into wastewater reuse that identify age (Probe Research Inc., 2017), gender (Baghapour *et al*., 2017; Gibson & Burton, 2014), educational level (Garcia-Cuerva *et al*., 2016; Gu *et al*., 2015; Wester *et al*., 2015), and previous knowledge (Dolnicar *et* al., 2011; Fielding & Roiko, 2014; Goodwin *et* al, 2018) as important characteristics. For example, the utility for reusing water in ***toilet flushing*** is positive for all respondents. However, it is lower for female respondents in the high water expenditure group (T_2) and for respondents with low education, compared to those in the reference group, although this negative impact of low education is weaker in the high water expenditure group.

Correlation across choices: Another important result is that the standard deviation of the normal errors incorporated to deal with the pseudo panel effect is highly significant (t-ratio: 20.31). This indicates a strong correlation in the responses across the six scenarios for the same respondent.

Table 3-3. Detailed estimates of discrete choice model parameters

	Log-likelihood at zero (for all parameters = 0)	-3361.754		
	Final Log-likelihood (at convergence)	-2524.648		
	Adjusted ρ^2	0.2371		
Attrib.	General description	Estimate	Robust std error	Robust t-ratio
	Constant for left most alternative	-0.489	0.080	-6.10
Colour	Clear or light blue	0	-Fixed-	
	Dark blue	-0.430	0.091	-4.72
Odour	Odourless	0	-Fixed-	
	Light chlorine	-0.400	0.100	-4.01
	Strong chlorine	-1.156	0.135	-8.58
	… shift for high-water expenditure group	0.208	0.186	1.12†
	Savings on water bill	0.138	0.030	4.55
	… shift for high-water water expenditure group	-0.076	0.033	-2.33
Toilet flushing	Base parameter	1.463	0.354	4.13
	… shift for female	0.476	0.309	1.54†
	… shift for female and high-water expenditure group	-1.289	0.510	-2.53
	… shift for low education	-1.266	0.326	-3.89
	… shift for low education and high-water expenditure	0.695	0.415	1.68†
	… shift for previous knowledge	0.928	0.379	2.45
	… shift for previous knowledge and high expenditure	0.491	0.521	0.94†
Garden Irrigation	Base parameter	1.087	0.321	3.39
	… shift for female	0.453	0.279	1.62†
	… shift for female and high-water expenditure	-2.009	0.487	-4.13
	… shift for low education	-1.550	0.303	-5.11
	… shift for low education and high-water expenditure	1.184	0.376	3.15
	… shift for previous knowledge	1.105	0.311	3.56
Washing Clothes	Base parameter	0.717	0.306	2.34
	… shift for female and high expenditure	-1.312	0.453	-2.89
	… shift for age below 55 and high-water expenditure	0.612	0.280	2.19
	… shift for low education	-0.639	0.254	-2.52
	… shift for previous knowledge	1.022	0.363	2.82
	… shift for previous knowledge and high-water expenditure	0.690	0.487	1.42†
Washing hands	Base parameter	0.009	0.247	0.03
	… shift for female and high-water expenditure	-0.581	0.408	-1.42†
	… shift for previous knowledge	0.364	0.335	1.08†
	… shift for previous knowledge and high-water expenditure	1.132	0.511	2.21
Shower/ Tub	Base parameter	0.734	0.264	2.78
	… shift for female and high-water expenditure	-1.519	0.412	-3.69
	… shift for low education	-0.592	0.242	-2.45
	… shift for previous knowledge and high-water expenditure	1.355	0.429	3.16
Drinking water	Base parameter	-1.435	0.335	-4.28
	… shift for female	0.763	0.342	2.23
	… shift for female and high-water expenditure	-2.134	0.529	-4.03
	… shift for age below 55 and high-water expenditure	0.773	0.365	2.12
	… shift for previous knowledge and high-water expenditure	1.894	0.467	4.06
	Standard deviation of error component (σ)	1.686	0.083	20.35

† Parameter not significant at the 95% level of confidence

3.3.3. Predicted uptake for single type of greywater reuse

We now look at the six possible options for greywater reuse and calculate the predicted uptake of greywater for a single use instead of mains water. This shows the split in probability according to our model, between using mains water for all uses, or using greywater for a specific activity. Separate calculations were made with four levels of savings in the water bill, between 0% and 30% (in steps of 10%), two levels of colour (clear/light blue and dark blue) and three levels of odour (odourless, light odour, strong odour). We then computed the weighted probability for each type of reuse (compared to mains water) across the 32 respondent profiles.

Table 3-4 considers four differing cases of greywater characteristics. The first corresponds to the best possible situation, where the treated greywater is clear/light blue, odourless, and the monthly savings are 30% on the mains water bill. The second considers the same appearance of the treated greywater as before, but with no savings. The third considers the worst treated greywater appearance (i.e. dark colour, strong chlorine odour), but maximum savings (30%), and the final case is the worst one in terms of both water appearance and savings (0%).

Table 3-4. Predicted uptake for greywater vs mains water depending on greywater quality and savings

	Use of treated greywater	Clear/light blue water and odourless		Dark water colour and strong chlorine odour	
		Maximum Savings	No savings	Maximum Savings	No savings
		Case 1	Case 2	Case 3	Case 4
1	Toilet flushing	84.7%	72.6%	58.7%	41.5%
2	Garden irrigation	74.0%	59.0%	44.6%	29.4%
3	Clothes washing	75.2%	60.1%	44.9%	29.0%
4	Washing hands	70.0%	52.2%	36.0%	21.0%
5	Shower/Tub	69.3%	52.8%	37.3%	22.3%
6	Drinking	43.9%	27.6%	16.8%	8.8%

The results show clear differences across the six possible types of greywater use, with some uses predicted to have a substantial share in a binary choice against using mains water. These probabilities correctly decrease if the condition of the treated water worsens in terms of odour and colour, and also if the savings on the water bill are reduced. Moreover, if we analyse the influence of the variation in savings on the probability of choice, there is a decrease in the probability of choice between 12.1 and 17.8% for the best treated greywater conditions (i.e. Case 2 *vs* Case 1). Conversely, for the worst greywater conditions, offering the maximum monetary incentive (30%) could achieve an increase between 8 and 17.2% (case 3 *vs* case 4). The changes in probability also differ across uses. In particular, given the best possible conditions of treated greywater and savings, the probability of choice varies between 84.7% and 43.9%. However, if instead of having the best treated water appearance and maximum savings, we had the worst treated greywater appearance and no savings, a decrease of up to 49 percentage points would occur (i.e. for washing hands, there is a drop from 70% to 21%). On the other hand, the smallest percentage decrease when comparing these 'best' and 'worst' cases, occurs for drinking, where the percentage goes down from 43.9% to 8.8%.

The 8.8% share for drinking in Case 4 (i.e. the worst treated greywater conditions in terms of odour, colour and savings) may seem a bit counterintuitive. This has to be understood on the basis of the models being probabilistic, where even undesirable alternatives have a non-zero probability. Given sample size requirements, the survey design process assumed a generic response to water quality across uses, i.e. did not allow us to then later estimate an interaction between quality and use, meaning that the shift in utility as a result of lower quality is the same across uses. Although the directionality is expected to be the same, it is unlikely that the impacts will be exactly equal, which could partly explain this result. To further analyse this issue, the probabilities for each of the 32 profiles were computed for case 4. These are shown in Figure 3-1 alongside the corresponding weights in the data (i.e. what share of the data a given profile represents), and the weighted average in the probabilities. The highest probability of greywater reuse for drinking is for men in the high water expenditure group, aged under 55 and with prior knowledge about greywater reuse. These respondents cover two socio-demographic profiles (26 and 30) but only represent 1.96% of all respondents.

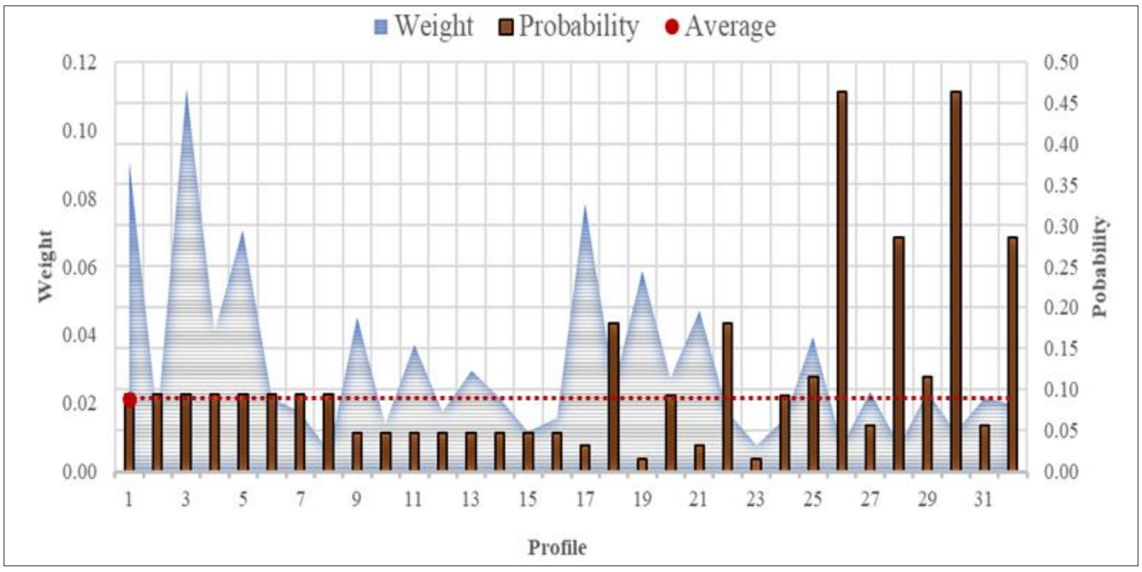


Figure 3-1. Representativeness of different profiles and associated probabilities of using treated greywater for drinking in Case 4 shown in the table 3-5 (worst odour and colour, and no savings.

3.3.4. Monetary valuation

Finally, we provide a monetary representation of the acceptability of using greywater inside the home using the marginal rate of substitution between the utility for a given type of greywater reuse and the monthly savings ($\beta_{savings}$); see the discussion about willingness-to-pay (WtP) in Sillano & Ortúzar, (2005). For linear-in-parameters utility functions, the WtP is given by the ratio of the corresponding utility parameters, and its interpretation thereof depends on the sign of the numerator. For example, for toilet flushing, the monetary valuation is given by:

$$MV_{toiletflushing} = {}^{\beta_{Toilet\ flushing}}\Big/_{\beta_{savings}}. \tag{3.3}$$

As $\beta_{bathroom\ discharge}$ is positive, the monetary valuation is positive too. Notwithstanding the possibility of asymmetric responses to money gains and losses, this would imply that respondents would be willing to incur extra charges for such a reuse. Despite the fact that only savings are included in the survey, we can thus interpret this as a willingness-to-pay. The problem of finding an adequate payment mechanism in choice experiments is sometimes quite challenging (Ortúzar, 2010); we are confident that the use of savings in this case is appropriate, and is not dissimilar for example from looking at increased income in some other studies (e.g. Beck & Hess, 2016). Our example here looked at a generally desirable attribute. On the other hand, for generally undesirable options, such as using grey water for drinking, the numerator would be negative, and the marginal rate of substitution would also be negative. This would imply that respondents would need a monetary incentive to accept such greywater reuses.

WtP values were first calculated for each of the 32 profiles and for three cases, namely clear/light blue colour and odourless greywater, clear/light blue colour and strong chlorine odour, and dark blue greywater with a strong chlorine odour. We then expressed these monetary valuations as a percentage of the monthly water expenditure for the specific group (using CLP 20,000 for T_1 and CLP 40,000 for T_2).

Table 3-5 presents the weighted average across the 32 profiles for these valuations. The results indicate that, for the best appearance conditions of treated greywater, people are willing to pay monthly between 1.7% and 18.7% of the water service bill. This WtP is applicable for all uses except drinking, where a compensation of 18.3% of the value spent on the water bill would be required.

Table 3-5. Monetary valuation of the different treated greywater uses as share of monthly expenditure

	Uses	**Clear/light blue water, odourless**	**Clear/light blue water, strong chlorine**	**Dark blue water, strong chlorine**
1	Toilet flushing (vs. no greywater use)	18.7%	0.93%	-6.3%
2	Garden irrigation (vs. no greywater use)	7.6%	-10.20%	-17.4%
3	Washing clothes (vs. no greywater use)	8.0%	-9.83%	-17.0%
4	Washing hands (vs. no greywater use)	1.7%	-16.09%	-23.3%
5	Shower/Tub (vs. no greywater use)	1.7%	-16.13%	-23.3%
6	Drinking (vs. no greywater use)	-18.3%	-36.11%	-43.3%

If we instead consider the case of the worst appearance conditions of treated greywater (dark colour and strong chlorine odour), respondents would require, on average, a monthly compensation between 6.3% and 43.3% of the value they pay monthly for their water service. Again, the compensation expected by respondents varies according to the level of contact they would have with the greywater and remains highest for drinking. For qualitative water appearance in between these two extreme cases, as shown in the middle column, the valuations are similarly intermediate values between the best and worst cases.

The results in Table 3-5 are weighted averages across the different socio-demographic groups and thus do not show the heterogeneity in valuations across different types of consumers. To provide further insights into this heterogeneity, Figure 3-2 shows box-plots for the distribution of the actual valuations (i.e. in monetary terms rather than expressed as a percentage of the water bill), highlighting the extent of heterogeneity in valuations across individuals (given the vertical spreads of the boxplots), across uses, and also as a function of three different conditions of supply of treated greywater in the home (clear/light colour and odourless, clear/light colour and strong colour, and dark colour and strong odour).

In the first graph, we note that in the cleanest water case, most respondents have a positive monetary valuation for using greywater for all uses except drinking. However, in this case we want to highlight the fact that although garden irrigation is an indirect and out of home use (in terms of human contact), almost half of the respondents (47.65%) would require financial compensation to decide to reuse water for this purpose. Detailed inspection of the results shows that the group with the most negative valuations for this use are women in the high consumption group without past knowledge of water reuse, where this is especially negative for those with low education.

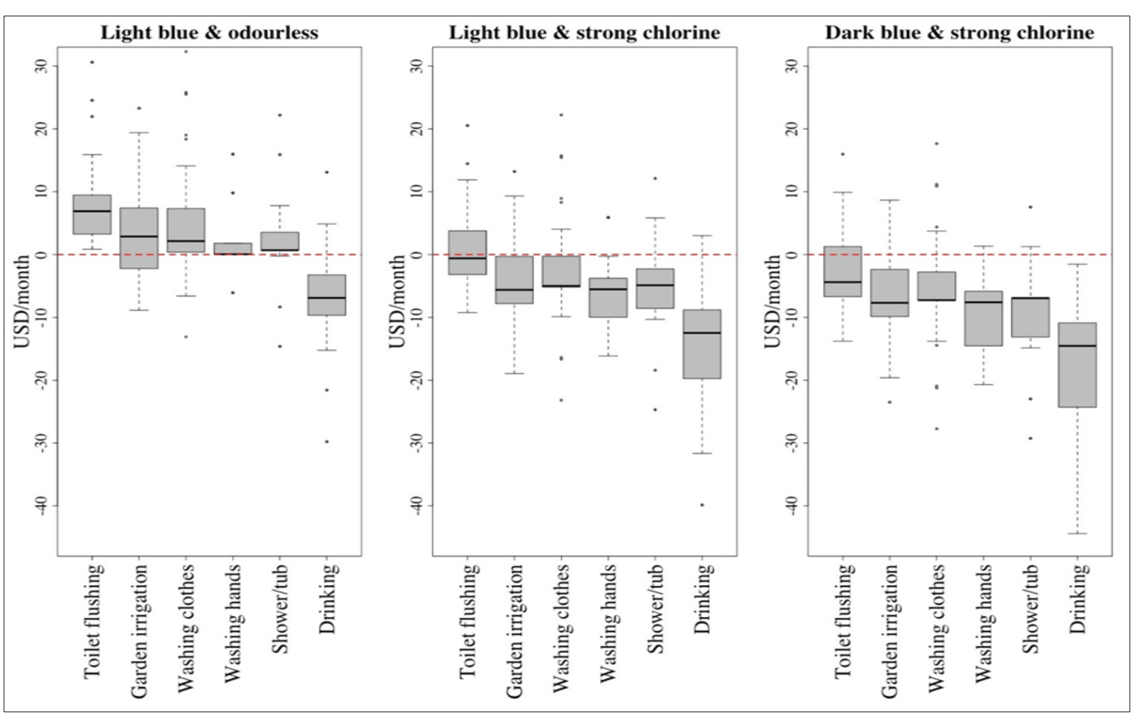


Figure 3-2. Distribution of monetary valuations across respondents and as a function of water quality

Only 33% of respondents without past knowledge of greywater reuse have a positive valuation for using the highest quality greywater for garden irrigation. For drinking, we obtain negative valuations for 95.29% of respondents, where the valuations are only positive for male respondents in the high consumption group with past knowledge of water reuse, where this is especially positive for those aged under 55. Other striking socio-demographic effects include the fact that all men have positive valuations for using greywater for washing clothes, washing hands and shower/tub (in addition to toilet flushing, which is positive for all respondents), all respondents with past knowledge have a positive valuation for all uses except shower/tub and drinking, and the valuations for all uses except drinking are positive for over 85% of respondents with high education.

In the second graph, we can see how the monetary valuation is affected if the treated water presents strong levels of chlorine odour even though the colour remains clear/light blue. Given this situation, the direct uses (washing hands, shower and drinking) show negative valuations for over 95% of respondents. The share of respondents with a positive valuation remains high for toilet flushing, at 42.9%, where the affected groups are primarily those respondents with higher levels of education (85% of those respondents) and past knowledge (89% of those respondents). The highest valuation is obtained for men with high education and past experience in the high expenditure group. Education and past knowledge also matter for garden irrigation (where the monetary valuation is positive for 64% of high education respondents) and washing clothes (where the monetary valuation is positive for 60% of respondents with past experience).

Finally, the third graph shows how the monetary valuations would be distributed if the treatment caused the greywater to present a dark colouration and a strong chlorine odour. As expected, the economic valuation becomes negative for the vast majority of respondents, which indicates that people would expect compensation if these were the conditions. However, it is interesting to see that among the respondents there is a percentage of people who, even under these water conditions, would be willing to pay for reusing greywater for the different uses. The monetary valuation for using greywater for toilet flushing remains positive for 89% of respondents with past knowledge of greywater reuse, but only 19% of those without past knowledge. Looking at garden irrigation and washing clothes, which obtain similar shares of positive valuations (11.18% and 12.94%, respectively), all the affected respondents fall into the higher education category, with the exception of men in the high expenditure group who also have past knowledge of greywater reuse.

From these results, we want to highlight that some of the socio-demographic effects are striking in their impact. Looking at the case of greywater with the best possible qualitative appearance, those respondents with past knowledge of greywater reuse are more than three times as likely to have a positive utility for reusing greywater for garden irrigation than those with low or no past knowledge, while men are over 60% more likely than women to have a positive utility for reusing greywater for showering and 42% more likely in the case of washing hands. Looking at the worst qualitative appearance, those with high education are over three times as likely to have a positive utility for using greywater for washing hands or showering than those with low education, while men are over five times as likely as women to have a positive utility in the case of garden irrigation, and over three times as likely in the case of washing clothes.

3.4.Conclusions, limitations and future research directions

This study has investigated the potential preferences for, and acceptability of, residential greywater reuse, considering specifically qualitative attributes that could impact the desirability of greywater reuse. We calculate monetary valuations on the basis of the results from an econometric analysis. Our survey was designed to remove the bias related to the cost of installation, which is highly influential in decision making, and to focus respondents' attention on the qualitative attributes of this new source of water supply, both in terms of the appearance, odour, and the type of reuse. Indeed, any successful deployment of treated greywater reuse technology would be conditional on a priori identifying those households most willing to actually use the treated greywater.

Quantifying the influence exerted by attributes of a potential source of water supply on this acceptability is crucial to understand how effective greywater reuse codes and policies

- such as the one currently approved in Chile - might be. Our results show clear evidence that although in the city of Santiago most people do not have previous experience about water reuse, they may be willing to reuse treated greywater for a variety of direct and indirect purposes. This is however conditional on the treated greywater having a similar quality as mains water in terms of colour and odour. If changes occur in the colour or odour levels of the treated greywater, our model predicts that the acceptability of reusing water would decrease considerably, even for indirect uses. In addition, the preferences vary extensively across socio-demographic groups.

Our findings provide a reference for starting to establish more effective broadcast messages about decentralized water systems. The findings relating to the importance of knowledge about greywater reuse (which does not necessarily imply personal experience of using greywater) suggest that broadcasting campaigns in TV advertisements, newspapers, and social networks, highlighting the potential reuse inside the home, can have a positive impact on the acceptability of greywater reuse for direct and indirect uses. Given the findings in relation to qualitative attributes, such campaigns should also focus on the quality of treated greywater, thus decreasing the influence of the disgust factor and increasing acceptability.

These types of information campaigns are of course most successful when targeting individuals who are more likely *a priori* to accept greywater reuse. In this context, the findings on heterogeneity are key, and the resulting disaggregated information (i.e. predicted acceptability at the level of individual households) could be used to predict which areas have the highest potential for reuse based on census zoning information. These results can form part of a comprehensive water management plan, allowing policy makers to focus efforts and propose incentives in areas where the acceptability is greater, and allow to alleviate the pressure of water resources through the use of alternative water sources. For example, the places where the diffusion campaigns can be more effective in the study zone are those areas where the population has higher education levels (information available in census data).

As with any study, there are limitations to highlight and opportunities for future research to explore. Firstly, although we based our hypothetical choice scenarios on real situations (Domnech & Saurí, 2010; Ilemobade et al., 2013); The Guardian[4], 2014; Wester et al., 2016), inevitably for the participating individuals this was still a hypothetical situation. As with any such survey, without direct experience individuals can interpret qualitative attributes differently (Ortúzar & Willumsen, 2011, sec. 3.4.2.7). For example, the odour attribute had three levels (odourless, slight chlorine odour, strong chlorine odour), and although most individuals have some experience of the smell of chlorine (e.g. swimming pool), what constitutes a light or strong level of chlorine can vary between individuals and this cannot be measured by the modeller (e.g. two individuals in the same pool, may find the same chlorine odour to be strong or light). While previous studies have shown that results from this type of stated preference survey are a good tool to obtain prior information about goods or services that do not yet exist (Louviere et al., 2000), future work should seek to validate the perceptions and behaviour on real data.

Secondly, this study has looked specifically at the situation where a grey water reuse system is already installed and thus provides important insights into the acceptability of water reuse and its potential uses. This is a first step and demonstrates the immediate interest in greywater reuse for new properties and the potential for wider uptake in existing properties. The next step is to understand the costs of implementing and operating widespread greywater reuse systems, and the affordability of these systems for residential and commercial properties, especially in the context of existing homes being considered retrofitted, where the marginal cost would be higher than for new builds.

Finally, different cultural, spiritual and socio-economic values of water in different places mean that our results may not be universally applicable. Any transfer of this approach to other locations should, therefore, undertake a similar process of setting up a pilot survey to establish relevant local factors.

[4] https://www.theguardian.com/lifeandstyle/2014/jul/21/greywater-systems-can-they-really-reduce-your-bills

4. USING HYBRID CHOICE MODELS TO CAPTURE THE IMPACT OF ATTITUDES ON RESIDENTIAL GREYWATER REUSE PREFERENCES

4.1. Introduction

Problems with water scarcity are affecting many large cities around the world (J. Liu et al., 2017; Mekonnen & Hoekstra, 2016). Successful experiences of water reuse in Australia, California, Singapore, Spain and areas of South Africa, have clearly shown that greywater offers a promising avenue for improving the sustainability of urban water supply (Lefebvre, 2018; Muthukumaran et al., 2011; Roshan & Kumar, 2020; Vuppaladadiyam et al., 2019). There are also substantial environmental benefits given the volume of water that may be recovered (50-80%), proportional to household consumption, and the optimization in its allocation (Wilcox et al., 2016). By being based on water free from faeces, food residues, oil and fats (i.e. not from the toilet or dishwasher), the treatment required to allow greywater reuse is much cheaper than in the case of water coming from desalination and wastewater treatment processes (Lambert & Lee, 2018). Treated greywater can be suitable for different uses ranging from drinking water to flushing toilet, as long as the water is properly treated considering the level of human contact (direct or indirect) for the desired use (Fielding et al., 2019; Jefferson et al., 2004), and according to the quality of greywater collected (Shaikh & Ahammed, 2020). However, previous studies have shown that the public acceptability of water reuse is one of the most important barriers that must be overcome to achieve success, longevity and reliability of reuse schemes (Garcia-Cuerva et al., 2016; Hurlimann et al., 2008; Smith et al., 2018).

Acceptability and consumer behaviour are clearly influenced by implementation and usage costs and by the benefits arising from reduced mains water use (Wilcox et al., 2016). This is in line with a “rational” view of human behaviour, where undesirable characteristics (e.g. increased costs) reduce the appeal and hence the likelihood of choosing a product, with the opposite applying for desirable characteristics. However, acceptance of a new technology is, at least in part, driven by subjective psychological constructs that determine what is desirable and what is not for each individual (cf. (Oteng-Peprah, det al., 2020; Yang & Yoo, 2004); the outcome might appear irrational from an economic perspective. For example, even though technology can remove every contaminating microscopic particle from water at an acceptable cost, this does not imply that all users can eliminate the mental association of treated greywater with impure water (Ching, 2015). Clear evidence of this comes from the fact that even though the most common residential water uses (toilet flushing, garden irrigation) do not require direct water-skin contact, the disgust factor still remains a significant effect on acceptability (Garcia-Cuerva et al., 2016; Leong, 2016).

Mental associations in the water reuse context are thus clearly linked to perceptions and attitudes. These are psychological phenomena that have attracted much attention in behavioural research in recent years (Bahamonde-Birke et al., 2017; Wester et al., 2016). Both concepts can contribute to how the characteristics of a good or service are viewed in terms of being desirable or undesirable by individual decision makers, and also to how overall intentions of approval or disapproval can be driven by wider attitudes to life, society, etc. (Aitken et al., 2014; Yang & Yoo, 2004). There is empirical evidence to support the relevance of this work in a greywater reuse (GWR) context. For example, Domnech & Saurí, (2010) studied perceptions about greywater reuse for toilet flushing, which has been in widespread use in a municipality in Barcelona (Spain) since 2004. There was clear evidence of heterogeneity in the perception of the colour of the water, and what constituted a desirable colour. Similarly, in a wider environmental setting, the empirical benefit of giving due consideration to the role of attitudes is clear (cf. Hoyos et al., 2015).

The analysis of human behaviour is a complex undertaking, and this is further amplified when attempting to capture the role of attitudes and other psychological constructs. Past studies in greywater research found important differences in preferences across individual households (Fielding et al., 2019), but a key question then is to what extend these differences relate to variations in underlying attitudes and perceptions. That is an important objective of the present chapter.

To obtain useful and reliable results requires a careful approach that separates out the many potential and simultaneous influences on behaviour. This rules out simplistic approaches, such as basic tabulations (or correlation analysis) of answers to attitudinal questions and stated willingness-to-adopt greywater reuse. In the literature, particular attention has been paid to two approaches: the use of the *Theory of Planned Behaviour (TPB)* and of *Discrete Choice Models* (DCMs). TPB (Ajzen, 1985) is focused on explaining behavioural intentions through attitudes, subjective norms and perceived behavioural control. The behavioural intention can then be used, again together with perceived behavioural control, to explain actual behaviour. For example, one recent study in greywater reuse developed by (Oteng-Peprah et al., 2020) found that the impact of beliefs from personal norms such as, moral obligation, feeling of guilt and better feelings, had the greatest impact on household's willingness to adopt a greywater treatment and reuse system. While TPB focusses primarily on attitudinal intentions, DCMs have become a popular tool to quantify the influence of different product/service characteristics on choices (Saldias et al., 2016; Tchetchik et al., 2016), as well as to measure the heterogeneity across decision makers (cf. Hess & Daly, 2014; Ortúzar & Willumsen, 2011, Chapters 7–9; Train, 2009 for a coverage of application areas). A key advantage of DCMs is their suitability for modelling behaviour in a multi-alternative multi-attribute setting rather than simply explaining willingness to adopt or not.

Tchetchik et al., (2016) go further than this by allowing for the influence on behaviour of "unobserved" heterogeneity in preferences across people. They also link some of this heterogeneity to answers to attitudinal questions concluding, for example, that more pro-environmental people are more likely to adopt GWR. The work by Tchetchik et al. (2016) groups answers to attitudinal questions together using factor analysis, and then use the resulting factors as error free measures of attitudes. However, there is now a growing recognition that attitudes and perceptions can never be observed with certainty by an analyst, and that answers to attitudinal questions are thus not error free and should not be used as explanatory variables in a model (cf. Ben-Akiva et al., 2002). This has led to the development of an advanced group of DCMs, known as *Hybrid Choice Models* (HCMs), which treat attitudes as latent (i.e. unobserved) variables and use the answers to attitudinal questions as “indicators” of attitudes, rather than “measures”. HCMs allow an analyst to understand the role of the characteristics of the decision makers in the formation of attitudes, and then use them in the computation of substantive model outputs, such as elasticities and willingness-to-pay measures, as well as in forecasting (Abou-Zeid & Ben-Akiva, 2014).

To know where efforts should be focused to achieve greater acceptability in the management plans of waters, it is important to both understand the sources of heterogeneity for greywater allocation in different uses and to know how important these factors are in the preferences. Most studies have focused on measuring the correlation of reuse preferences and the socioeconomic characteristics of the individual (Garcia-Cuerva et al., 2016; Ryan et al., 2009), while others have more recently concluded that attitudes are also influential (Etale et al., 2020; Oteng-Peprah et al., 2020; Yuriev et al., 2020). However, these two sources of heterogeneity are not mutually exclusive, and the missing piece is to quantify the weight that both aspects exert on reuse choices. Such a decomposition of heterogeneity is a crucial potential use of HCMs, as we illustrate in the present chapter.

This study considers the scenario of a large metropolitan area, Santiago de Chile, where greywater reuse is legally permitted but does not take place at present. Santiago is affected by water scarcity problems that are common to many cities around the world. More importantly, Santiago has been experiencing an ongoing draught, further increasing the need for new water supply measures and making it a very topical case study. Given the complexity of measuring perceptions in a context where the market is unknown, the study focused on a longer-term underlying pro-GWR attitude, while at the same time allowing for heterogeneity in preferences as a function of the characteristics of the treated greywater. The estimated model finds statistical support for the role of this attitudinal construct in shaping the heterogeneity of preferences for different greywater reuse options within a home.

One of the most important contributions of the present study is that it is, to the best of our knowledge, the first application to GWR of a HCM, an approach that has become increasingly popular across disciplines, including environmental science (cf. Mariel & Meyerhoff, 2016). As highlighted by Vij & Walker, (2016), many applications of HCMs, however, use inferior specifications leading to potential misattribution of heterogeneity, notably an overestimation of the role of attitudes. A second highly relevant contribution is the full decomposition of the sources of heterogeneity, which allows pinpointing what share of the heterogeneity in GWR preferences can, in fact, be linked to underlying attitudes.

While many of our findings are in line with past work, the methods used are more robust than past work, avoiding the potential confounding between different influences and exposure to endogeneity bias. This provides reliable results and important insights for policy makers, indicating the scope to which changes in attitudes may help with increasing the uptake of GWR. In addition, the work demonstrates the benefit of the approach in general, opening up scope for using the models -and in particular the analysis of sources of heterogeneity- in a wider water reuse context, and also to study the influences of more specific attitudes, including the disgust factor.

4.2.Preliminary work: Selection of attitudinal statements

Initially a factor analysis was conducted to explore which of the statements were related to each other. The most consistent findings were obtained when using a single factor, which loaded strongly onto six of the statements (with loadings larger in absolute value than 0.3, marked in bold in Table 4-1).

Table 4-1. Attitudinal statements and loadings in factor analysis (retained statements shown in bold)

	Attitudinal question	**Loading**
A	Water protection will provide a better world for me and my family	0.66
B	Water and the environment must be protected for the well-being of the entire population	0.77
C	We must worry more about protecting water than about economic growth	0.47
D	Water service companies limit my choice and personal freedom in terms of water uses	-0.14
E	In case of water cuts, people should worry more about taking their own measures	0.15
F	Everyone can contribute by saving water	0.67
G	The claims that there is a drought are exaggerated	-0.51
H	If the government does not take care of water problems, why should I?	-0.38
I	When I wash crockery, I let the water run, I accumulate it in a bowl and wash the crockery with this	-0.24
J	When I take a shower, I let the water run for more than one minute	-0.15
K	I do everything possible to reduce my water consumption	0.14

As can be seen, these six statements were split into two groups, where people who agree with the first four (A, B, C, F) were more likely to disagree with the final two (G, H), and vice versa.

4.3. Overall model structure

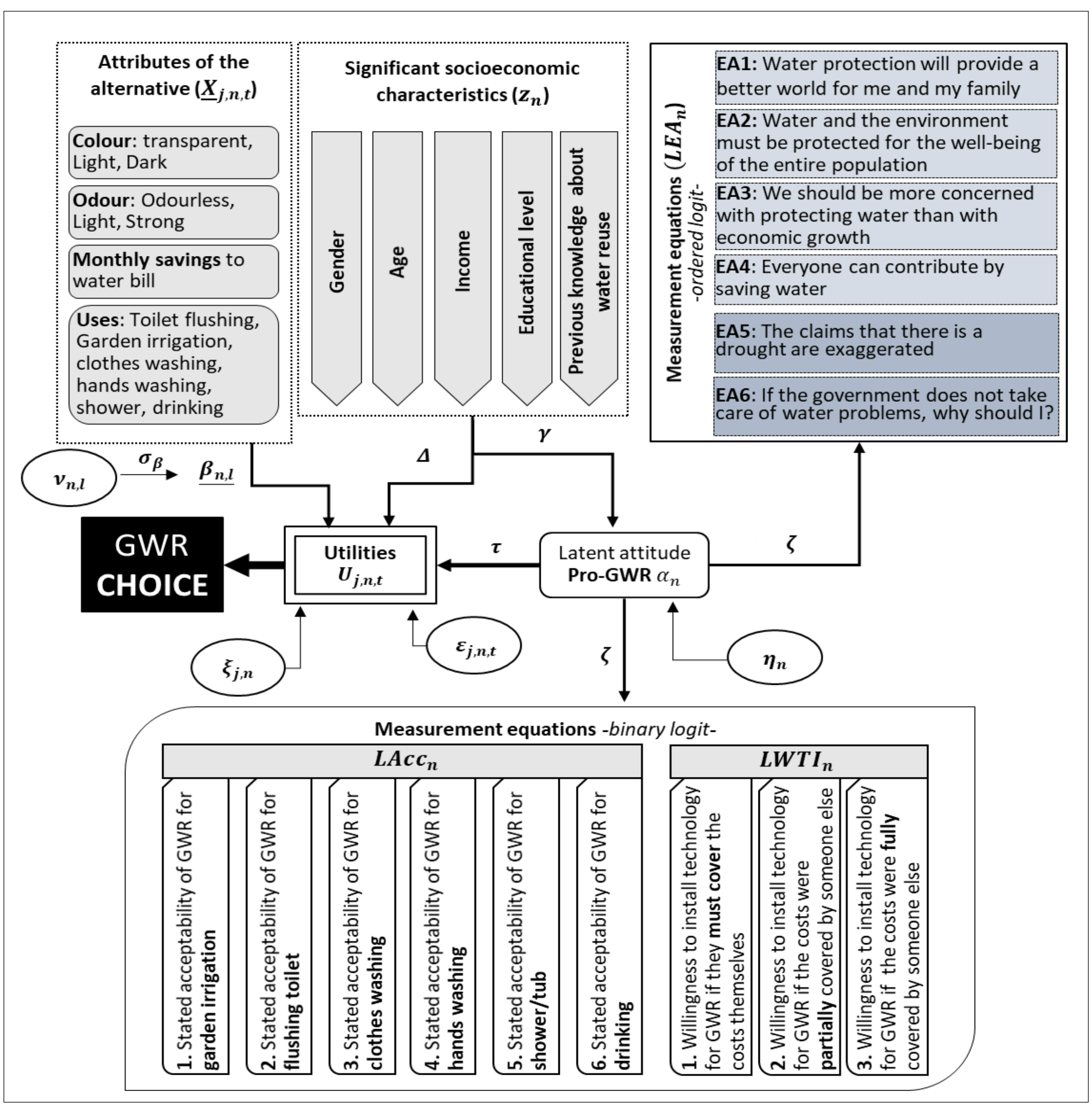
Econometric methods belonging to the family of discrete choice models were used, and specifically those based on random utility theory, to help disentangle the different influences on choice. In these models, the probability of choosing a specific option amongst mutually exclusive alternatives increases in the presence of desirable characteristics and decreases in the presence of undesirable characteristics (Train, 2009).

HCMs are an advanced type of DCM that treat attitudes as unobserved and represent them through latent variables (LV). These have a deterministic component, linking the latent attitude to observed decision maker characteristics such as socio-demographics, and a random component, accounting for noise across individual decision makers. The LV are used to explain the answers to attitudinal questions, and also part of the heterogeneity across individuals in the utilities for different alternatives in the choice model.

A HCM thus consists of a number of individual components, namely: (a) a structural equation for each latent variable, (b) a structural equation for the utility function of each alternative in the choice model, where at least some of these utilities are affected by the latent variables, (c) a measurement model for each indicator (e.g. attitudinal question), where each of these uses at least one of the LV as an explanator, and (d) a choice model component to explain the observed choices on the basis of the utilities (the choice model is a measurement model for the choice data). For a general introduction about HCMs the reader is referred to Abou-Zeid & Ben-Akiva, (2014).

The estimated model is complex due to the number of components to be analysed. However, in contrast with other approaches used in past work, HCMs have two key benefits. First, they do not treat the answers to attitudinal questions as error free measures of attitudes; instead they see them simply as “indicators” of underlying attitudes which are latent. The answers to the attitudinal questions are thus treated as dependent variables rather than explanatory variables. Second, a careful specification allowing the full level of flexibility, as done in this chapter, allows an analyst to pinpoint what share of heterogeneity in preferences can be linked back to the attitudinal constructs. HCMs are now seen as a reliable tried and tested tool across fields, and this chapter brings this technique to the important area of GWR. Figure 4-1 shows our model schematically. The model is made up of:

- One latent variable, where its structural equation uses five socio-demographic characteristics of the respondent (z_n).
- Three structural equations for the utilities in the choice model; these are a function of attributes of the alternatives in the SC scenarios for respondent *n* (X_n), and vary across alternatives (*j*) and across choice tasks (*t*).



*Greek symbols are explained in the text

Figure 4-1. Greywater reuse (GWR) hybrid choice model

The latent variable and the utilities are then used in several separate model components:

- A choice model for the choices (C_n) of respondent n (answers to T_C= 6 tasks with three alternatives each).
- Six measurement models for the answers to attitudinal questions (EA_n: set of T_{EA}= 6 questions, 5-point Likert scale – a standard approach for testing agreement in psychology).
- Six measurement models for the stated willingness to accept different uses (Acc_n: set of T_{Acc}= 6 questions, binary yes/no, one per use).
- Three measurement models for the stated willingness to install technology questions (WTI_n: set of T_{WTI}= 3 sequential questions, binary yes/no).

4.3.1. Structural equations

a) Structural equation for the latent variable

The structural equation for the single latent variable α_n is given by (4.1):

$$\alpha_n = \gamma z_n + \eta_n, \qquad (4.1)$$

where z_n is a vector of socio-demographic characteristics of person n, γ is a vector of estimated parameters, and η_n is a random error that distributes $N(0,1)$.

b) Utilities in the choice model

The choice model has three alternatives, the utilities of which differ across scenarios and respondents as a function of the characteristics of both the alternatives and the respondents. In particular, the utility of alternative j in task t for person n is given by:

$$U_{j,n,t} = \delta_j + \underline{\beta_n} \underline{X}_{j,n,t} + \xi_{j,n} + \varepsilon_{j,n,t}, \qquad (4.2)$$

where δ_j is a constant for alternative j, which is only estimated for the left-most alternative (i.e., for j=1) and $\underline{\beta_n}$ is a vector of parameters associated with the impact of the different explanatory variables for respondent n. In particular, the utility component for attribute l (which could be either the continuous *savings* attribute or one of the levels of a categorical variable, i.e., usage type, colour and odour) is given by one of the elements in $\underline{\beta_n}$, say $\beta_{n,l}$, as follows:

$$\beta_{n,l} = \beta_l + \Delta_{hc,l} z_{n,hc} + \sum_{m=1}^{4} z_{n,m} (\Delta_{\mathrm{m,l}} + \Delta_{\mathrm{m,l,hc}} z_{n,hc}) + \sigma_l \nu_{n,l} + \lambda_l \alpha_n \quad (4.3)$$

The sum over m refers to the four characteristics other than water expenditure level (gender, age, education and previous greywater experience). The different terms in (4.3) are as follows:

- β_l captures the value of the parameter for attribute l for a respondent in the base category for all socio-demographic variables.

- $\Delta_{hc,l}$ captures a shift in this base value for respondents in the high water expenditure group (T_2), where the socio-demographic variable $z_{n,hc} = 1$ if respondent n falls into that group (and 0 otherwise);

- The remaining four socio-demographic characteristics are captured by the indicators $z_{n,m}$, where, for example, $z_{n,1} = 1$ if respondent n is female (and zero otherwise). $\Delta_{\mathrm{m,l}}$ captures the shift in the sensitivity to attribute l for a respondent who has the socio-demographic characteristic $z_{n,m}$, while $\Delta_{\mathrm{m,l,hc}}$ captures an additional additive shift if that respondent also belongs to the high water expenditure group (T_2).

- σ_l is the standard deviation for the random heterogeneity in the sensitivity $\beta_{n,l}$ across respondents; this is standard normal distributed, such that $\nu_{n,l} \sim N(0,1)$, and is only incorporated for the six types of uses (i.e. and not for the qualitative attributes or the savings attribute).

- λ_l captures the impact of the latent variable α_n (from equation 4.1) on the value of $\beta_{n,l}$, where these impacts are only captured for the six different uses (i.e. again, not for the qualitative attributes or the savings attribute).

The utility function in (4.2) also contains two error terms. The first, $\xi_{j,n}$, is identically and independently distributed (IID) across alternatives and respondents according to a Normal $N(0, \sigma_\xi)$ distribution; σ_ξ is estimated and serves to treat the pseudo panel effect inherent to SC data (Ortúzar & Willumsen, 2011, Chapter 8). The second term, $\varepsilon_{j,n,t}$, is IID across alternatives and observations, and follows a type I extreme value distribution, leading to a logit type probability of choice (Train, 2009).

The discussion above has been very technical and detailed with the aim of ensuring that readers who seek to adopt a similar specification for other applications recognise the inter-play between the different component. A key feature of the specification used in this chapter is that the heterogeneity in preferences in the utility function (i.e. Equation 4.3) is not limited to either heterogeneity linked to attitudes or heterogeneity not linked to attitudes. Rather, it does both at the same time. This avoids the issue highlighted by Vij & Walker, (2016) of models misattributing all heterogeneity to attitudes. It also sets the scene for the analysis of the sources of heterogeneity in Section 4.4.4.

4.3.2. Measurement models and joint likelihood

The model jointly explains the values of 16 different dependent variables; namely, the answers to six attitudinal questions, six willingness-to-accept questions, up to three willingness-to-install questions, and the SC component (with six observations per respondent). The estimation of the model parameters involves the maximisation of the joint log-likelihood (LL) of all model components, given by:

$$LL = \sum_{n=1}^{N} log \int_{\eta} \int_{\xi} P_{C_n} \cdot LEA_n \cdot LAcc_n \cdot LWTI_n d\xi d\eta \quad (4.4)$$

The data for each individual *n* contributes to this overall LL in the form of the likelihood of the observed sequence of stated choices (P_{C_n}), the likelihood of the stated agreement with the environmental statements (LEA_n), the likelihood of the stated willingness-to-accept greywater reuse ($LAcc_n$), and the likelihood of the stated willingness-to-install technology ($LWTI_n$). All four components depend on the latent variable α_n, while the choice model component also makes use of the random panel effect term (ξ). Thus, (4.4) incorporates an integral over the distribution of the two random components in the model. As this integral does not have a closed form solution, it was approximated through numerical simulation, using 500 Modified Latin Hypercube Sampling (MLHS) draws per random component and per individual (Hess et al., 2006). All models were coded and estimated in Apollo v.0.1.0 (Hess & Palma, 2019).

The remainder of this section now looks at the functional form of the four separate model components included in (4.4).

a) Choice model component: P_{C_n}

Given the IID extreme value assumption for $\varepsilon_{j,n,t}$ in (4.2), the probability of the sequence of six choices is given by:

$$P_{C_n} = \prod_{t=1}^{6} \sum_{i=1}^{3} (c_{nt} == i) \left(\frac{e^{\delta_i + \underline{\beta}_n \underline{X}_{i,n,t} + \xi_{i,n}}}{\sum_{j=1}^{3} e^{\delta_j + \underline{\beta}_n \underline{X}_{j,n,t} + \xi_{j,n}}} \right) \tag{4.5}$$

where c_{nt} identifies the alternative chosen by respondent *n* in task *t*, and where the term $(c_{nt} == i)$ will be equal to 1 if and only if respondent *n* chooses alternative *i* in task *t*. This probability is conditional on the random component (η_n) within the latent variable α_n (which influences β_n) as well as the random panel effect term ($\xi_{j,n}; j = 1,2,3$).

b) Attitudinal statements: LEA_n

To model the response to the six attitudinal statements (see Table 4-1), an ordered logit model (Train, 2009) was used, with likelihood given by:

$$LEA_n = \prod_{t=1}^{6} \sum_{p=1}^{5} (EA_{nt} == p) \left(\frac{e^{\tau_{EA_t,p} - \zeta_{EA,t}\alpha_n}}{1 + e^{\tau_{EA_t,p} - \zeta_{EA,t}\alpha_n}} - \frac{e^{\tau_{EA_t,p-1} - \zeta_{EA,t}\alpha_n}}{1 + e^{\tau_{EA_t,p-1} - \zeta_{EA,t}\alpha_n}} \right) \tag{4.6}$$

where the term $(EA_{nt} == p)$ will be equal to 1 if and only if respondent *n* answers with level p to question EA_t, where *p=1,…,5*. The $\tau_{EA_t,p}$ parameters are thresholds to be estimated (with the normalisation that $\tau_{EA_t,0} = -\infty$ and $\tau_{EA_t,5} = +\infty$); furthermore, as no respondents chose the lowest level (i.e. strong disagreement) in the case of the first two statements (i.e., *t=1,2*), we also set $\tau_{EA_t,1} = -\infty$. The estimated parameter $\zeta_{EA,t}$ measures the impact of latent variable α_n on EA_{nt}. If the parameter is significantly different from zero, the latent attitude α_n has a statistically significant impact on the answers provided to the attitudinal question EA_{nt}.

c) Stated acceptability questions: $LAcc_n$

To model the answers to the six acceptability of use questions, where $Acc_{nt} = 1$ if use *t* was acceptable to person *n*, and 0 otherwise, a simple binary logit model was used, with likelihood:

$$LAcc_n = \prod_{t=1}^{6} \frac{\left(e^{\delta_{\mathrm{Acc}_t} + \zeta_{\mathrm{Acc}_t}\alpha_n}\right)^{Acc_{nt}}}{1+e^{\delta_{\mathrm{Acc}_t} + \zeta_{\mathrm{Acc}_t}\alpha_n}}, \tag{4.7}$$

where the exponent Acc_{nt} ensures that the numerator takes the appropriate value depending on the answer provided by the respondent (noting that Acc_{nt} is either 0 or 1); δ_{Acc_t} is an estimated constant that explains the average rate of respondents answering yes, while $\zeta_{\mathrm{Acc_t}}$ captures the impact of the latent attitude.

d) Willingness-to-install questions $LWTI_n$

Finally, the response to the sequential willingness-to-install questions were modelled. These were, at most, three sequential binary answers. So, three binary logit models were used, but with the latter stages only applying if the previous ones were answered negatively, with the likelihood given by:

$$LWTI_n = \frac{\left(e^{\delta_{\mathrm{WTI}_1} + \zeta_{\mathrm{WTI}_1}\alpha_n}\right)^{WTI_{n1}}}{1+e^{\delta_{\mathrm{WTI}_1} + \zeta_{\mathrm{WTI}_1}\alpha_n}} \cdot \left(\frac{\left(e^{\delta_{\mathrm{WTI}_2} + \zeta_{\mathrm{WTI}_2}\alpha_n}\right)^{WTI_{n2}}}{1+e^{\delta_{\mathrm{WTI}_2} + \zeta_{\mathrm{WTI}_2}\alpha_n}}\right)^{1-WTI_{n1}} \cdot$$

$$\left(\frac{\left(e^{\delta_{\mathrm{WTI}_3} + \zeta_{\mathrm{WTI}_3}\alpha_n}\right)^{WTI_{n3}}}{1+e^{\delta_{\mathrm{WTI}_3} + \zeta_{\mathrm{WTI}_3}\alpha_n}}\right)^{(1-WTIc_{n1})\cdot(1-WTI_{n2})} \tag{4.8}$$

where WTI_{nt}=1 if and only if the respondent answered yes to the question in stage *t*. The values for WTI_{nt} was automatically set to zero if the answer to $WTI_{nt-1} = 1$. Therefore, these exponents ensure that the second and third components in (4.8) are simply equal to one when a positive answer was given in an earlier stage. The estimated parameters have the same definition as for the binary acceptability questions.

4.4. Results and discussion

In this section, the results corresponding to each of the components of the model are described and analysed. Firstly, the directionality of the impacts of the nature of the latent variable is investigated, followed by the socio-demographic drivers of the attitudes, and finally the role of the latent attitude in the choice model. For each model component, ρ^2 is presented as a goodness of fit measure[5]. The results show the estimate for each parameter, the associated robust standard error and its t-ratio (i.e., the ratio of the two). The latter is used to test the null hypothesis (H_0) that the parameter is equal to zero[6].

4.4.1. Measurement models for indicators

Table 4-2 shows the results for the six ordered logit models estimated to explain the answers to the six attitudinal questions considered in our study. For each model, all the estimated thresholds ($\tau_{EA_t p}$, discussed in 4.3.2 Measurement models/attitudinal statements) show the required increase i.e., utility needs to be larger for a stronger agreement with a statement. The distances between thresholds reflect the uneven distribution of answers in the data – a bigger gap between two thresholds means that more answers fall into that area.

The additional parameter ζ_{EA_t} in each model is the marginal utility of the latent variable α_n in the ordered logit model. A positive estimate means that, as the latent variable α_n increases, respondents are more likely to agree more strongly with the statement that the model seeks to explain, with the opposite applying for a negative estimate.

[5] ρ^2 would be zero for a model with equal shares for all outcomes and one for a deterministic (perfect) model. In choice modelling, this is used as a goodness of fit measure especially for multi-alternative choice models, with values between 0.2 and 0.4 often considered to provide a satisfactory fit (McFadden, 1974).

[6] The critical value to reject H_0 at a 95% confidence level is 1.96 in a two-sided test (i.e., when the expected sign of the parameter is unknown); if the sign is known, a one-sided test is applicable and the critical value in that case is 1.64.

Table 4-2. Ordered logit models results for answers to attitudinal questions

Statements for measurement equations (ordered logit)	Estimate	Robust. std. err.	t-ratio
1. Water protection will provide a better world for me and my family			
… Threshold $\tau_{EA_1 1}$	-∞	fixed	fixed
… Threshold $\tau_{EA_1 2}$	-7.272	0.959	-7.59
… Threshold $\tau_{EA_1 3}$	-4.553	0.589	-7.73
… Threshold $\tau_{EA_1 4}$	-2.133	0.412	-5.17
… ζ_{EA_1}(impact of LV)	1.555	0.342	4.55
Goodness of fit for model component (ρ^2)	0.550		
2. Water and the environment must be protected for the well-being of the entire population			
… Threshold $\tau_{EA_2 1}$	-∞	fixed	fixed
… Threshold $\tau_{EA_2 2}$	-8.013	1.109	-7.23
… Threshold $\tau_{EA_2 3}$	-4.683	0.838	-5.59
… Threshold $\tau_{EA_2 4}$	-2.645	0.646	-4.09
… ζ_{EA_2} (impact of LV)	2.610	0.555	4.70
Goodness of fit for model component (ρ^2):	0.450		
3. We should be more concerned with protecting water than with economic growth			
… Threshold $\tau_{EA_e 1}$	-6.469	0.764	-8.47
… Threshold $\tau_{EA_3 2}$	-4.734	0.386	-12.25
… Threshold $\tau_{EA_3 3}$	-2.021	0.240	-8.43
… Threshold $\tau_{EA_3 4}$	-0.738	0.200	-3.69
… ζ_{EA_3} (impact of LV)	1.009	0.154	6.56
Goodness of fit for model component (ρ^2):	0.340		
4. Everyone can contribute by saving water			
… Threshold $\tau_{EA_4 1}$	-7.592	0.996	-7.62
… Threshold $\tau_{EA_4 2}$	-6.060	0.702	-8.63
… Threshold $\tau_{EA_4 3}$	-3.365	0.475	-7.09
… Threshold $\tau_{EA_4 4}$	-1.391	0.356	-3.91
… ζ_{EA_4} (impact of LV)	1.744	0.307	5.68
Goodness of fit for model component (ρ^2)	0.370		
5. The claims that there is a drought are exaggerated			
… Threshold $\tau_{EA_5 1}$	-0.098	0.183	-0.54
… Threshold $\tau_{EA_5 2}$	0.452	0.204	2.21
… Threshold $\tau_{EA_5 3}$	1.538	0.248	6.20
… Threshold $\tau_{EA_5 4}$	2.913	0.301	9.69
… ζ_{EA_5} (impact of LV)	-1.023	0.179	-5.71
Goodness of fit for model component (ρ^2)	0.080		
6. If the government does not take care of water problems, why should I?			
… Threshold $\tau_{EA_6 1}$	-1.160	0.141	-8.22
… Threshold $\tau_{EA_6 2}$	-0.619	0.137	-4.53
… Threshold $\tau_{EA_6 3}$	0.777	0.157	4.97
… Threshold $\tau_{EA_6 4}$	2.135	0.204	10.45
… ζ_{EA_6} (impact of LV)	-0.655	0.127	-5.14
Goodness of fit for model component (ρ^2)	0.080		

* Recall that thresholds $\tau_{EA_1 1}$ and $\tau_{EA_2 1}$ were fixed to -∞ as nobody selected them in the survey.

Looking at the statements in Table 4-2, two opposite effects are highlighted, namely:

- Results for the first four statements show that the ζ_{EA_t} estimate is positive and highly significant. Thus, a more positive value for the latent variable increases the probability of stronger agreement with the attitudinal statements. These four attitudinal statements relate to water protection and the public good nature of water. The actual size of the impact varies across statements and is especially strong for environmental protection.

- For the remaining two statements, the impact of the latent variable as captured by ζ_{EA_t} is negative and highly significant. This implies that people with a more negative latent attitude are more likely to agree with these attitudinal statements. The impact varies across these two statements and is especially strong for droughts being exaggerated. These two statements relate much more to water shortage scepticism, and thus go in the opposite direction of the first four, so the opposite signs for ζ_{EA_t} in both groups are entirely reasonable.

The goodness of fit measures implies much higher performance for the first four indicators. The lower fit statistics for the final two are simply a result of the shares for the five levels being very similar for these last two indicators, meaning that no model can offer substantial improvements in fit over an equal-shares model. The more important finding is, of course, that the estimated parameters are statistically significant across all indicators.

In the case of the six binary logit models for the stated acceptability of greywater use (Table 4-3), an estimate for a constant in each case was obtained, capturing the baseline utility (δ_{Acc_t}), and another for the impact of the latent variable (ζ_{Acc_t}). A positive value for δ_{Acc_t} would imply that net of the effect of the latent variable, a larger share of respondents would be willing to accept greywater reuse for that specific usage. The estimated constants decrease across uses, showing that the stated acceptability gets progressively lower with the more direct uses, as expected.

Table 4-3. Results for binary logit models for acceptability of use

Measurement equations (binary logit)	Estimate	Robust. std. err.	t-ratio
Stated acceptability of greywater reuse for flushing toilet			
…Constant δ_{Acc_1}	1.943	0.250	7.79
…ζ_{Acc_1} (impact of LV)	1.349	0.248	5.43
Goodness of fit for model component (ρ^2)	0.150		
Stated acceptability of greywater reuse for garden irrigation			
…Constant δ_{Acc_2}	1.003	0.145	6.92
… ζ_{Acc_2} (impact of LV)	0.648	0.136	4.75
Goodness of fit for model component (ρ^2)	0.070		
Stated acceptability of greywater reuse for clothes washing			
…Constant δ_{Acc_3}	0.048	0.158	0.30
… ζ_{Acc_3} (impact of LV)	0.895	0.198	4.52
Goodness of fit for model component (ρ^2)	0.020		

Measurement equations (binary logit)	Estimate	Robust. std. err.	t-ratio
Stated acceptability of greywater reuse for hands washing			
…Constant δ_{Acc_4}	-1.144	0.183	-6.25
… ζ_{Acc_4} (impact of LV)	1.148	0.329	3.49
Goodness of fit for model component (ρ^2)	0.270		
Stated acceptability of greywater reuse for shower/bath			
…Constant δ_{Acc_5}	-1.759	0.245	-7.20
… ζ_{Acc_5} (impact of LV)	1.435	0.408	3.52
Goodness of fit for model component (ρ^2)	0.420		
Stated acceptability of greywater reuse for drinking			
…Constant δ_{Acc_6}	-3.051	0.280	-10.89
… ζ_{Acc_6} (impact of LV)	1.011	0.366	2.76
Goodness of fit for model component (ρ^2)	0.760		

The impact of the latent variable is positive across all categories, and the ζ_{Acc_t} estimates are highly significant. The positive signs imply that respondents with a more positive value for the latent variable are more likely to indicate that they would be willing to use greywater for these uses. The actual impact again varies across the six categories, but it is strongest for *Shower/tub* (1.435) followed by *Hand washing* (1.148), and lowest for *Garden irrigation* (0.648). The goodness of fit measures again implies a varied picture across the six indicators, and those cases where ρ^2 is lower, simply reflect the fact that the binary split in the data is very close to 50-50. The more important point, again, is that the impact of the LV is statistically significant across the six indicators.

Finally, the three binary logit models for the sequential questions about willingness to install new technology in the house to treat and to reuse greywater were analysed (Table 4-4). In the first two models, a negative value for δ_{WTI_t} was obtained (-1.565 and -1. 423), representing the lower number of respondents that would be willing to invest their money, totally or partially, to fit a new technology for reusing treated greywater at their homes. By contrast, the positive value of δ_{WT3} (1.462) implies an overall positive response in the third stage. Note that across the three stages, the positive and significant estimate of ζ_{WTI_t} implies that increases in the latent variable would lead to increases in the stated willingness to fit the new technology. In terms of the goodness of fit, once more the lower fit for the final component is due to its shares being much closer to 50-50 than for the other components.

Table 4-4. Binary logit models' results for acceptability of installing greywater reuse technology

Measurement equations (binary logit)	Estimate	Robust. std. err.	t-ratio
Willingness to invest their money in a new device for GWR			
…Constant δ_{WTI_1}	-1.565	0.136	-11.48
…ζ_{WTI_1} (impact of LV)	0.521	0.160	3.25
Goodness of fit for model component (ρ^2)	0.390		
Willingness to invest partially their money in a new device for water reuse			
…Constant δ_{WTI_2}	-1.423	0.144	-9.87
…ζ_{WTI_2} (impact of LV)	0.311	0.158	1.97
Goodness of fit for model component (ρ^2)	0.330		
Willingness to accept a new device for water reuse but without investment			
…Constant δ_{WT3}	1.576	0.254	6.21
…ζ_{WT3} (impact of LV)	0.989	0.244	4.05
Goodness of fit for model component (ρ^2)	0.100		

4.4.2. Structural equation for the latent variable

Section 4.4.1 shed some light on the role and interpretation of the latent variable α_n. In particular, a more positive value for α_n correlates with stronger agreement with water conservation statements, stronger disagreement with the statements expressing scepticism about water shortage claims, and a greater willingness to accept greywater reuse and to install greywater reuse technology. This suggests that the attitudinal construct can be interpreted as a ***pro-greywater reuse attitude***.

The next step consists of seeking to understand how this latent attitude varies across our sample. Table 4-5 shows the estimates for the parameters γ explaining the influence of the socio-demographic characteristics on the latent variable. Here, it is important to remember the presence of the additional standard Normal disturbance term, meaning that there is also random variation in the attitudinal construct. Our model estimates show that female respondents, those younger than 55 years and those with low education, have a lower value for the latent variable than men, respondents over 55 years, and people with high education. In contrast, prior knowledge and being in the lowest income category has a positive influence on the latent variable. The largest estimate is for people with low income.

Table 4-5. Results for structural equation for latent variable (deterministic part)

Impact of socio-demographics on α_n (γ parameters)	Estimate	Robust. std. err.	t-ratio
Female	-0.199	0.113	-1.75
Age below 55	-0.323	0.108	-3.00
Low income (less than 200.000 CLP)	0.509	0.290	1.75
Low education	-0.367	0.115	-3.20
Previous knowledge	0.299	0.131	2.28

The findings that previous knowledge and higher education lead to respondents being more pro-greywater reuse is not surprising. However, the finding that low income and older respondents appear to be more pro-greywater reuse is not necessarily in line with *a priori* expectation and provides important new insights. Note that the use of attitudinal constructs allows us to detect situations where a group of people can be more pro-greywater reuse without necessarily being in a position to turn this attitude into reality due to other constraints on their behaviour. This is a greywater reuse analogue to an occasional finding in transport research, that women and lower income people may actually be more pro-car than men and higher income people (Hess et al., 2018), but represent a smaller share of car travellers due to other constraints on their behaviour (namely income).

4.4.3. Choice model component

Finally, the results of the choice model component (Table 4-6) first show a reduced rate of choosing the left-most option (δ_1=-0.697) and a strong pseudo-panel effect, that is, correlation across choices for the same respondent (σ_ξ=1.945). The goodness of fit of the choice model component is 0.28, exceeding the value of 0.25 found using the Error Components Mixed Logit model (chapter 3). This shows that adding the latent variable and additional random terms on top of the components linking attribute preferences to socioeconomic characteristics allows for a better understanding of the heterogeneity in choices of greywater reuse, giving valuable insights for establishing acceptability strategies.

The utilities include seven socio-demographic effects which are not significantly different from zero at the 95% confidence level (three in the *Toilet flushing* attribute, one for *Garden irrigation*, two for *Washing clothes* and one for *Shower/tub*), plus the standard deviation. They were kept in the model because they had the expected sign and were the best estimates, we could get with our sample size (cf. Ortúzar & Willumsen, 2011, p. 278).

a) Appearance

The negative signs show that an increase in the level of odour and colour, negatively affects the choice of reusing water; but there is no difference between clear and light blue in the case of colour. This is consistent with other investigations (Domnech & Saurí, 2010; Ilemobade et al., 2013).

b) Savings in the water bill

Monetary savings is a relevant attribute in the decision to reuse greywater. However, we found that it had different weights according to the household's water expenditure. The marginal utility (i.e. the per-unit value) is larger for people whose households have lower water expenses (0.189) compared to those who have higher expenses (0.189 + (-0.106) =0.083), as expected.

a) Uses

The respondents' utility for reusing greywater varies across uses and needs to be interpreted relative to using mains water only for each type of use (where that utility was set to zero for normalisation). In each case, we have a mean utility, along with random and deterministic heterogeneity, and the impact of the latent variable.

- <u>Mean utility and deterministic heterogeneity not linked to LV</u>: Results show that the mean utility (μ) is positive for all uses except for drinking. These estimates, however, only relate to the base socio-demographic group (male, highly educated, aged over 55 and not in the lowest income group). *Gender* is the common characteristic that influences most purposes. In the low water expenditure group, we see a more positive utility for reusing greywater for toilet flushing, garden irrigation, and drinking in the case of women.

Table 4-6. Results for choice model component

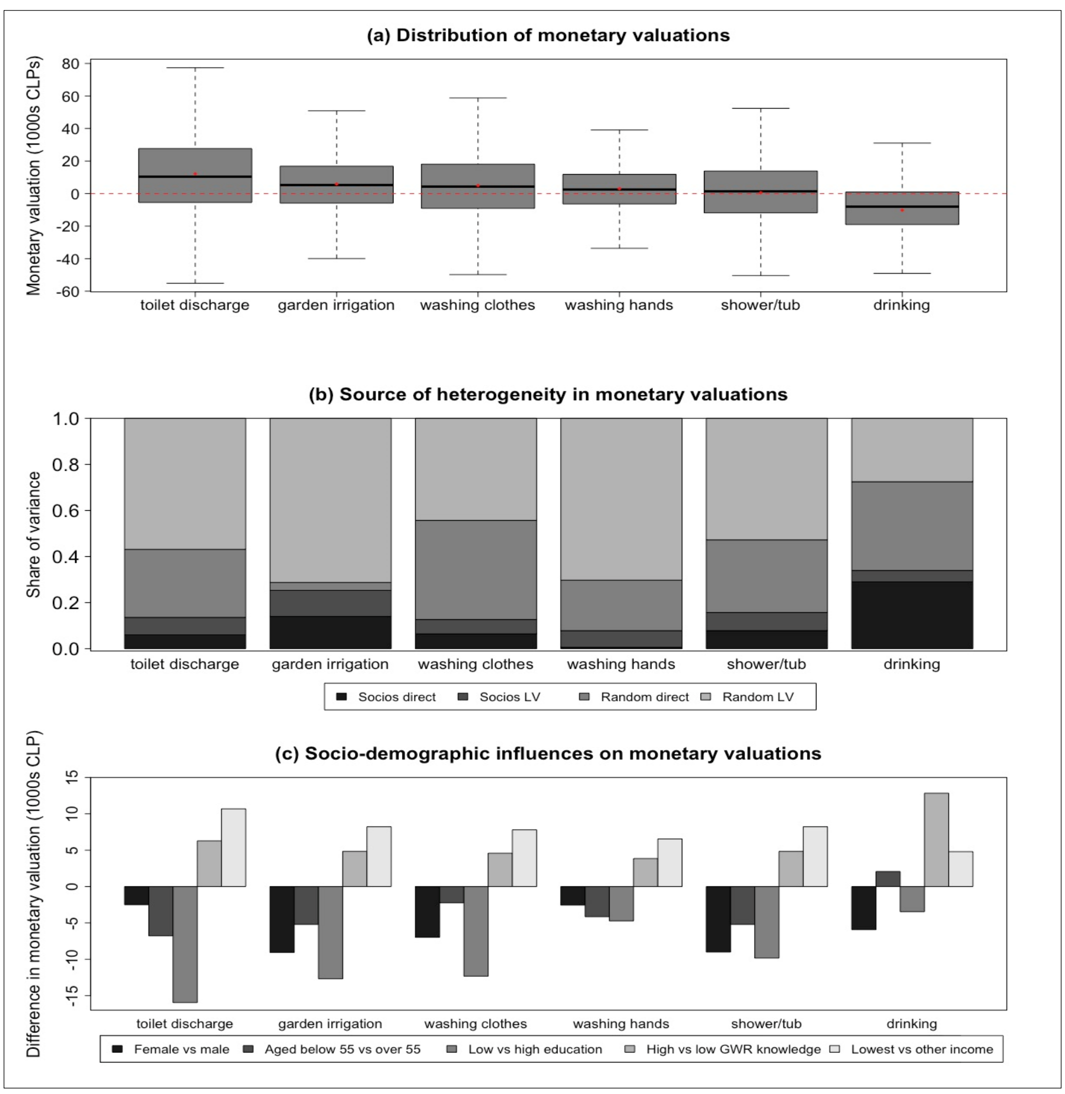
Attribute	General description	Estimate	Robust. std. err.	t-ratio
	Constant for left most alternative (δ_1)	-0.697	0.125	-5.58
Colour	**Clear or light blue**	**0**	***-Fixed-***	
	Dark blue (β)	-0.651	0.123	-5.28
Odour	**Odourless**	**0**	***-Fixed-***	
	Light chlorine (β)	-0.517	0.138	-3.74
	Strong chlorine (β)	-1.480	0.158	-9.39
	Savings on water bill (β)	**0.189**	**0.040**	**4.70**
	… shift for high-water water expenditure group (Δ)	-0.106	0.040	-2.66
Toilet flushing	**Mean for utility β (μ_1)**	**3.172**	**0.552**	**5.75**
	Standard deviation for β (σ_1)	**1.846**	**0.375**	**4.92**
	… λ_1 (impact of LV)	2.565	0.322	7.95
	… shift for female (Δ)	0.751	0.482	1.56
	… shift for female and high-water expenditure group (Δ)	-0.861	0.594	-1.45
	… shift for low education (Δ)	-1.457	0.471	-3.09
	… shift for low education and high-water expenditure (Δ)	0.707	0.629	1.12
Garden irrigation	**Mean for utility β (μ_2)**	**2.615**	**0.414**	**6.31**
	Standard deviation for β (σ_2)	**0.432**	**0.299**	**1.45**
	… λ_2 (impact of LV)	1.972	0.288	6.84
	… shift for female (Δ)	0.445	0.323	1.38
	… shift for female and high-water expenditure (Δ)	-1.827	0.473	-3.86
	… shift for low education (Δ)	-1.617	0.348	-4.65
	… shift for low education and high-water expenditure (Δ)	1.246	0.452	2.76
Washing clothes	**Mean for utility β (μ_3)**	**2.095**	**0.415**	**5.05**
	Standard deviation for β (σ_3)	**1.847**	**0.325**	**5.68**
	… λ_3 (impact of LV)	1.872	0.345	5.43
	… shift for female and high expenditure (Δ)	-0.758	0.418	-1.82
	… shift for age below 55 and high-water expenditure (Δ)	0.521	0.403	1.29
	… shift for low education (Δ)	-0.819	0.347	-2.36
Washing hands	**Mean for utility β (μ_4)**	**1.092**	**0.343**	**3.18**
	Standard deviation for β (σ_4)	**0.878**	**0.280**	**3.14**
	… λ_4 (impact of LV)	1.572	0.261	6.02
Shower/ Tub	**Mean for utility β (μ_5)**	**1.728**	**0.400**	**4.32**
	Standard deviation for β (σ_5)	**1.530**	**0.275**	**5.57**
	… λ_5 (impact of LV)	1.973	0.327	6.03
	… shift for female and high-water expenditure (Δ)	-1.117	0.365	-3.06
	… shift for low education (Δ)	-0.478	0.322	-1.48
Drinking water	**Mean for utility β (μ_6)**	**-1.066**	**0.463**	**-2.30**
	Standard deviation for β (σ_6)	**-1.366**	**0.452**	**-3.02**
	… λ_6 (impact of LV)	1.152	0.258	4.46
	… shift for female (Δ)	0.870	0.443	1.96
	… shift for female and high-water expenditure (Δ)	-2.153	0.592	-3.64
	… shift for age below 55 and high-water expenditure (Δ)	0.985	0.460	2.14
	… shift for previous knowledge and high-water expenditure (Δ)	1.928	0.587	3.28
	Standard deviation of error component (σ_ξ)	1.945	0.144	13.51
	Goodness of fit for model component (ρ^2)	0.280		

In contrast, women in the high expenditure group have lower utility (than men) for all uses, except for washing hands, which is the only use without any direct sociodemographic interactions (i.e. net of the latent attitude). Another finding is that *Prior knowledge* has a direct (as opposed to via the latent attitude) positive influence only in the utility of reusing treated greywater for drinking. This is in contrast with the strong positive influence of *Prior knowledge* on the pro-greywater reuse attitudes, which suggests that prior knowledge is more likely to have an indirect (i.e., through the attitude) rather than direct impact on choices, supporting the theoretical points of (Ajzen & Fishbein, 1975).

- Random heterogeneity not linked to LV*:* There is extensive random heterogeneity around the above values with a larger magnitude in the greywater reuse for *Toilet flushing*, *Washing clothes* and *Shower/tub* (σ_{toilet}: 1.846, $\sigma_{clothes}$: 1.847, σ_{shower}: 1.530), meaning that there is a non-trivial probability of negative values throughout these uses. For the remaining three uses, the random heterogeneity is less extensive, but with the estimated standard deviations remaining statistically significant.
- Impact of LV*:* Additionally, our estimates show that the utility of using greywater for all uses increases for respondents with a more positive value for the latent variable. The impact of this pro-greywater reuse attitude is different in magnitude according to the use. The strongest impact of the attitudinal construct is observed for the utility of greywater reuse for *Toilet flushing* ($\lambda_{toilet} = 2.565$), followed by *Shower/tub* ($\lambda_{shower} = 1.973$), *Garden irrigation* ($\lambda_{garden} = 1.972$), *Washing clothes* ($\lambda_{clothes} = 1.872$), *Washing hands* ($\lambda_{hands} = 1.572$), and finally *Drinking* ($\lambda_{drinking} = 1.152$). This is a first indication that for some uses, especially the most direct ones, there is less scope for changes in attitudes leading to changes in behaviour.

4.4.4. Analysis of sources of heterogeneity

A more detailed analysis of the heterogeneity in the model, with a focus on the importance of the latent attitude is described in this section. In particular, a situation where the greywater is clear and odourless but has no financial savings associated with it, was analysed. Results indicate that the mean monetary valuation is positive for all uses except *Drinking*, where a strong monetary incentive would be required (Figure 4-2a). Across uses, the willingness to pay of users decreases as uses involve more direct contact. Note the strong heterogeneity in the monetary valuations across individuals, reflected in the wide confidence interval of the valuations. Heterogeneity comes mainly from the utility associated with the various uses rather than from the sensitivity to the monetary incentive (where only a shift for the high expenditure group was captured, cf. Table 4-6).



*Note that for the box-plots, the "box" is bounded by the lower and upper quartile limit (25% and 75%), the horizontal line is at the medium, the mean is represented by a dot, and the whiskers are situated 1.5 times the interquartile range below the lower quartile and above the upper quartile limit.

Figure 4-2. Analysis of heterogeneity in monetary valuations.

Given the careful and detailed specification used in this chapter, the model allows the separation of four sources of heterogeneity: (i) deterministic heterogeneity, not linked to the latent variable; (ii) deterministic heterogeneity in the latent variable itself and, finally, two types of random heterogeneity: (iii) net of the latent attitude, and (iv) through the latent attitude. In what follows, components (i) and (iii) are labelled as "direct" by not entering the utility through the latent variable.

The results first show that a large share of heterogeneity is random across uses (Figure 4-2b). The main exception is the case of *Drinking*, where just over a third of the total heterogeneity can be linked to observed respondent characteristics, driven by the strong influence of *Gender*, *Age* and *Previous knowledge*. These effects are primarily direct, rather than being captured through the latent attitude. In terms of random heterogeneity, it can be observed that a larger share of this variation can be linked to the attitudinal construct (size of λ) rather than being unrelated random heterogeneity (size of σ) for all uses except *Washing clothes* (where the two sources are roughly equal in importance) and *Drinking* (where the direct random heterogeneity is larger than that through the latent attitude).

Finally, Figure 4-2c looks at the influence of respondent characteristics on monetary valuations, given by the combined effects of direct influences or through the latent attitude. A key point to note is that all the λ parameters are significant and have the same sign (positive). As a result, if a socio-demographic variable has an impact on the latent attitude, it will have an impact (although of different magnitudes) on the six utilities, and its effect will be in the same direction across all uses. However, this can be counteracted or in fact strengthened by the direct effects (i.e. the inclusion of the socio-demographics in the utilities, net of the impact of the latent attitude). For *Gender*, the latent attitude for women is more negative, leading to a reduced utility across all six uses. In the case of *Toilet flushing*, this reduction is party cancelled out by a positive direct shift (-4.17+1.67), while for all other uses (except *Washing hands*), there is a further negative direct effect. For respondents aged below 55, the latent attitude is again more negative, but this impact is reduced by a positive direct effect for *Washing clothe*s (-4.95+2.70), while the direct effect is so positive as to change the overall utility difference compared to older respondents in the case of *Drinking* (-3.04+5.11). *Low education* leads to a lower (or negative) monetary valuation, with the opposite applying for *Previous knowledge*. Finally, the positive shift in the monetary valuation for the lowest income group, is driven entirely by the strong positive latent attitude estimated for that group.

4.4.5. Role of attitudes in behaviour

A more in-depth account of the role of attitudes in the potential preferences for greywater reuse is possible by analysing the relative importance of the latent attitude and the qualitative appearance of greywater. The results in Figure 4-3 show that any change away from the best possible qualitative appearance (i.e., clear colour and no odour) will lead to a loss in utility.

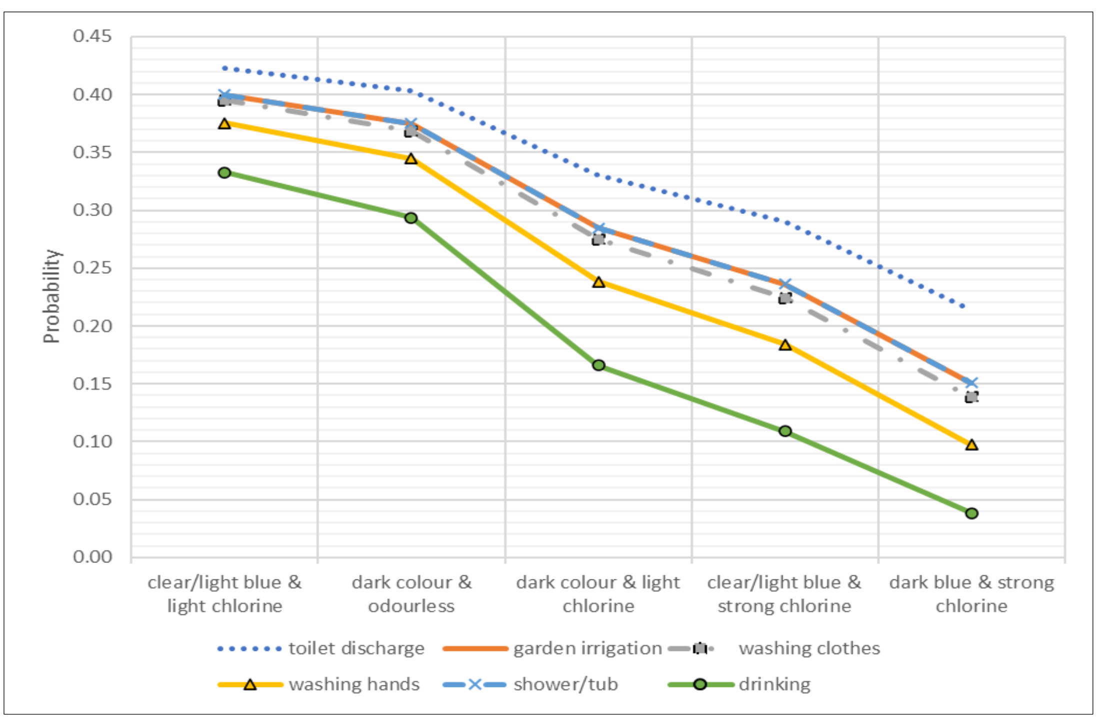


Figure 4-3. Probability of latent attitude compensating for inferior appearance for different treated greywater uses

The underlying attitude varies across the sample population, while its impact on utility varies across the six uses. A positive latent attitude can compensate for the loss of utility resulting from a deterioration of the qualitative appearance. Of course, this is only possible for positive values of the latent attitude, and the share of respondents where the attitude is strong enough decreases as the qualitative appearance becomes worse. There are also differences across uses, and the share is the lowest for *Drinking*; note that this is not because this type of use has the lowest utility across uses, but rather because the role of the latent attitude is the weakest in the utility of greywater reuse in this case (λ_6). The effects are identical for *Garden irrigation* and *Shower/tub*, given the near identical λ for these two uses.

Figure 4-4 looks at a different type of trade-off, namely how increased savings can cancel out the negative impact on utility for GWR for the share of the population with anti-GWR attitudes. As expected, the probability of increased savings cancelling out the negative impact are linked with the amount of the savings. In particular, for the use where the impact of the latent attitude is strongest (i.e., *Toilet flushing*), even the highest incentive would only compensate for 47% of the negative attitude in the population. In the case of *Drinking* this is much higher (79%), given the lower role of the latent attitude in that use ($\lambda_6 = 1.152$, is the smallest of the λ parameters). So, even though drinking is the least attractive use overall, the further decrease in its utility for respondents with the most negative attitudes is smaller than for other uses.

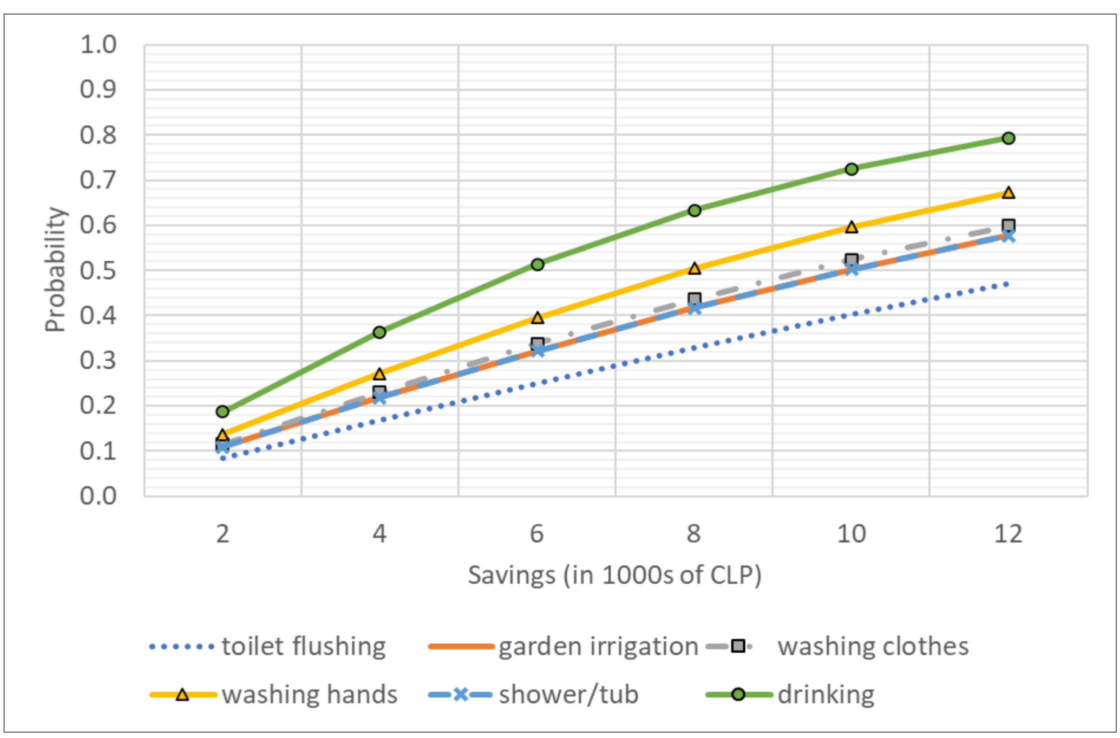


Figure 4-4. Probability of savings compensating for negative attitude

A key interest in studying the role of attitudes is to try and understand how behaviour might change if attitudes change. As discussed by Chorus & Kroesen, (2014), the cross-sectional nature of typical data and the arbitrary scale of the latent attitudes, mean that it is not meaningful to look at the impact of a given percentage change in attitudes. Instead, we focus on studying the best possible outcome of a policy that would uplift the negative (or less strong positive) attitudes in the population, to those of the segment with the most positive attitude. Again, the analysis was carried out considering the best qualitative appearance scenario (i.e., clear and odourless), but for the case of having no financial savings. The outcome of this is shown in Figure 4-5, which shows the binary probabilities of a given type of greywater reuse being preferred to using mains water, for all uses.

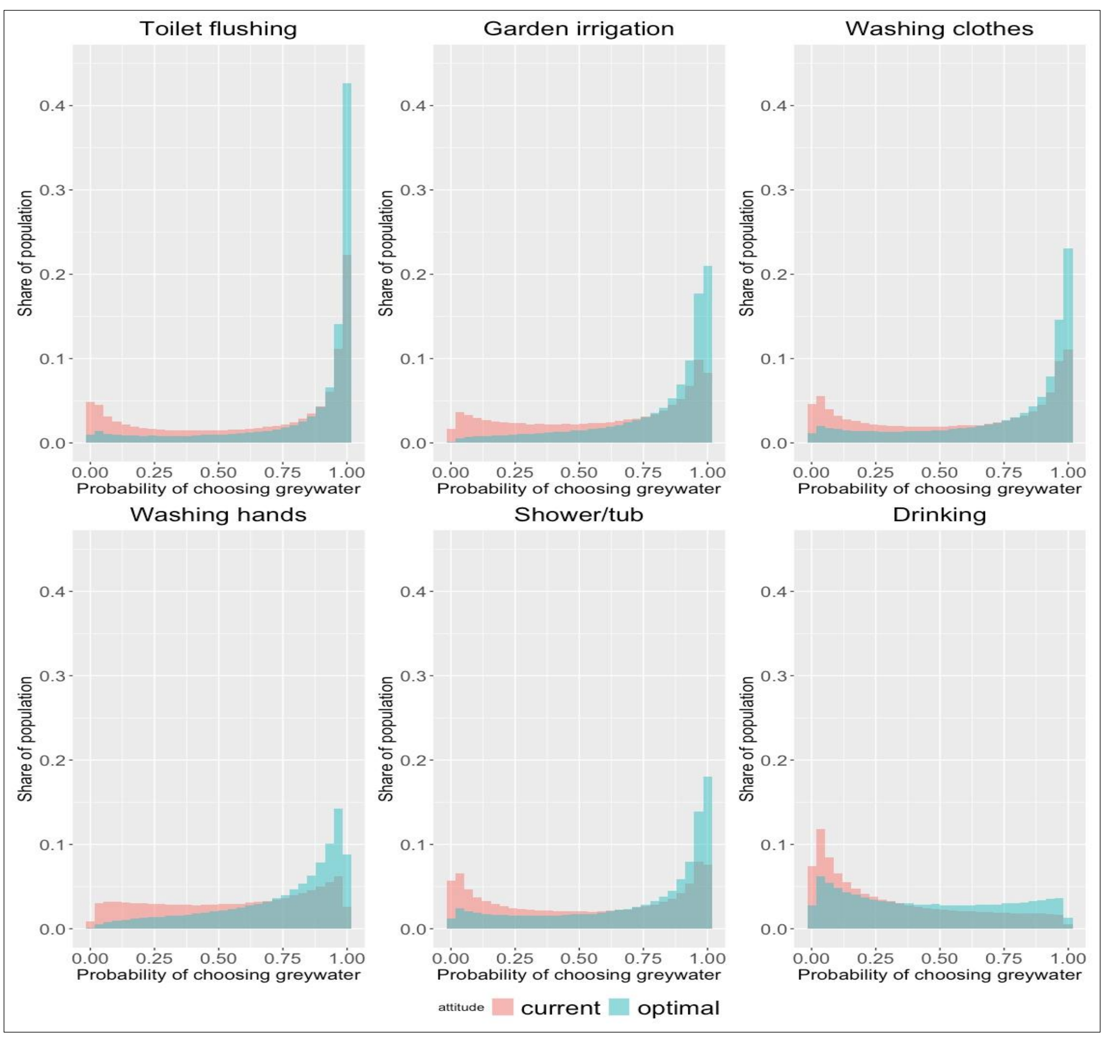


Figure 4-5. Potential change in acceptability of different uses after change in attitudes

Of course, the probabilities vary across individuals as a function of both deterministic and random heterogeneity, some of it linked to the latent attitude. As a result, each panel in Figure 4-5 shows two distributions. The first, labelled as *current*, shows the probabilities for the current attitudes, while the second, labelled as *optimal*, shows the probabilities in a situation where all attitudes are at the level of the most positive individuals in the sample. This represents an upper bound on what can be achieved (on the basis of our results and for our sample), and shows clear shifts in the shape of the distribution (and hence also in the means and median probabilities of accepting greywater reuse).

4.5. Conclusions, limitations and future research directions

There is growing interest in the possibility of treating greywater at the source (i.e. in individual residences) and reducing the demand for mains water in urban areas with water scarcity problems. The success of any policy related with promoting GWR clearly relies on a good understanding of the potential response by households to this new type of service. A growing number of studies are considering econometric models to understand household preferences in this context, and how they may vary across individual households. An emerging body of empirical work has also attempted to link this heterogeneity to underlying attitudes. This chapter follows in the footsteps of such work but makes two important novel contributions. First, it is so far the only application of a HCM to investigate the impact of pro-greywater reuse attitudes in households' preferences for different types of uses. The advantage of this method is that it correctly recognises that attitudes can never be observed by an analyst and that the use of answers to attitudinal questions as error free measures of attitudes (as done in past work) thus leads to endogeneity bias and measurement error. Second, the chapter has demonstrated how a careful specification of a HCM allows an analyst to separate out the different sources of heterogeneity, and thus being able to determine what share of the heterogeneity can be linked to the attitudinal constructs.

The results provide a variety of insights into the drivers of preferences in the context of greywater reuse decisions. These preferences vary as a function of the characteristics of the greywater option (i.e. quality, type of use, and savings), showing for example that uses requiring more direct contact are less popular, and that the appeal of GWR reduces as the qualitative appearances becomes worse. In addition, however, we highlight how preferences vary across individuals for the same product configuration. Although part of this heterogeneity can be linked back to the individuals' characteristics (e.g., gender and age), a remaining part is random heterogeneity. Importantly, parts of both the deterministic and random heterogeneity are linked to the pro-greywater reuse attitude incorporated in the HCM.

The results indicate that the utility of using greywater, for all uses, increases for respondents with a more positive value of the latent attitude. The share of the heterogeneity that can be linked back to the attitude however varies across uses and is by far the lowest for drinking. This could suggest that there are other sources of heterogeneity when it comes to the acceptability of using greywater for drinking; for example, other attitudes - linked more to disgust or safety concerns - than towards water resources in general. For other uses, the share of heterogeneity linked to the attitudes is much higher, reaching over 80% for garden irrigation, and over 50% for all uses except drinking.

A crucial next step would be to use the results from analyses such as those presented here in practice. Currently, the Chilean regulations about water reuse establish that greywater must be treated inside the dwelling (Law 21,075). However, even if the water quality is good enough, the lawful uses are only toilet discharge and garden irrigation, which together only account for a maximum of 36% of the mains water consumption. This study provides evidence that additional types of water uses could contribute substantially to water reuse (recovery of up to 50% of the mains water). Indeed, the results find that in the best scenario examined, the adoption of pro-water reuse attitudes can cause the acceptability of indirect uses to increase by between 16.3% and 18.7%, and between 13.8% and 18.9% for direct uses.

While the work in this chapter is largely technical in its nature, there are clear real world benefits to it. With a decentralised system such as home-based greywater treatment, it is clear that household-level preferences will drive uptake, and our work helps policy makers understand which consumers are more likely to accept the technology, and where incentives may be needed. A key issue is, of course, how to shift attitudes. One possibility is the use of diffusion strategies that can focus, initially, on persuading individuals through messages about the direct (i.e. water saving) and indirect (environmental benefits, water security, autonomy) benefits associated with greywater reuse. Looking at the combined effect of socioeconomic characteristics, direct and through the attitudes, we note that diffusion strategies about reusing greywater could start by targeting women, given that they have the most negative latent attitude. Our results also show that monetary incentives can compensate for the negative impact of attitudes on acceptability, especially when there is also a deterioration of the qualitative appearance.

While the work presented in this chapter relates to one specific application area (i.e. the city of Santiago de Chile), the methods themselves are almost directly transferable to other locations. The results of this work highlight the benefits of the method in terms of exploring sources of heterogeneity and how this can be linked to underlying attitudes. Thus, the work serves as an important blueprint for repeating the application in other cities. Conducting similar surveys in other areas will only require tailoring the attributes to a local context, while the methods themselves can be transferred directly subject to new specification searches for the utility functions. The extent to which the current empirical results are transferable to other cities is unclear without empirical testing. However, the large role played by attitudes in this case study would make it unlikely for such a role to not exist elsewhere.

As with any study, there are limitations to highlight and opportunities for future research to explore. Firstly, this work includes only the perception of uses but does not consider the costs of installing and operating/maintaining the technology. The results thus provide an approximation about individual acceptability and could be useful in explaining the interest in greywater reuse for new properties equipped with the technology or for a situation where there is a subsidised installation in existing properties. Future work needs to incorporate the additional cost elements to obtain insights into their impact on the decision to treat and reuse greywater. Secondly, it should be noted that, with treated greywater reuse not yet being in operation in the study city, this work has relied on hypothetical settings. Stated choice experiments are an established tool for contributing to the planning process which allow us to gain insights into the behaviour of the population regarding a non-existent good or service (Bennett & Blamey, 2001). However, the survey-based presentation of tangibles attributes (e.g. savings in potable water bill) as well as capturing of intangible elements associated with users' perceptions and attitudes could be influenced by survey artefacts. There is thus, as ever, a need for future studies to validate these results using new data, including, when possible, data on real world choices. Third, future studies should investigate the role of more specific attitudinal factors, including feelings of disgust. This requires including additional attitudinal questions. Fourth, it would be beneficial to combine the quantitative work with further qualitative work in future studies, allowing the analysts to fine tune the questions used for probing for underlying attitudes, for example. Finally, for use in actual policy work, the results would need to be reweighted to bring the data in line with the socio-demographic distribution of the target population.

Despite these gaps, this chapter presents a wealth of new results and, more importantly, provides a useful template for future research using Hybrid Choice Models in a recycling context in general, and GWR in particular.

5. CAPTURING AND ANALYSING HETEROGENEITY IN RESIDENTIAL GREYWATER REUSE PREFERENCES USING A LATENT CLASS MODEL

5.1.Introduction

Opportunities for using new alternative sources of water supply for households and the availability of new technology for reusing water are reshaping the way water is managed in cities (Wilcox et al., 2016). In particular, now there exist decentralized hybrid water supply systems that draw only part of the water from the mains network (between 50-70%) while the remainder (50-30%) comes from reused greywater that is locally treated (Lefebvre, 2018; Vuppaladadiyam et al., 2019). The source is greywater from the same household, that is, water that is free of faeces, food residues, oil and fats, collected from washing machines, showers, tubs, and washbasins (Lambert & Lee, 2018).

Experience in urban settings such as the Persian Gulf region and the broader Middle East (Lambert & Lee, 2018), and Sydney (Pham et al., 2011), indicates that individuals prefer to allocate reclaimed water for two non-potable purposes, namely toilet flushing and garden irrigation. Both uses are very attractive due to a higher perceived safety (i.e. no direct contact with the skin) and lower treatment costs, as high-quality standards are not needed, and also because they are two of the uses that consume the largest water volumes in the household (Roshan & Kumar, 2020). However, at certain times of the year (e.g. winter or rainy months), garden irrigation is not a daily practice, or depending on rainfall, may not be required[7]. As a result, at those times, the amount of greywater available would be higher than what consumers can use for other residential uses Dolnicar & Schäfer, 2009). Discharging the extra greywater to the conventional sewage system would be an economic loss for users who pay for the maintenance and operation of the treatment technology (Lambert & Lee, 2018). Thus, if allowed by law, allocating treated greywater

---

[7] https://www.organicgardener.com.au/blogs/watering-winter

for other uses could be beneficial since a higher volume of the greywater that was treated can be used.

The perceptions that consumers hold about greywater reuse are fundamental for the success of a decentralized hybrid water supply system, since they are the primary agents that interact with the greywater, as well as operate and take care of the technology (Domnech & Saurí, 2010). To ensure that laws, regulations, and policies contribute to making these systems more attractive and to remain successful over time, an understanding of the key determinants of consumer preferences is essential (Mukherjee & Jensen, 2020). Several studies on water reuse have empirically demonstrated that there is heterogeneity in preferences and that this is mainly linked to socio-demographic characteristics, and other psychological constructs (Oteng-Peprah et al., 2020). The starting point of our work is that even within the same sociodemographic group, differences in preferences may exist, in terms of which (if any) uses of greywater are desirable, and what the role of the appearance of the water is (Chapter 4). We postulate that classes or groups of individuals can be established to capture this heterogeneity, and that consumer characteristics can be used to at least partially explain which group an individual is more likely to belong to (Hess, 2014). In particular, our study focuses on exploring different population segments, each with its own behaviour (choice regarding preferences) in the allocation of treated greywater for six domiciliary uses that vary according to the level of skin contact, based on our earlier survey work in chapter 2.

Our modelling context is based on hypothetical scenarios that replicate real experiences of water reuse in dwellings in Spain (Domnech & Saurí, 2010) and South Africa (Ilemobade et al., 2013). This method uses SC experiments to explore the preferences of respondents for the qualitative and quantitative characteristics of mutually exclusive alternatives (Louviere et al., 2000). Due to the nature of the data and our study objectives, we analyse the choices in the hypothetical scenarios using latent class discrete choice models allowing for heterogeneity in preferences across consumers. These types of data and models are becoming more common in studies of technological innovations (Su et al., 2018; Franceschinis et al., 2017), mainly because they can produce insights on preferences in the absence of an existing market (Ortúzar & Willumsen, 2011, sec. 8.6.3.2). They also offer a way of knowing about how feasible and successful a project can be and understanding which characteristics should be improved to achieve higher acceptability before it goes on the market, or prior to regulations being established.

Discrete choice models of the type used here explain choices under the assumption that consumers maximize the "utility" or benefit they receive by choosing a particular alternative. This utility is based on the characteristics or attributes that define the alternative (Ortúzar & Willumsen, 2011, sec. 7.1), and the sensitivities of the user towards them. In the particular context of our study, the characteristics defining treated greywater in the hybrid water system are: (i) it's different levels of colour and odour, (ii) possible uses (e.g. toilet flushing) and (iii) the resulting savings in mains water. Our work seeks to uncover different classes of respondents, with different sensitivities to the attributes, and to understand why individuals belong to each class. We leave aside traditional economic theory (which would consider a full cost-benefit approach), since, although the cost of technology is known to be highly influential, the inclusion of cost would have dominated the scenarios and precluded our focus on understanding other subjective elements that may influence individuals' acceptability of treated greywater, and the heterogeneity in this across people.

The study context is Santiago, the capital city and largest conurbation in Chile (INE, 2017), a place with seasonal water availability problems, and where its population has no previous experience about greywater reuse (even the concept itself is largely unknown). Although mandatory water quality standards are not established, the permitted uses for greywater are known to be garden irrigation and toilet flushing (as prescribed in the law 21,075[8]). With this research we aim to provide evidence, with statistical support, to show that regulations could allow other greywater uses considering the preferences in different population segments. We also provide statistical evidence suggesting that it is possible to preserve the balance between recovered water volumes and the amount of water used,

[8] https://www.bcn.cl/leychile/navegar?idNorma=1115066

while ensuring that the system's operation provides the greatest benefits without compromising individuals' health. Along with presenting empirical results for the specific case of Santiago de Chile, the chapter provides a demonstration of the method that can be replicated in other countries that need an empirical approach to acquire knowledge about people's preferences in greywater reuse allocation, before including greywater reuse schemes in their water and sanitation regulation.

5.2. Overall model structure

We formulated and estimated a latent-class (LC) choice model to identify different segments in the population, each with its own preferences for reusing treated greywater in different uses inside the house. A LC model probabilistically segments the sample population into a number of segments with different behaviour/preferences. In our application, each class was based on random utility theory, which postulates that individuals form a utility for each alternative, based on their perceptions about what characteristics describing a good or service are desirable or undesirable. Decision makers then choose the option that provides them with the highest utility. As the process of utility formation is not observed by the analyst, the models incorporate a random component and the choices become probabilistic (Train, 2009). In our LC model, the different classes are characterised by different sensitivities to the characteristics of the greywater system (Greene & Hensher, 2003). We now describe the two main components of the analysis, namely the model specification and estimation, and the post-estimation processing of the estimates.

5.2.1. Model specification and estimation

The LC model uses a probabilistic class allocation model, where respondent *n* belongs to class k (out of a total of K classes) with probability $\pi_{n,k}$, where $0 \leq \pi_{n,k} \leq 1 \; \forall k$ and $\sum_{k=1}^{K} \pi_{n,k} = 1 \, , \forall k$. LC models are generally specified with an underlying multinomial logit (MNL) model inside each class, but can easily be adapted for more general underlying structures (Hess, 2014). Let $P_n(j_{n,t} \mid \beta_k)$ give the probability of respondent *n* choosing alternative *j* in task *t*, conditional on respondent *n* falling into class *k*, where the model in this class uses the vector of parameters β_k.

We observe a sequence of T_n choices for person *n*, say j_n^*, where alternative $j_{n,t}^*$ is chosen in choice situation *t*. With an underlying MNL model, we have that:

$$P_n\ (j_{n,t}^* \mid \beta_K) = \frac{e^{V_{j_{n,t}^*}}}{\sum_{j=1}^{J} e^{V_{j_{n,t}}}} \tag{5.1}$$

where $V_{j_{n,t}}$ is the deterministic component of utility (i.e. the fraction of utility associated with attributes that the analyst can measure or observe) for person *n*, alternative *j*, in choice situation *t*, given by:

$$V_{j_{n,t}} = f(x_{j_{n,t}}, z_n, \beta_k) \tag{5.2}$$

where $x_{j_{n,t}}$ are characteristics of alternative *j* in choice situation *t*, z_n are characteristics of individual *n*, and β_k are parameters to be estimated. The functional form $f(x)$ is typically linear in attributes.

Equations (5.1) and (5.2) are conditional on respondent *n* falling into class *k*, but this is not observed by the analyst. The unconditional (on *k*) choice probability for this sequence of choices for respondent *n*, $L_n\ (j_n^* \mid \Omega)$, is then given by:

$$L_n\ (j_n^* \mid \Omega)\ =\ \sum_{k=1}^{K} \pi_{n,K} \left(\prod_{t=1}^{T_n} P_n\ (j_{n,t} \mid \beta_K) \right) \tag{5.3}$$

that is, the weighted sum across the *K* classes of the probabilities of the sequence of choices, with the class allocation probabilities being used as weights. The vector Ω groups together all parameters used in the model.

As seen in Equation (5.3), the LC model uses a weighted summation of class-specific choice probabilities. In the most basic version of an LC model, the class allocation probabilities are constant across respondents, such that $\pi_{n,k} = \pi_k, \forall n$. However, the real flexibility arises when the class allocation probabilities are not constant across respondents and a class allocation model is used to link these probabilities to characteristics of the respondents. Typically, these characteristics take the form of socio-demographic variables, such as income, age and employment status. With z_n representing the vector of characteristics for respondent *n*, and with the class allocation model taking a MNL form, the probability of respondent *n* falling into class *k* is given by:

$$\pi_{n,k} = \frac{\left(e^{\delta_k + g(\gamma_k, z_n)}\right)}{\sum_{l=1}^{K} e^{\delta l + g(\gamma l, z_n)}} \tag{5.4}$$

where δ_k is a class-specific constant, γ_k is a vector of parameters to be estimated, and g (·) corresponds to the functional form of the utility function in the class allocation model.

Here, a major difference arises between class allocation models and choice models. In a choice model, the attributes vary across alternatives while the estimated coefficients (with a few exceptions) stay constant across alternatives. In a class allocation model, the attributes normally stay constant across classes while the parameters vary across classes, and are set to zero for one class for normalisation. This allows the model to allocate respondents to different classes depending on their socio-demographic characteristics. For example, a situation where high-income and low-income respondents are allocated to two classes could be represented with a positive income coefficient for the first class (with the coefficient normalised to zero for the second class). In a LC model, taste heterogeneity is accommodated as a mixture between a deterministic and a random approach.

A probabilistic model is used to allocate respondents to the different classes that characterise different tastes in the sample. However, the class allocation in Equation (5.4) is not purely random, but a function of socio-demographic characteristics of the respondents. In addition, it is also possible to incorporate heterogeneity in preferences directly in the utility functions in Equation (5.3), for individual classes, rather than in the class allocation model. In some cases, such as for example an income effect on cost sensitivity, it also makes sense to keep these effects the same across classes.

The LC model was estimated using Apollo v 0.1.1 (S. Hess & Palma, 2019). The estimation of a discrete choice model involves the maximisation of the likelihood of the observed choices, where we typically work with the log-likelihood function, given by:

$$LL(j_n^* \mid \Omega) = \sum_{n=1}^{N} \log \left(L_n \left(j_n^* \mid \Omega\right)\right) \qquad (5.5)$$

where N is the number of individuals, $L_n\ (j_n^* \mid \Omega)$ is given by Equation (5.1), which itself uses Equations (5.2) and (5.4). The log-likelihood function for a LC model is notoriously difficult to maximise, with a risk of convergence to poor local optima. We address this issue by moving away from gradient based approaches and using an expectation-maximisation process (Train, 2009, Chapter 14).

5.2.2. Posterior analysis

The estimation of a LC model provides parameters for the choice model used inside each class, in this case always a MNL model. In addition, we obtain estimates for the parameters used in the class allocation models. The utility parameters provide insights into the preferences and sensitivities within each class, while the class allocation parameters explain the allocation of individuals to different classes. The differences in parameters across classes give insights into the sample level patterns of heterogeneity. Each individual belongs to each class up to a probability, where this probability varies across individuals as a function of their characteristics. For example, in a model that retrieves two classes characterised by differences in the sensitivity to cost, the class allocation model will likely show that higher income individuals have a higher probability of belonging to the class with lower cost sensitivity. However, this treats two individuals who are identical on the socio-demographics used in Equation (5.4) as also having identical sensitivities, contrary to the notion of random heterogeneity. In addition, it does not provide information about how preferences may vary as a function of socio-demographic (or other) characteristics that were not included in Equation (5.4).

Further insights can be obtained, post estimation, in a Bayesian manner by calculating information relating to a given individual's sensitivities on the basis of the sample level model estimates and her observed choices. Let us return to the example with the classes used above. Two individuals with the same income may still make different choices in our data. Bayesian analysis then allows us to further disaggregate the class allocation of these individuals. If one of the two chooses more expensive options than the other on average, her likelihood of falling into the low cost sensitivity class is higher. On the other hand, if we have two individuals with different income but the same choice patterns, then the person with lower income will still have a lower probability of falling into the low cost sensitivity class. This is an illustrative example, just to explain the concept, which is now formalised using Bayesian analysis as follows.

The first step is to calculate posterior class allocation probabilities, where the posterior probability of individual *n* for class *k* is given by:

$$\widehat{\pi_{n,k}} = \frac{\pi_{n,k} L_{n,k}\ (j_n^* \mid \Omega_\mathrm{k})}{L_n\ (j_n^* \mid \Omega)} \tag{5.6}$$

where $\pi_{n,k}$ and $L_n\ (j_n^* \mid \Omega)$ are given by Equations (5.4) and (5.3), respectively, and where $L_{n,k}\ (j_n^* \mid \Omega_\mathrm{k})$ is the likelihood of the observed choices for individual *n*, conditional on class *k*, that is, the term inside the sum across classes in Equation (5.3).

We then use the output of Equation (6) to produce a membership profile for each class. From the parameters in the class allocation probabilities, we know which class is more or less likely to capture individuals who possess a specific characteristic. Crucially, this can be done for characteristics not included in the model specification during estimation. Let us use the example of a given socio-demographic characteristic z_c. We can then calculate the likely value for z_c for an individual in class *k* as:

$$\widehat{z_{c,k}} = \frac{\sum_{n=1}^{N} \widehat{\pi_{n,k}} z_{c,n}}{\sum_{n=1}^{N} \widehat{\pi_{n,k}}} \tag{5.7}$$

where $z_{c,n}$ is the value for this characteristics for individual *n*. Thus, Equation (5.7) considers the weighted average of the value for characteristic z_c for all individuals in class *k*, using the posterior class allocations from Equation (5.6) as weights. Alternatively, we can also calculate the posterior probability of an individual in class *k* having a given value κ for z_c by using:

$$P\left(\widehat{z_{c,k}} = \kappa\right) = \frac{\sum_{n=1}^{N} \widehat{\pi_{n,k}}\left(z_{c,n} == \kappa\right)}{\sum_{n=1}^{N} \widehat{\pi_{n,k}}}, \tag{5.8}$$

where $\left(z_{c,n} == \kappa\right)$ will be equal to 1 if and only if $z_{c,n}$ equals k.

The calculation of these posterior values for characteristics in each class opens up the possibility of graphical analysis, using three dimensions, as we will demonstrate in Section 4.2.2. In particular, this allows us to study the relationship between the posterior class allocation probabilities (Z dimension) and two different socio-demographics (X and Y) at the same time. In the graphical analysis, the inverse distance weighting method (IDW) was implemented to interpolate the estimates of Z within the data range, which implies that the assigned weights will be bigger at the points closest to the prediction location and that these will decrease as a function of distance. The reason for this is that the IDW method assumes that closer points are more similar than those that are further away. To have a common reference system, the data used for the X and Y axes were standardized.

5.2.3. Initial model specification considerations

A number of decisions are needed prior to specify the models. These decisions relate to the levels used as reference for categorical variables, the inclusion of socio-demographic characteristics in the model, the existence of any generic parameters across classes, and the number of classes to use.

The survey used three alternatives, two of which were greywater reuse (GWR) options, and the third implied using mains water. We specified mains water as reference and, thus, a parameter for each of the six types of greywater reuses could be estimated. In addition, we estimated a constant for the left-most alternative, to capture any left-to-right (reading) bias in the data. The other categorical variables were related to odour and colour; here we again used dummy coded coefficients, with the best level (i.e. clear for colour, and odourless for odour) being the reference and fixing its parameter to zero for identification.

In LC models, the socio-demographic parameters are typically used only in the class allocation model, (i.e. to explain which types of individuals are more or less likely to fall into given classes). For extra flexibility, we additionally incorporated some socio-demographic variables directly in the utility functions. These variables related to differences in the preferences for different GWR uses as a function of gender and past knowledge, and in the sensitivity to water bill savings as a function of the current level of water expenditure in the household. These socio-demographics were kept generic (i.e., with the same parameter) across classes. In addition, the sensitivity to the water bill savings was kept constant across classes, as earlier results showed that segmenting by level of expenditure was sufficient to capture the heterogeneity in cost sensitivity.

Within individual classes, we also tested for the significance of differences between parameters, and imposed some constraints where appropriate; for example, if the preferences for two or more uses were found not significantly different from each other. These constraints are highlighted in the presentation of the results. Similarly, some parameters were excluded from specific classes if the associated attributes did not have a significant impact on utility in those classes (marked in the tables as n.s., for non-significant to distinguish from those parameters fixed to zero as reference). Finally, socio-demographic characteristics were also incorporated in the MNL class allocation model. For identification purposes, we set class 1 as reference and estimated an offset (δ_k in Equation (4)), as well as socio-demographic effects (γ_k), for the other classes.

A key decision in specifying a LC model relates to the number of classes to use. We evaluated different models to define the optimal number of classes (Table 5-1). The log-likelihood (LL) improves with additional classes, but at the cost of additional parameters. In line with best practice for LC models, we compared models on the basis of the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). While the former favoured a 5-class model, the latter narrowly favoured a 3-classs model. The 4-class model provided a good balance between the two, with additional behavioural insights over the 3-class model. Some further parameter constraints (i.e. removing insignificant parameters) in this model led to our final specification.

Table 5-1. Determining the number of classes

Number of classes	LL	Nº of parameters	AIC	BIC
1	-3,129.02	18	6,294.04	6,370.25
2	-2,398.48	31	4,858.96	4,990.23
3	-2,319.93	45	4,729.85	4,920.40
4	-2,282.31	58	4,680.63	4,926.22
5	-2,262.79	69	4,663.58	4,955.75
4 (with additional Constraints)	-2,304.57	34	4,677.15	4,882.04

5.3.Results and discussion for final model

When working with LC models, an analyst needs to make a decision between an "exploratory" LC model and a "confirmatory" LC model (cf. Hess, 2014). While "confirmatory" LC is useful for testing for the presence of specific behavioural traits, "exploratory" LC lets the data "speak", that is, the preferences in the classes as well as their composition are revealed by the data, rather than pre-imposed by the analyst. We use such an "exploratory" LC model, where the four classes can then be interpreted by studying the estimated sensitivities to different characteristics, including the type of use and the appearance of the treated greywater.

The results in Table 5-2 show the parameter estimates (which give the impact on utility by a given attribute) alongside the robust t-ratios (given by dividing estimates by their robust standard errors, with for example 1.96 implying a 95% significance level for rejecting the null hypothesis that the parameter is not different from 0 in a two-sided test). The parameters show the impact of the attribute on utility, with a negative sign implying a reduction in utility (i.e. an undesirable attribute), and the opposite applying for a positive estimate.

Table 5-2. Estimation results for latent class model

	Class 1		Class 2		Class 3		Class 4	
	Estimate	**Robust t- ratio**	**Estimate**	**Robust t-ratio**	**Estimate**	**Robust t-ratio**	**Estimate**	**Robust t-ratio**
(1) ALTERNATIVE SPECIFIC CONSTANT								
***Left alternative*†**	-0.367	-6.39	-0.367	-6.39	-0.367	-6.39	-0.367	-6.39
(2) GREY WATER APPEARANCE								
Colour								
… Clear (reference)	0	*reference*	0	*reference*	0	*reference*	0	*reference*
… Light blue	0	n.s.	0	n.s.	0	n.s.	-1.301‡	-2.05
… Dark blue	-0.313	-3.13	0	n.s.	-0.619	-5.09	-1.301‡	-2.05
Odour								
… Odourless (reference)	0	*reference*	0	*reference*	0	*reference*	0	*reference*
… Light chlorine	-0.169	-1.45	0	n.s.	-0.472	-3.53	0	n.s.
… Strong chlorine	-0.816	-6.48	-11.057	-21.08	-1.032	-6.4	0	n.s.
(3) USES								
0. Mains water (reference)	0	*reference*	0	*reference*	0	*reference*	0	*reference*
1. Toilet flushing	3.963‡	6.74	-4.959‡	-9.79	0.303‡	2.14	5.957‡	2.1
… shift for female†	0.728	4.26	0.728	4.26	0.728	4.26	0.728	4.26
… shift for previous knowledge†	0.375	1.35	0.375	1.35	0.375	1.35	0.375	1.35
2. Garden irrigation	3.963‡	6.74	-4.959‡	-9.79	0.303‡	2.14	5.957‡	2.1
3. Clothes washing	3.963‡	6.74	-4.959‡	-9.79	0.303‡	2.14	0	n.s.
… shift for female†	0.257	1.75	0.257	1.75	0.257	1.75	0.257	1.75
… shift for previous knowledge†	0.448	2.22	0.448	2.22	0.448	2.22	0.448	2.22
4. Hands washing	3.71‡	5.98	-4.959‡	-9.79	0	n.s.	0	n.s.
… shift for female†	0.289	2.05	0.289	2.05	0.289	2.05	0.289	2.05
5. Shower/Tub	3.71‡	5.98	-15.29‡	-18.02	0	n.s.	0	n.s.
6. Drinking	2.397	3.88	-15.29‡	-18.02	-0.82	-3.33	0	n.s.
… shift for female†	0.448	2.15	0.448	2.15	0.448	2.15	0.448	2.15
(4) SAVINGS ON WATER BILL								
Low water expenditure group†	0.089	4.26	0.089	4.26	0.089	4.26	0.089	4.26
High water expenditure group†	0.039	3.39	0.039	3.39	0.039	3.39	0.039	3.39

	Class 1		Class 2		Class 3		Class 4	
	Estimate	**Robust t-ratio**	**Estimate**	**Robust t-ratio**	**Estimate**	**Robust t-ratio**	**Estimate**	**Robust t-ratio**
CLASS ALLOCATION MODEL								
Constant	0	*reference*	-1.574	-3.7	-0.595	-2.41	-8.091	-5.52
Low educational level	0	*reference*	0.723	2.75	0.471	1.79	-1.046	-1.95
Garden	0	*reference*	-0.824	-2.49	0	n.s.	6.771	4.34
House	0	*reference*	1.402	2.98	0	n.s.	0	n.s.
Class weight	40%		24%		30%		6%	

†: parameter shared across classes

‡: parameter shared across multiple uses or multiple levels of categorical attribute

n.s.: parameter constrained to zero after initial estimate was not significantly different from zero

5.3.1. Generic parameters

Parameters indicated with the symbol † in Table 5-2 are generic across classes. They fall into three categories. First, there is an alternative specific constant (ASC) for the left-most alternative, which captures the difference in baseline utility between the two greywater reuse options. The negative value shows that, all else being equal, respondents will choose the middle option (i.e. the second GWR alternative) more often than the first. There is no apparent reason for this, as the survey design was balanced. Second, there are a number of generic socio-demographic effects. These relate to differences in sensitivities between men and women, and between those with and without prior knowledge. Women, for example, have an additional increase in utility compared to men, if water reuse is for flushing toilets (0.728), laundry (0.257), handwashing (0.289) and drinking (0.448). Previous knowledge only results in an additional increase in utility if water reuse is for toilet flushing (0.375) and clothes washing (0.448). Note that the impact of gender on the utility of reusing greywater for toilet flushing is much larger than that of having prior knowledge, while the opposite is true for laundry.

The third and final generic set of parameters relate to the savings in the water bill. This is subject to household water consumption, so the model contains two estimates, one for the low consumption group and another for the high consumption group. Each time, the coefficient multiplies the actual saving expressed in 1000s of Chilean pesos (CLP). The results show that the impact per 1000 CLP in savings for the low water consumption group are more influential (0.089) than for the high water consumption group (0.039). The influence exerted by the savings attribute is positive, which is an indication that this attribute is key to achieving higher acceptability of reusing water for different uses.

5.3.2. Class specific parameters

We now look at those parameters which vary across the four classes, as well as giving a behavioural interpretation to each class.

Class 1 – Enthusiasts: this class corresponds to individuals who have a positive perception of reusing treated greywater for the six uses considered. Table 5-2 shows that toilet flushing, garden irrigation and laundry are perceived the same in terms of benefits and are also the uses with greater utility. Reusing greywater for washing hands or shower/tub has the same utility in this group, slightly lower than the previous three uses, but still with a substantially higher utility than reusing treated water for drinking. Regarding the impact of appearance on utility, increased colour (though not if only increasing to light blue) and odour levels negatively influence acceptability, especially if the treated water has high levels of odour (-0.816). In this class, the influence of appearance (colour and odour) on utility is small compared to its influence in the other classes. Furthermore, for this group, the positive impact of using treated greywater on utility is much higher than the negative utility resulting from changes in the appearance that the use of treated greywater would produce.

Class 2 – **Greywater sceptics**: this class corresponds to individuals who have a negative perception of greywater reuse, especially those uses that require more direct skin-to-water contact (shower/tub and drinking). The size of the estimates shows that, in this class, the difference in utility between mains water and greywater is much larger than in other classes, with a substantial loss of utility for greywater options. This loss is further amplified if the water has a strong chlorine smell, while colour is not a characteristic that influences the utility in this class.

Class 3 – **Appearance conscious:** this class corresponds to individuals who perceive positively greywater reuse for toilet flushing, garden irrigation and laundry if the treated greywater is odourless and clear/transparent. In this class, individuals are more sensitive to changes in the appearance of treated water than to the uses themselves (comparing the weights of the appearance attributes with the weights for uses). The three uses with a positive utility (compared to mains water) are those that require less skin contact.

Class 4 – Water expenditure conscious: this class corresponds to individuals who have an increase in utility when treated greywater is available for toilet flushing and garden irrigation. We label these as expenditure conscious, as the preferred uses for these consumers are those with highest water consumption (toilet flushing between 10 and 20 litres per flush, while a 100 m^2 garden area can use up to 1000 litres, SISS, 2019). Additionally, in this class, changes in the colour level of water are highly influential compared to individuals from other classes. However, the utility of using treated greywater for toilet flushing and garden irrigation is much higher than the loss of utility associated with changes of appearance.

5.3.3. Class allocation model

The final part of the model estimates relates to the class allocation model (see Table 5-2). This component explains which respondents are more likely to fall into specific classes. At the sample level, the probability of belonging to Class 1 is 40%, of belonging to Class 2 is 24%, 30% for Class 3 and only 6% for Class 4. These sample level class allocation probabilities are driven in large parts by the offset (δ_k in Equation (4)) included in the class allocation model, where with Class 1 taken as reference, negative constants for the remaining classes are observed. These constants relate to an individual in the base socio-demographic group (mid or high education, without a garden and living in a flat), where the probability of belonging to Class 1 is the highest (and the lowest for Class 4). However, these probabilities vary as a function of respondent characteristics. Note that having a lower level of education increases the likelihood of belonging to the sceptic class (Class 2) or the class concerned about greywater appearance (Class 3). Having a garden reduces the likelihood of falling into the sceptic class (Class 2) and substantially increases the likelihood of falling into Class 4, which assigns high utility for using greywater for garden irrigation (with Equation (4) implying a change in probability for class 4 from near zero to 14%). Thus, this finding is entirely in line with expectations. Finally, those living in a house as opposed to a flat, have an increased likelihood of falling into Class 2.

5.4. Results and discussion for posterior – analysis

The discussion in Section 5.3.3 focussed on the sample level class allocation probabilities. This process only requires the class allocation model, and thus implies that the class assignment probabilities are identical for individuals with the same characteristics. We now go a step further, making use of the approach in Section 5.2.2 to determine posterior class allocation, using the estimates of the sample level model and the observed choices of each individual. Unlike the direct results from the class allocation model, this posterior analysis makes use of respondent characteristics that were not included in the class allocation model.

5.4.1. Posterior values of socioeconomic characteristics across classes

In Table 5-3 we compare the posterior share (cf. Section 5.2.2) of given sociodemographic characteristics across classes. For each characteristic, the crucial comparison is against the sample average, showing whether individuals with given characteristics are more likely to fall into specific classes. There is also some insight to be gained by comparing the posterior across characteristics (e.g. male vs. female), but care needs to be taken if there are differences in the sample level representation.

Table 5-3. Socio-demographic characterization into the classes

Socio-economic characteristic	Class 1	Class 2	Class 3	Class 4	Sample average
Gender					
… Male	0.37	0.32	0.34	0.34	0.35
… Female	0.63	0.68	0.66	0.66	0.65
Age					
… Under 30 years old	0.16	0.09	0.06	0.10	0.11
… Between 30 and 60 years old	0.57	0.55	0.62	0.65	0.58
… Over 60 years old	0.28	0.36	0.32	0.25	0.31
Education level					
… Elementary school	0.18	0.22	0.10	0.10	0.16
… High school	0.37	0.48	0.54	0.24	0.44
… Technical education	0.17	0.13	0.14	0.21	0.15
… University studies	0.23	0.11	0.14	0.42	0.18
Main occupation					
… Stay at home	0.24	0.31	0.26	0.25	0.26
… Retired	0.15	0.19	0.15	0.12	0.16
… Part-time	0.05	0.04	0.06	0.12	0.05
… Full-time	0.48	0.41	0.50	0.40	0.47
Income					
… Under 600 USD	0.42	0.47	0.42	0.40	0.43
… Between 600 – 1,820 USD	0.48	0.44	0.49	0.40	0.47
… Over 1,820 USD	0.10	0.09	0.09	0.21	0.10
Previous knowledge about water reuse					
… None	0.65	0.79	0.68	0.48	0.68
… Medium	0.11	0.06	0.12	0.17	0.10
… High	0.25	0.15	0.20	0.35	0.21

Gender. Women have a larger overall representation in our sample. We see only small differences in the posterior allocation to the different classes. The highest female concentration is in Class 2 and the highest male concentration is in Class 1. This indicates a more negative view of GWR by women than by men, which is in agreement with results obtained in other studies (Wester et al., 2015), which have been linked to the higher susceptibility of women to associate reuse with high levels of risks (Mankad & Tapsuwan, 2011). However, it is important to highlight that other studies have also found the opposite effect or no relation between gender and water reuse acceptability (Garcia-Cuerva et al., 2016; Mason et al., 2018).

Age. Individuals between 30 and 60 years old are predominant in the sample. Our posterior analysis shows that individuals under the age of 30 have a higher representation in the enthusiasts class (Class 1) and a much reduced share in the class caring about appearance (Class 3). People between 30 and 60 years old have a higher representation in classes 3 and 4, where reusing water is desirable if greywater has a similar appearance to the mains water, or if more indirect uses are considered (i.e. toilet flushing and garden irrigation). Individuals over the age of 60 have a higher representation in Class 2, where reusing greywater for any option is undesirable, and a reduced share especially in Class 4.

Education level. Our sample had a majority of individuals with high school, followed by individuals with university studies, technical education, and elementary school. Our results show that people with higher educational levels are more likely to belong to classes that have a positive perception of reusing water for two or more uses (classes 1, 3 and 4). People with elementary school only are most likely to belong to Class 2 (water reuse sceptics), people with high school education have a greater frequency in Class 3 (appearance matters), and people with technical or university education have a greater frequency in Class 4 (greywater for indirect uses) and Class 1 (water reuse enthusiasts). In general, our results are consistent with outcomes revealed Gu et al. (2015) who suggest that people with higher educational levels are more willing to reuse greywater. However, our results also show detailed information indicating that according to the educational group of the individual, the appearance and the uses could have a greater or reduced level of importance.

Main occupation. The sample was composed mainly of individuals working full-time, followed by people that stay at home, old age pensioners and, finally, individuals with a part-time job. Our results indicate that individuals who are at home or retired have a higher concentration in Class 2, i.e. those who would dislike reusing water, people with a part-time job have a greater presence in Class 4, while this class is the least likely one for people with a full-time job.

Income: Households with the lowest monthly income (under 600 USD) have a higher frequency in Class 2 (greywater reuse sceptics) than in any other class. Households with an intermediate monthly income (between 600 USD and 1,820 USD) have their highest frequency in classes 1 (enthusiasts) and 3 (appearance conscious). Finally, households with highest income (over 1820 USD) are more prevalent in Class 4 (water expenditure conscious), and this is likely correlated with having gardens and larger properties.

Previous knowledge about water reuse. Most individuals in our sample had no previous knowledge about water reuse, as expected in a country only starting to allow residential greywater reuse. As anticipated, individuals without previous knowledge about water reuse have the highest presence in Class 2 (greywater sceptics). In contrast, people with high knowledge have a notable greater presence in Class 4 (most indirect uses) and Class 1 (enthusiasts); this has also been reported before (Garcia-Cuerva et al., 2016; Dolnicar et al., 2011). Likewise, individuals with medium knowledge have a similar incidence in the classes with a positive perception of reusing water for two or more uses (classes 1, 3, 4).

5.4.2. Posterior values of household characteristics across classes

We extended the analysis to such variables, focusing on household composition, and two key dwelling influences on water consumption, namely the number of bathrooms and the presence of gardens. The results of this analysis are summarised in Table 5-4, using the same approach as in Section 5.4.1.

Table 5-4. Household characterization into the classes

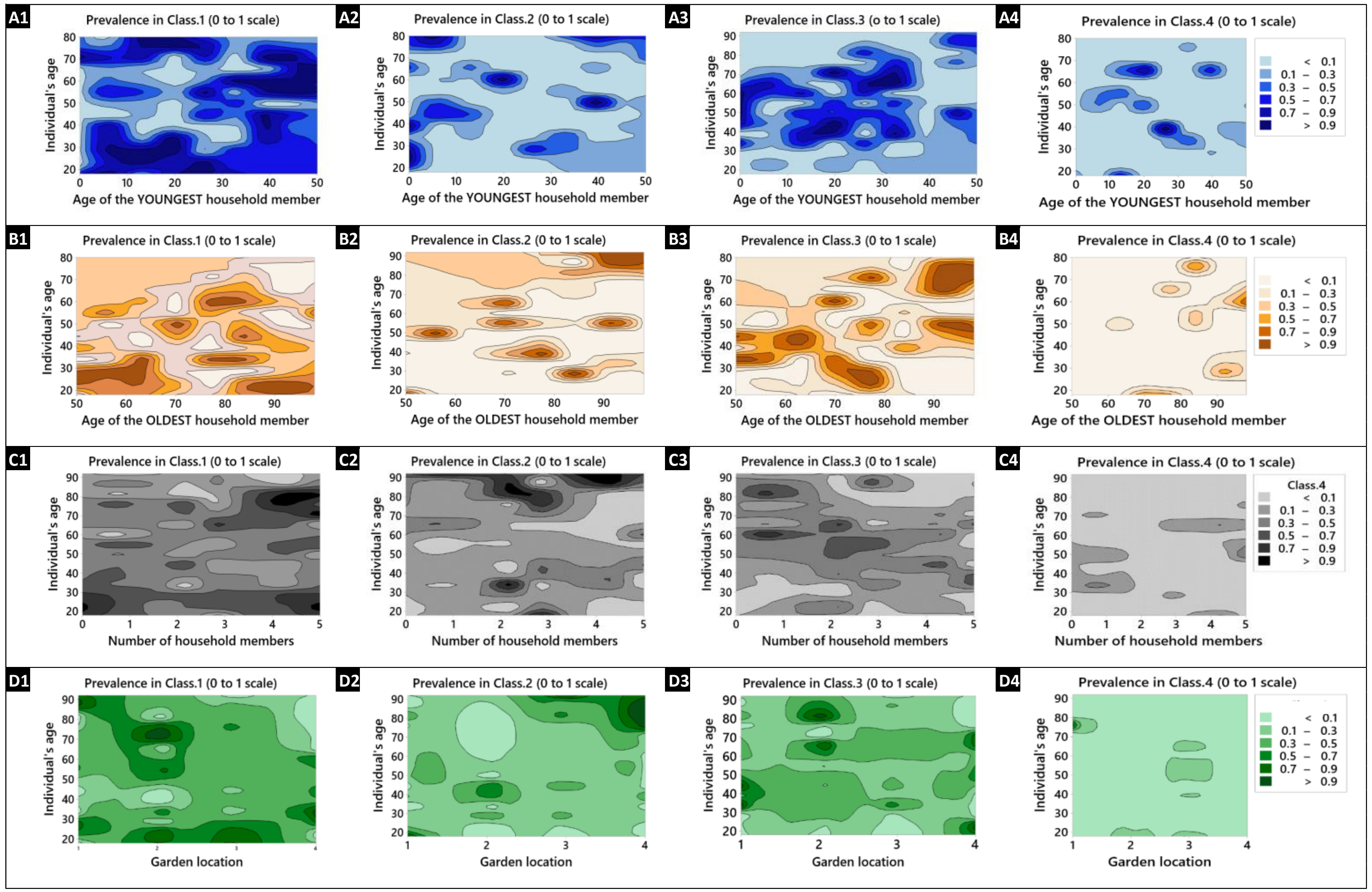
Socio-economic characteristic	Class 1	Class 2	Class 3	Class 4	Sample average
Presence of sensitive population					
… Homes with kids under 15	0.41	0.43	0.41	0.39	0.41
… Homes with adults over 74 years old	0.17	0.22	0.14	0.18	0.17
Number of people living in the same place					
… 1 to 2	0.28	0.29	0.35	0.24	0.30
… 3 to 5	0.61	0.60	0.53	0.64	0.59
… Over 5	0.11	0.11	0.12	0.12	0.11
Number of bathrooms					
… 1 to 2	0.65	0.62	0.71	0.47	0.65
… 3 to 5	0.35	0.38	0.28	0.49	0.34
Garden					
… Front garden (1)	0.25	0.25	0.27	0.18	0.25
… Rear garden (2)	0.09	0.06	0.10	0.01	0.08
… Front and rear garden (3)	0.51	0.50	0.47	0.81	0.51
… None (4)	0.15	0.19	0.17	0.00	0.16
Type of garden					
… Front garden with grass	0.28	0.31	0.33	0.43	0.31
… Front garden with another type of vegetation	0.59	0.65	0.55	0.85	0.61
… Rear garden with grass	0.14	0.12	0.13	0.41	0.15
… Front garden with another type of vegetation	0.39	0.36	0.32	0.52	0.37

In addition, we produced contour diagrams (Figure 5-1), where we summarize the prevalence of characteristics across classes for the three most influential features of the households: presence of sensitive population (i.e. with people under the age of 15 and over the age of 74), household size, and presence and location of gardens. The highest concentrations are shown in darker colours and correspond to values higher than 0.5 on a 0 - 1 scale. We used three dimensions: (i) the characteristics of the home on the X-axis, (ii) the age of the individual making the decision on the Y-axis, and (iii) the latent classes 1, 2, 3 and 4 in the Z-axis.

Presence of a sensitive population: Respondents whose households include sensitive population were more prevalent in Class 2 (0.43), i.e. the greywater sceptics (Table 5-4). A reason for this could be that people in these age ranges are more susceptible to acquiring infections (Leng & Goldstein, 2010). Additionally, the prevalence in each class was found to vary as a function of relative age. For example, if the youngest family member is between 0 and 30 years old, then respondents between 20 and 35 have a higher probability of belonging to Class 1 (greywater enthusiasts – Figure 5-1-A1). If the youngest person among the household's members is between 20 and 40, then individuals between 50 and 65 have a higher probability of belonging to Class 1. We also found that if the oldest family member was between 50 and 70 or over 85, then individuals between 25 and 30 had a high probability of belonging to Class 1 (Figure 5-1-B1).

In the case of Class 2, individuals whose youngest family members were under the age of five had a higher probability of belonging to this class. Moreover, the highest probability of belonging to this class is for 60-year old individuals with the youngest family member being in their twenties. Concerning people more likely to belong to Class 2, there are different sensitivities between the different age ranges and the age of the household's members. For example, younger individuals (20 - 35 years of age) are more likely to belong to this class if the oldest family member is more than 80 years old. People in other age ranges are likely to belong to this class if they have family members older than 65.

Figure 5-1. Posterior share in classes according to the most influential dwelling characteristics



The predominant individuals in Class 3 would be mainly: (i) people between 20 and 30 years old whose family has one or more adults between 65 and 80 (Figure 5-1-A3); (ii) individuals between 30 and 45 years old with the youngest member of the family being between 15 and 20, and if there are adults over 50 years old among the household (Figure 5-1-B3); (iii) individuals between 45 and 60 years old living with children under the age of 5.

Class 4 is dominated by three groups, namely: (i) individuals near to 20 years of age living with younger family members (Figure 5-1- A4) or family members older than 65 years old (Figure 5-1- B4); (ii) individuals of approximately 35 years of age, whose family members have similar ages (Figure 5-1 A4) or family members older than 90 (Figure 5-1- B4); and (iii) individuals over 50 living in households with one or more individuals aged around 20 years (Figure5-1-A4, or in the case that there are family members over 70-year-old, Figure 5-1-B4).

Household size: Single-person household have a greater prevalence in Class 3, where the appearance of greywater matters most. Households with 3 to 5 people have greater representation in Class 4, and households with more than 5 people are homogeneously distributed across classes. Household size is a characteristic that has been previously defined as relevant. For example Mason et al. (2018) found that the likelihood of using greywater during dry seasons increases by 24% for each additional household member. Nevertheless, our results complement that information with a more detailed analysis about uses and types of consumers.

Garden presence and its location: Overall, households belonging to Class 4 have a higher incidence of gardens, with a prevalence of mixed gardens with vegetation different from grass, mainly in their front yards. Dwellings of respondents belonging to classes 1, 2 and 3 consistently have a small presence of gardens with grass, and a higher presence of front yards with vegetation other than grass. Note that these characteristics, which are associated with bigger dwellings (i.e. large number of bathrooms, presence of gardens), and more household members, are associated with households who tend to have a higher prevalence in class 4.

5.5. Conclusions

This study aimed to extend our understanding about heterogeneity in the acceptability of uses for treated greywater and the factors that influence it, by focusing on the interaction of variables that rarely receive attention. The most novel finding is associated with the possibility of quantifying the relationship between the acceptability of reusing water, by use, and the characteristics of a consumer, their household and their dwelling. Our approach offers numerical support for making predictions about how different latent classes of individuals may behave when facing different reuse options.

In particular, the method implemented has been more commonly used in other disciplines such as transport research, health and most recently in innovation appliances. The latent class approach we used is valuable in showing that a pre-feasibility empirical analysis can be carried out to assess greywater projects or initiatives in zones with no experience in reusing water. Likewise, these results are valuable to demonstrate that uses other than flushing toilets and garden irrigation can also be accepted once the potential users are aware of all possible uses of treated greywater.

This study considers the case of residents in future buildings that must adhere to new greywater regulations, which establish that new buildings must have a parallel greywater system. However, future studies should incorporate the cost of technology, operation and maintenance in order to include those consumers that want to adopt these new systems in their existing dwellings. These studies can be based on real-world pilot experiences carried out in areas with a high concentration of people, with characteristics similar to those identified in our study as having the highest level of acceptability of GWR. On the basis of that new evidence, policies can then be updated to produce management strategies that can achieve greater user acceptability.

6. FROM MATHEMATICAL MODELS TO POLICY DESIGN: A MULTI-COMPONENT ASSESSMENT FRAMEWORK TO ANALYSE RESIDENTIAL GREYWATER REUSE PREFERENCES

6.1. Introduction

A sufficient and reliable supply of water is crucial to the health and wellbeing of people. However, climate change, urban development and other factors are putting pressure on water resources. One strategy to address the water security problem is to reconfigure the conventional system of drinking water supply, allowing cities to use local water treatment systems for domestic purposes through “decentralized systems” which supply water in parallel to the main distribution network (Wilcox et al., 2016). In this context, one such approach receiving increased attention is the reuse of greywater, which involves storage and recycling of water previously used for hand washing, bathing, or laundry. Reusing treated greywater reduces the requirement for high quality treated water from the mains distribution systems for activities such as toilet flushing and garden irrigation. Greywater does not contain faeces, food residues, oil and fats, making it easier to treat (Lambert and Lee, 2018), and there are now technologies to treat greywater for non-consumptive (e.g. through biological treatments) or consumptive activities (e.g. through biological processes combined with solids separation, filtration and disinfection practices) that can be deployed *in-situ* in households (Fountoulakis et al., 2016; Jefferson et al., 2004; Li et al., 2009; Wu, 2019).

The implementation of greywater reuse schemes in Australia, California, India, Singapore, Spain and areas of South Africa, has revealed that treated greywater reuse in cities can provide clear environmental benefits and improve water security (Wilcox et al., 2016). These schemes have shown that the reduction in the demand for water from the mains system can range from 30% to 80%. This wide range is attributed to two factors. First, regulatory restrictions will limit the allowed uses for public health reasons. Second, the amount of water that can be saved depends on consumer preferences (i.e., whether people are actually willing to reuse greywater if allowed). There is evidence that this willingness is heterogeneous among individuals (Ilemobade et al., 2013; Wester et al., 2015), that is, two people may perceive reusing water differently, which directly impacts the potential uptake of greywater reuse and therefore, the success of management measures (Lefebvre, 2018; Muthukumaran et al., 2011; Subramanian et al., 2020; Roshan and Kumar, 2020; Vuppaladadiyam et al., 2019).

Deployment and uptake of greywater reuse must be enabled by appropriate laws and policies, and the above discussion suggests that successful laws and policies need to consider the role of end user preferences. The ideal way of understanding user's uptake of greywater reuse would clearly be to acquire this knowledge from evidence based on real-world policy schemes. However, in cities that are starting to allow residential water reuse, much time and money would be required for the implementation and monitoring of pilot practices (Wanjiru and Xia, 2018), and this has made basing regulations on the results of practices of other locations an appealing solution. While the implementation and use of greywater reuse systems elsewhere is a key input for cities that want to integrate greywater reuse as part of their supply sources, the direct transfer of policies and regulations could lead to unsuccessful outcomes due to differences between areas (Ormerod et al., 2019). Indeed, as with any innovation, the extent to which practices of greywater reuse is transferable between cities is unclear (Wester and Broad, 2021).

Until now, insights into individuals' responses to water reuse schemes have been based on social and psychological interpretations of the individual (Dolnicar et al., 2011; Fielding et al., 2019; Goodwin, Raffin et al., 2018; Hartley, 2006), and different approaches have been used to understand these public responses towards reuse (Smith et al., 2018), such as methods based on the *theory of planned behaviour* (Ajzen, 1985), *random utility models* (Domencich and McFadden, 1975), statistical analysis, for example using *Statistical Package for the Social Sciences* SPSS (see some aplications in Buyukkamaci and Alkan, 2013; Gu et al., 2015); among other approaches that are more focused on guiding and monitoring behaviour change, such as the Focus, Opportunity, Ability, and Motivation (FOAM) that aims to understand who is the target audience and what is the desired behaviour (Coombes and Devine, 2010). The most valuable contribution of these methodologies in the field of water reuse is that they have highlighted that acceptability, a key element in the success of the policy, can be linked to different factors such as mental, physical and/or cultural associations (Hurlimann and Dolnicar, 2016; Mankad and Tapsuwan, 2011; Wester and Broad, 2021), and can vary by geographic location (Ormerod et al., 2019; Beveridge et al., 2017). They have also provided guidance and allowed to monitor behaviour change (Aldirawi et al., 2019; Coombes and Devine, 2010). However, although the identification of the most promising *target audience* for new schemes is a very important step, many of these studies do not make the transition from the academic field to the real world for policy design. Specifically, there is a gap in using these methods to make forecasts or evaluate the pre-implementation feasibility of measures in terms of designing policies and regulations for cities without widespread current greywater reuse.

In this chapter, the attention is consequently focussed on areas where greywater reuse is not a widely implemented practice. Particularly, this study considers the scenario of a city, Santiago de Chile, where the residential reuse of greywater is legally permitted (Law 21,075 of 2018) for two uses, toilet flushing and garden irrigation, but as yet there are no official technical regulations supporting the actual implementation of the law. We propose an integrated framework to build bridges between theory and practice, taking quantitative results from modelling work that measures the impact of both quantitative and qualitative variables on potential uptake, and using them for policy evaluation through scenario testing. This final component is often a key missing step in academic work on consumer behaviour.

The integrated assessment framework suggested in this work focuses on five objectives (described later) that seek to understand individual water reuse preferences based on knowledge of *who* makes decisions about greywater consumption and *why, where* specific decisions are reached, *how much* these are likely to impact on water consumption, and *what* would happen *if* there were a change in policy or a shift in behaviour. Given that the central objective of this chapter is to move from mathematical models to policy design, we rely on the outputs of previously estimated models. In particular, two different model structures belonging to the family of Discrete Choice Models (DCM, cf. Train, 2009) were used in the work providing the inputs to this chapter. DCM are mathematical structures that seek to explain the role of product and consumer characteristics in decision making. They have been used in different areas such as: environmental assessment (Hoyos et al., 2015), flood impact reduction (Veronesi et al., 2014), water collection systems (Lu et al., 2019), technology (Su et al., 2018), health (Minton et al., 2017) and transport (Ortúzar et al., 2014). These models are grounded in micro-economic theory and are suitable for making predictions of future behaviour (Ortúzar and Willumsen, 2011 Chapters 3, 7, 8 and 9, Hess and Daly, 2014), yet also allow for the inclusion of psychological features (Hess et al., 2018).

While the two models used in this chapter differ in their structure and approach, they both share the key aim of capturing heterogeneity in preferences across consumers. The first, reported in Amaris et al. (2021a), is a latent class (LC) model used to identify segments in the population with different behaviour/preferences according to their sensitivities to changes in the greywater service. The second, reported in Amaris et al. (2021b), is a hybrid choice (HC) model used to capture the heterogeneity in preferences, based on individual characteristics and psychological constructs towards greywater. It is important to highlight that much of the work in this area makes use of experimental techniques rather than "real world" decisions, especially for choices involving new products and/or services. The same applies when seeking to understand the response to characteristics that are difficult or impossible to measure in real choices, such as risk, or characteristics with insufficient real-world variation to capture changes in behaviour, such as key qualitative attributes like noise and smell.

Alongside the specific geographic setting and application context addressed in this chapter, the work presents a general illustration of how results from such studies can be further processed. This comes in the form of a general framework which covers the essential stages going from data collection through modelling and on to use of the actual results for policy evaluation. This can provide insights into the potential impact of changes in sensitivities and attitudes, as well as public policies in urban environments, motivating strategies that integrate social and economic components, as well as technical ones. This work should facilitate the transition of methodological work from academia into real-world practice, aimed at developing approaches to motivate the implementation of residential greywater reuse as a water management strategy. Additionally, we use this analysis to assess the potential effectiveness of the current greywater laws, contrast them with alternative rules, and thus determine the potential of the city to implement a new parallel integrated system of greywater and drinking water.

6.2. Integrated assessment framework

In this study, we illustrate a multi-component assessment framework to analyse residential greywater reuse preferences and use empirical results to develop policy insights. In particular, we rely on mathematical models that can be used to understand and predict consumer decisions for real-world applications and illustrate how they offer valuable information for policymaking in cities that have no previous experience with greywater reuse.

The integrated assessment framework suggested focuses on five objectives that seek to understand individual water reuse. The first two objectives relate to understanding ***who*** makes specific decisions on greywater reuse, and ***why*** these decisions are reached, by seeking to understand the influence of consumer and service characteristics. The third objective is concerned with understanding ***where*** specific decisions are reached (i.e., studying the influence of geographic differences on preferences). The fourth objective looks at ***how much*** impact greywater reuse could have, that is, seeking to understand the quantitative impact (volume of water) of allowing the greywater reuse for different residential uses, considering users' preferences, and also understanding the potential impact of different policies on behaviour through scenario testing. Finally, the fifth objective looks at ***what*** would happen ***if*** there is behavioural adaptation and/or changes in policies. We hypothesise that once these questions are answered, it should be possible to create insights for policy knowing in advance the possible effectiveness of the measures in terms of highest willingness to use, and thus expected water demand reduction.

The framework comprises:

a) **Step 1**: collect data on end-user uptake, either from existing experiences or hypothetical settings (carefully design and with bases on real experiences);

b) **Step 2:** develop models that allows to quantify the willingness to reuse greywater and heterogeneity therein (*Who and why*);

c) **Step 3:** explore individual preferences and heterogeneity, including geographic differences expand the results from the sample level to the local population level (*Where*); and

d) **Step 4:** use the models to predict behaviour in potential future scenarios, including the effect of policy interventions and various management strategies (*What if*).

While each individual methodological step is not *novel*, their integration is, especially with a view to making the transition from modelling to practice (i.e., step 4 above).

It is important clarify that in many cases, including in the present chapter, steps 1 and 2 may draw from previous studies (i.e., using previously collected data and mathematical models that have been estimated before to identify the *who* and *why* of preferences in relation to greywater reuse). The interrelation between objectives in this framework are shown in Figure 6-1.

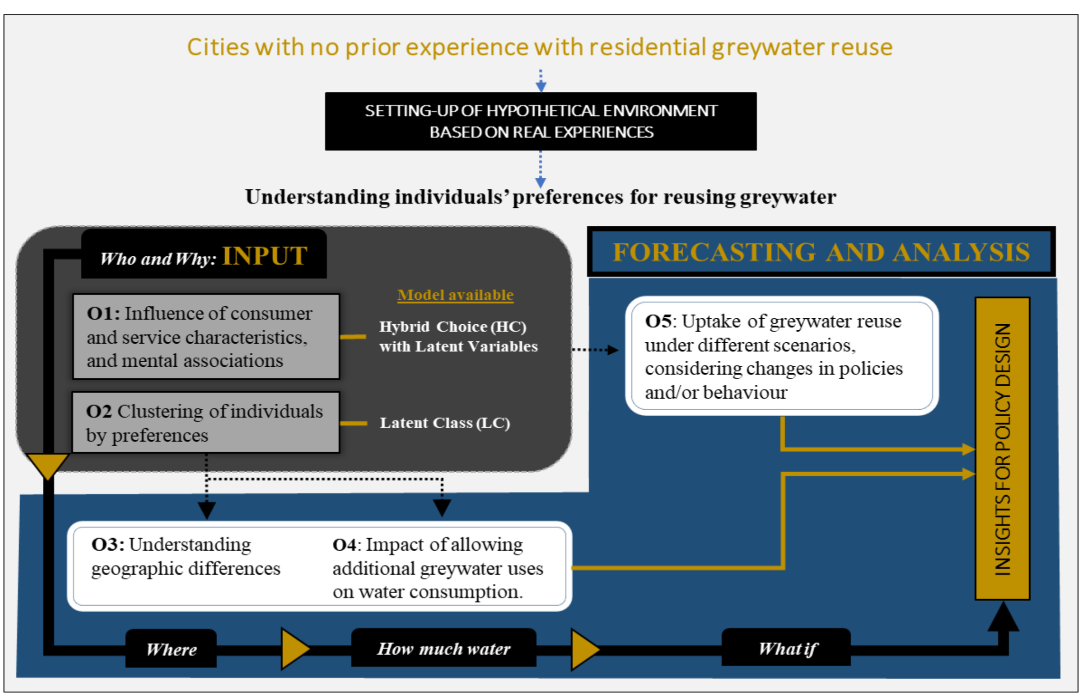


Figure 6-1. Integrated assessment framework for understanding the potential effectiveness of greywater reuse policies within a city.

6.3. Behavioural models

6.3.1. Overview

The models used in this study belong to the DCM family, which seek to explain how individuals make different choices as a function of changes in the characteristics that describe the product or service they are faced with, in our case through the choice scenarios in the SC survey. We specifically rely on Random Utility Maximisation (RUM) structures, which explain choices under the assumption that consumers maximize the "utility" or benefit they receive by choosing a particular alternative. This utility is based on the characteristics or attributes that define the alternative and the sensitivities of the user towards them (Ortúzar and Willumsen, 2011, Chapters 7–9; Train, 2009; Hess and Daly, 2014). Characteristics that describe the good/service can be desirable or undesirable for the respondent, and according to their perception, they will choose the option that provides the highest utility or benefit. As the process of utility formation is not observed by the analyst, the models incorporate a random component and the choices become probabilistic (Train, 2009).

In the present chapter, we reuse the results of two distinct models, with a particular focus on explaining differences in preferences across consumers. A brief overview of the aims of each model structure is given below, with more details on the econometric implementation given in the Chapter 4 and 5. Before describing the two models, it is important to highlight that both of them are complementary in the sense that both determine an individual's willingness to reuse greywater; the results are consistent by virtue of being based on the same data. However, each model studies behaviour from a different perspective, and this is very useful in evaluating policies that motivate the reuse of greywater.

6.3.2. Latent Class model (LC)

The latent class (LC) model used in this chapter was estimated previously Chapter 5. A LC model probabilistically splits decision-makers into classes with distinct preference patterns. This not only provides important insights into preference patterns in a population but is crucial in predicting how distinct consumer segments may behave in future scenarios.

The estimates for the LC model are shown in Table 5-2. According to the specific signs of the coefficients of attributes have been labelled as *"enthusiasts"* (class 1), *"greywater sceptics"* (class 2), *"appearance conscious"* (class 3) *and "water expenditure conscious"* (class 4). Note that all coefficients have a statistically significant impact on utility or benefit (at or above the 95% level) and, hence, on the probability of choosing a greywater option. Also note that the magnitude of the different coefficients show that the different attributes of the greywater service exert different weight and influence (positive or negative) on the utility or benefit that the user perceives, which directly affects potential uptake. The model highlights that worse appearance of the water reduces the probability of greywater reuse, while increased savings are beneficial. There are also differences as a function of the intended use of the greywater, where these vary as a function of respondent characteristics.

6.3.3. Hybrid choice model with latent variables

The hybrid choice model with latent variables used in this chapter was estimated previously in chapter 4. This type of model incorporates a role for additional psychometric constructs, in this case an attitude towards greywater reuse, which was calibrated using the six attitudinal statements described in Table 4-2. As with the LC model in Section 4.3, there are specific reasons for us adopting this model for the present study, given that psychometric factors are likely to play a major role in determining the success of greywater schemes.

The model coefficients relevant for the present chapter are shown in the table 4-5 and Table 4-6 (additional parameters for the measurement model for attitudinal indicators are available in section 4.4). Like the LC model, the HC model shows that worse appearance of the water reduces the probability of greywater reuse, while increased savings are beneficial for uptake. There are again differences in the utility of different uses (e.g., toilet flushing vs shower), and these differences again vary as a function of respondent characteristics. But in contrast with the probabilistic split into four classes in the LC model, the hybrid structure incorporates heterogeneity first through additional continuous random variation in preferences (σ terms), showing extensive differences in the appeal of different greywater uses across individuals. Notwithstanding this finding, for all six uses, the utility (and hence probability of choosing a given use) additionally varies as a function of underlying attitudes towards greywater reuse (λ parameters), where the utility increases/decreases with a more positive/negative attitude. This attitude itself is latent, and has a deterministic as well as a random component, where the former highlights a more negative attitude for female respondents, younger respondents, and those with lower education, and a more positive attitude for lower income respondents and those with past greywater reuse knowledge.

6.4. Results and discussion

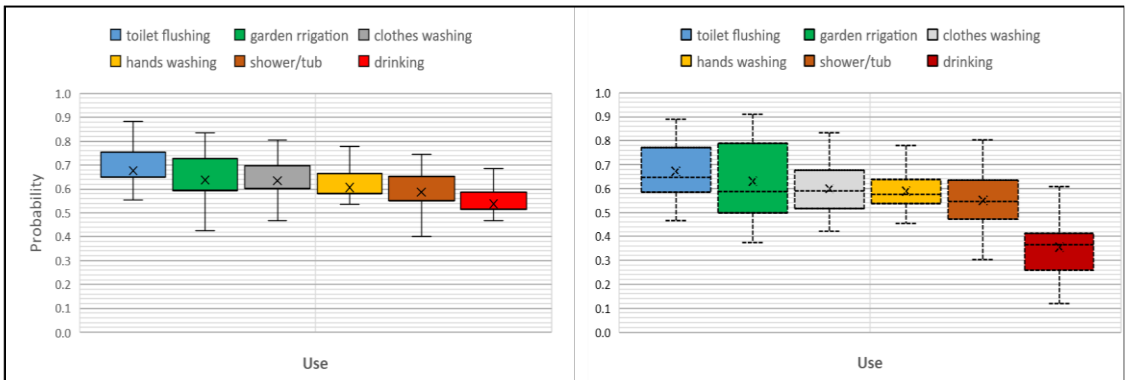
6.4.1. Statistics of predicted uptake

Once the data is collected (step 1) and the model(s) are estimated (step 2), the next step is to explore individual preferences and heterogeneity therein, including geographic differences. This also involves expanding the results from the sample level to the local population level (*step 3*).

We used the estimated models to predict the expected probability of reusing treated greywater at the level of individual consumers in the estimation sample, looking separately at each of the six types of use. We specifically did this for a case where the treated greywater is odourless and clear in colour, meaning that the greywater fully meets the standards of Law 21,075 for urban and rural areas of Chile.

We use the models to analyse the range of predicted uptake of treated greywater by respondents for different residential uses. Figure 6-2 contrasts the results for the two models. While the average predictions for the different uses are similar between the two models, the fact that each one measures different sources of heterogeneity (type of consumer in the LC model vs the role of greywater reuse attitudes in the HC model), means that the heterogeneity around the mean predictions (width of the box) is larger in the hybrid model; this is a result of the continuous treatment of random heterogeneity. The notable exception is for “drinking”, where the HC model uncovers more heterogeneity across consumers for this use.

Figure 6-2 shows that the probability of reusing greywater in the surveyed sample exceeds 40% for the vast majority of respondents across uses (except for drinking in the HC model), when treated to mains standards, for a modest 10% cost savings. Furthermore, for over half of the respondents, the predicted probability exceeds 50% for all uses apart from drinking. However, the mean probability decreases for uses with higher skin contact; this is consistent with other studies on water reuse (Aitken *et al*., 2014; Fielding *et al*., 2018; Massoud *et al*., 2018; Oh *et al*., 2018). While the mean probabilities are relatively stable across uses, the amount of inter-consumer heterogeneity differs more across types of use, revealing different levels of heterogeneity in the preferences that individuals have for different uses. Garden irrigation has the greatest variation, perhaps reflecting the range in garden sizes in the sample and the fact that many households do not have a garden (37%).



a. Prediction with latent class model

b. Prediction with hybrid model with latent variable

Greywater conditions:
Appearance: Water without colour and without odour
Water’s savings: 10% of water bill

Figure 6-2. Probability of using treated greywater (with no discolouration or odour) instead of mains water according to use (the whiskers extend up from the top of the box to the largest data element that is less than or equal to 1.5 times the interquartile range (IQR) and down from the bottom of the box to the smallest data element that is larger than 1.5 times the IQR)

Therefore, this step of the analysis indicates that a significant proportion of people would accept unconventional sources of greywater reuse for direct and indirect household uses, as long as the water's quality and appearance are similar to that obtained from the mains water supply system. This is consistent with other findings in the literature, from different types of analysis (Oteng-Peprah et al., 2018). However, as shown in the detailed results in Amaris et al. (2020), any reduction in the the quality of the treated greywater reduces predicted uptake.

6.4.2. Exploring preferences and heterogeneity, including spatial effects

Once we have characterized the preferences in statistical terms, we proceed to analyze the relationship between consumer characteristics, geographic location and reuse preferences. For this, we use the LC model as it allows us to segment people into clusters more easily than the continuous approach in the HC model. As described in Section 6.3.2., the latent classes classify the population into four categories reflecting their attitude towards greywater: "*Enthusiasts", "Sceptics",* "*Appearance Conscious*", and "*Expenditure water conscious"* (section 5.3).

After estimation, the *posterior* probability of belonging to each class (all four probabilities sum to one) was calculated for each respondent on the basis of the individual's demographic characteristics and their observed choices in the hypothetical scenarios. This information allows us to infer the characteristics of individuals in the different classes. This information allows us to infer the characteristics of individuals in the different classes. Table 6-1 shows a gender split in the enthusiast and sceptic classes; for example, men show a higher propensity to be in the former and women in the latter. A possible interpretation for this finding could be that women are more risk averse about the use of products that have a household-level health implication (i.e., water use). This is in line with general findings about gender roles and concerns about the well-being of others (Gustafsod, 1998; Kim et al., 2018).

Recognizing the characteristics of each class is fundamental to better understand potential future uptake, and, for instance, to develop the best possible campaigns to promote greywater reuse (Katz et al., 2015). This spatial analysis highlights that by adding one more dimension (geolocation) to the analysis, patterns emerge in the probabilities of class memberships that would not be seen otherwise. In this way, it can be recognized if there are other factors that can influence heterogeneity in preferences for greywater reuse, as is the case of other cities (e.g. the Reno-Sparks community area of northern Nevada, USA), and that can be relevant when establishing strategies to achieve greater uptake according to people's sensitivities (Wester and Broad, 2021).

Table 6-1. *Characterization of individuals in different classes*

Socio-economic characteristic	Class 1	Class 2	Class 3	Class 4	Sample average
Gender					
… Male	0.37	0.32	0.34	0.34	0.35
… Female	0.63	0.68	0.66	0.66	0.65
Age					
… Under 30 years old	0.16	0.09	0.06	0.1	0.11
… Between 30 and 60 years old	0.57	0.55	0.62	0.65	0.58
… Over 60 years old	0.28	0.36	0.32	0.25	0.31
Garden					
… Front garden (1)	0.25	0.25	0.27	0.18	0.25
… Rear garden (2)	0.09	0.06	0.1	0.01	0.08
… Front and rear garden (3)	0.51	0.5	0.47	0.81	0.51
… None (4)	0.15	0.19	0.17	0	0.16
Type of garden					
… Front garden with grass	0.28	0.31	0.33	0.43	0.31
… Front garden with another type of vegetation	0.59	0.65	0.55	0.85	0.61
… Rear garden with grass	0.14	0.12	0.13	0.41	0.15
… Front garden with another type of vegetation	0.39	0.36	0.32	0.52	0.37

In particular, our analysis of the results for the estimation sample relates to understanding the spatial element of heterogeneity trough the latent class model. In the model, each individual has a non-zero probability of falling into each class, but these probabilities become more skewed towards the 0-1 bounds when moving to posterior probabilities, as these also consider the individual-level choices. This allows us to make the simplifying assumption of considering that those individuals who have a posterior probability greater than 0.5 for one of the classes fall into that class (which was the case for 508 out of the 510 respondents). We then plotted the geographic location of these individuals, segmented by class. A geographic information system (GIS) was used, with results reported at the municipality level, as shown in Figure 6-3.

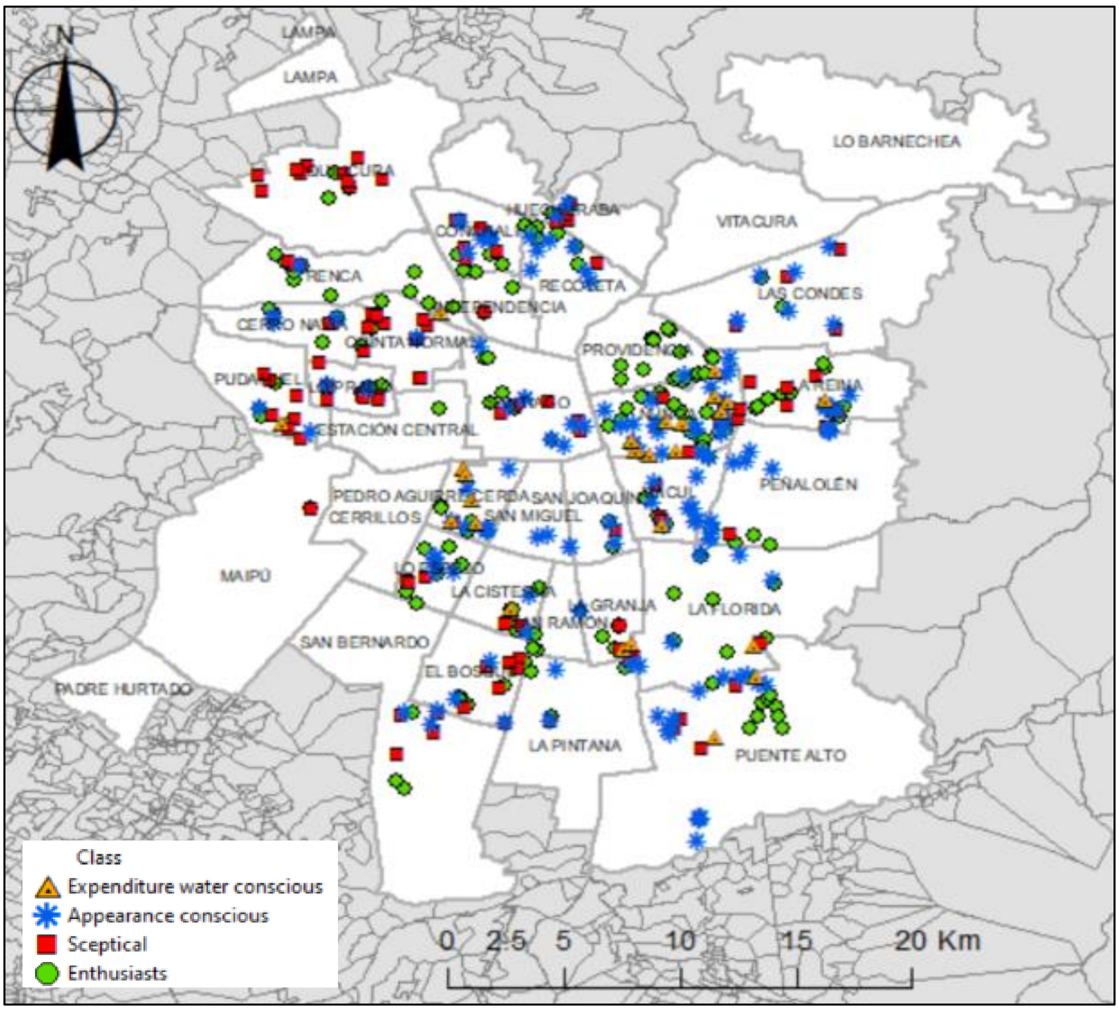


Figure 6-3. The most likely class membership for each respondent. In all cases the highest probability for the dominant class exceeds 50%.

The forecasts on the map allow us to look for spatial patterns of classes linked to the users' preferences for certain characteristics in the greywater service. For example, in Santiago, people that are more likely to belong to the category who are more positive about reusing greywater for any use (i.e., the "*Enthusiasts*") are more prevalent in the high-income municipalities of *Providencia*, *Ñuñoa*, *La Reina* and the eastern zone of *Puente Alto*. In the context of *El Gran Santiago*[9], these areas have a denser concentration and also have recent planning approval for buildings of 5 or more storeys (between 2010 and 2017). These areas are characterised by individuals with a total average monthly income per household of over CLP1,360,000 (1,772 USD), and socioeconomic groups that have clustered together because they share certain lifestyle attitudes and conducts (Gfk, 2019).

[9]https://www.ciperchile.cl/2020/01/03/contra-el-urbanismo-de-la-desigualdad-propuestas-para-el-futuro-de-nuestras-ciudades/

These findings are valuable in urban planning terms since the regulations for residential reuse of greywater in cities have considered new buildings as a starting point (Law 21,075 in Chile). The presence of people that are *enthusiastic* about reusing greywater in areas where new buildings have been planned could be key.

Another pattern is that although the people more likely to belong to the category of *Sceptics* (i.e., people with more negative perceptions about greywater reuse) are spread through the city, they are especially prevalent in zones to the north-west of Santiago, such as, *Quilicura, Quinta normal, Pudahuel, Lo Prado*, where the predominant socioeconomic levels are medium-low (C3), low (D) and very low (E). The link between scepticism and lower socioeconomic levels is consistent with Akter et al. (2017) and Schmuck (2000), who showed the relation between climate change action and low educational attainment, lack of access to information and, perhaps most importantly, increased prevalence of religious beliefs. On the other hand, individuals most likely to belong to the *Appearance conscious* class are spread throughout the city with no marked pattern; this is to be expected in areas without previous experience with water reuse.

6.4.3. Reweighting of results to match CENSUS data

The datasets used for estimating econometric models are not, in general, fully representative of the population of the study area. By virtue of relying on a limited sample size, some population segments may be under-sampled while others may be over-sampled. Therefore, the direct model results relate to the estimation sample rather than to the area's population. If the way in which preferences vary across consumers relates to the sampling method used, then a correction is required before using the results for policy analysis. Using weights during estimation is a statistically inefficient process, and also implies that the observations for under-sampled respondents are "more important" than those for over-sampled respondents. In addition, such weighting means that the results cannot easily be adapted for predicting future changes in the population. A more flexible approach is to correct for sampling after estimation. This can be done either by using sample enumeration (i.e. applying the models to a larger, more representative, sample), or by reweighting the predictions from the estimation sample using weights that correct for the under/over-sampling of specific segments (Hensher et al., 2015).

The results discussed so far relate to the unweighted estimation data, that, for example, over-samples women (65% of the sample vs. just over 50% from the census). We next used the 2017 Census data (INE, 2018) to create individual-specific weights for each respondent in our sample, correcting by gender and age (with three categories, namely under 54, 55-64, 65 and over). Of course, further reweighting along other socio-demographic dimensions would be possible with more detailed data. Combining the individual-level posterior probabilities for different classes (as used in Section 5.4) with the individual-level weights, we can compute an expected class-membership probability for each of the four classes for each neighbourhood, as shown in Figure 6-4.

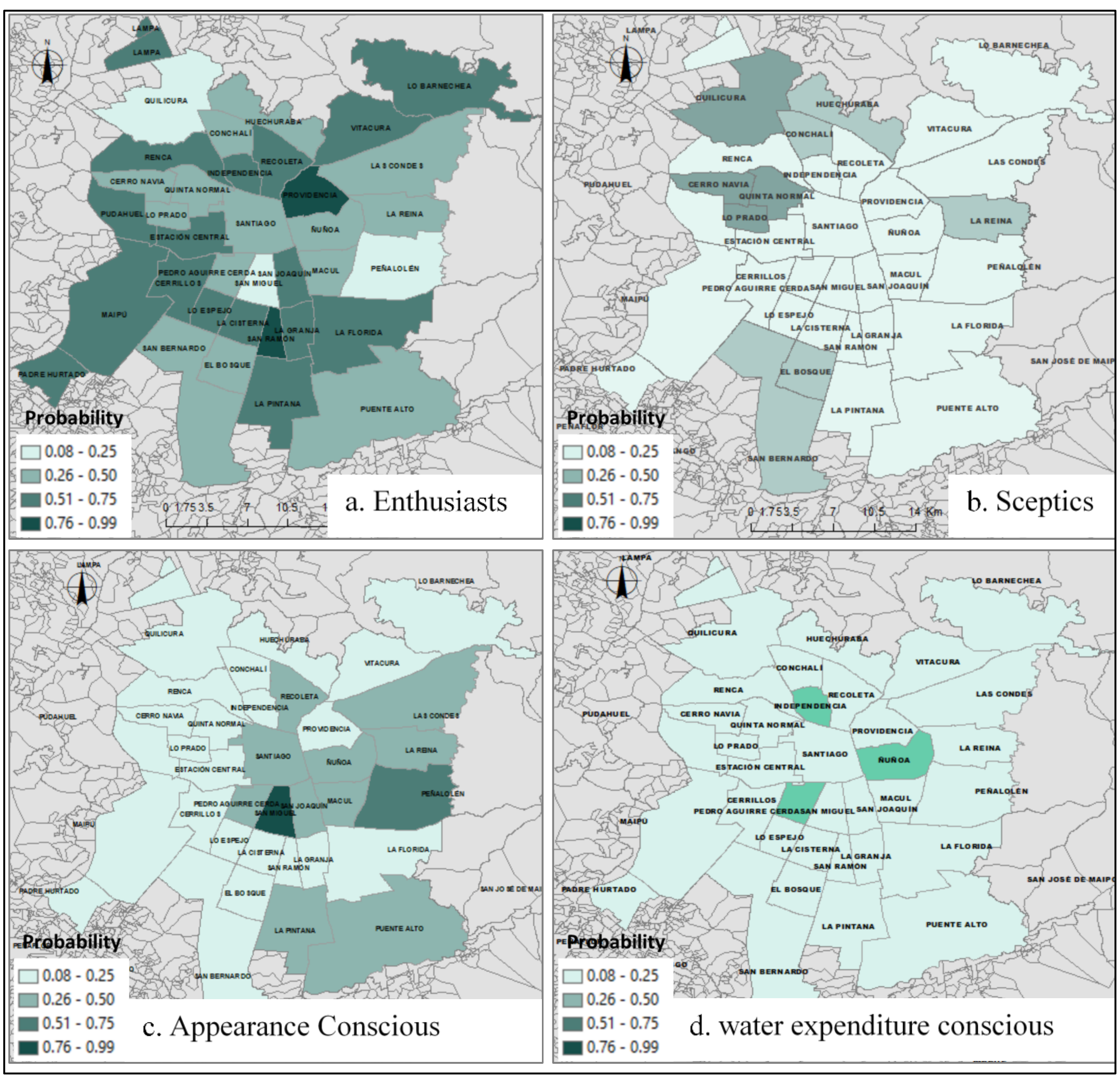


Figure 6-4. Probability of belonging to Classes

The maps shown in Figure 6-4 provide a preliminary indication of areas in Santiago most likely to be receptive to reusing greywater. By also taking into account the preference structures in the four different classes, we can further understand the type of reuses most likely to be accepted, and then, by implication, what type of information or policy approach could help to improve uptake. These maps also show how mathematical models can be translated into real life applications and can offer valuable information for policymaking in cities that have no previous experience with greywater reuse.

For example, in the case of Santiago, we could say that:

The municipalities of *Providencia and San Ramón* have the highest proportions of **enthusiasts** (Figure 6-4a that is, people who would use greywater for the widest range of domestic uses. High proportions are also observed in other areas, with the exception of *Peñalolen*, *Quilicura* and *San Miguel*. However, since the level of predicted uptake in each zone is not the same, different strategies would be required to increase the confidence of individuals regarding the residential reuse of greywater; these will be discussed later.

Figure 6-4b shows municipalities with high levels of **scepticism**, including *Quilicura, Cerro Navia, Quinta Normal, and Lo Prado,* where a policy consistent with the needs of these areas would be to design campaigns more oriented on raising awareness about the safety of treated greywater and the economic and environmental benefits that it provides. On the other hand, municipalities such as *Peñalolen and San Miguel* are dominated by **appearance conscious** people (Figure 6-4c). But it can also be seen that the high concentration of these individuals covers an area that corresponds to those zones with a high socioeconomic level in the *Gran Santiago* area (i.e. municipalities of *Las Condes*, *La Reina*). Therefore, for these areas it could be useful to promote campaigns focused on showing how technology can achieve optimal water quality and appearance for domestic uses. Finally, **expenditure conscious** people are the smallest group; in fact, only the municipalities of *Ñuñoa*, *Independencia* and Pedro *Aguirre Cerda* exceed 20% of people in this class. Strategies targeted at this group could be oriented to emphasize the amount of water (and hence also money) that can be saved if they decided to reuse residential grey water.

It is also important to highlight that, although some municipalities are heavily dominated by one class, many – including those with the most expenditure conscious people - are fairly mixed. For example, *Ñuñoa* is a mix of enthusiasts (48%), appearance conscious (27%) and expenditure conscious (18%) individuals. Strategies need to recognise this diversity by using a mixed approach to encourage uptake or focus on a particular group to initiate the process.

6.4.4. Assessment of policies and changes in behaviour

The final step in the analysis involves scenario testing to predict the potential uptake under different future settings. In the analysis, and according to the type of models used, the impact of two possible types of changes were included: (i) changes to policy in terms of which uses are allowed, and (ii) changes in preferences, for example as a result of education campaigns. In the first case, given the current mix of preferences, as established by the modelling work, an analyst can contrast the impact of different policy decisions, for example looking at the likely success of incentives or the impact of changes in regulation, such as allowing for additional types of uses of treated greywater. In the second case, with models that capture extensive heterogeneity in preferences, the analyst has the ability to predict the impact on potential uptake of changes in preference in the population. For example, one could simulate the success of educational campaigns or other practical demonstrations to reduce scepticism in a population as yet *unfamiliar* with the service.

In what follows, we describe both cases.

a) Impact of allowing for additional uses

Residential water reuse is typically preferred for uses that do not require direct contact with the skin (i.e., toilet flushing and garden irrigation; Mankad and Tapsuwan, 2011; Garcia-Cuerva et al., 2016; Leong, 2016), and this is reflected in the uses allowed by the current law in Santiago. This inevitably leads to a situation where some greywater remains unused and must be discarded (to avoid water stagnation[10]); this is especially the case

[10] https://www.waterless.com/blog/six-rules-for-using-grey-water-properly

when many people do not have gardens or do not need to water plants all year round. This section analyses the likely amount of greywater used (and discarded) depending on the permitted uses.

The process starts by making assumptions about consumption levels in each household. This was estimated based on the daily consumption per use and per inhabitant indicated by the Superintendency of Public and Sanitary Services of Chile (SISS; cf. table 6-2) and the characteristics of the households in our sample, after the reweighting explained in Section 6.4.1.

Table 6-2. Average per capita consumption of water from the mains (Chile)

		Winter		Summer	
id.	Use	(lt/d)	(m3/month)	(lt/d)	(m3/month)
1	Handwashing	10	0.3	18	0.54
2	Take a shower	90	2.7	100	3
3	Tub bath	250	7.5	300	9
4	Toilet flushing WC (new)	8	0.24	10	0.3
5	Toilet flushing WC (old)	20	0.6	22	0.66
6	Wash dishes by hand	22.5	0.675	30	0.9
7	kitchen and drink	16	0.48	22	0.66
8	Use the washing machine	75	2.25	90	2.7
9	Water 100 m2 of garden	400	12	400	12

The resulting averages are shown in Table 6-3 under *"average monthly consumption (L)"*, showing clear differences between winter and summer, and whether the household has a garden. We evaluated two possible regulations, namely the current one where only toilet flushing and garden irrigation are permitted uses, and a hypothetical situation where the use of greywater for laundry was also allowed.

Table 6-3. Impact of allowing additional greywater uses on water consumption

	No garden		*Garden*	
Description	current regulation	a third use allowed	current regulation	a third use allowed
	winter			
average monthly consumption (L)	13,947		17,177	
average monthly consumption in GW permitted uses (L)	1,928	2,766	3,461	4,384
average volume of GW available per month (L)	8,009	8,009	9,138	9,138
average predicted amount of greywater used per month (L)	1,176	1,566	2,026	2,436
share of available GW used	15%	20%	22%	27%
	summer			
average monthly consumption (L)	16,620		29,017	
average monthly consumption in GW permitted uses (L)	2,120	3,127	12,469	13,577
average volume of GW available per month (L)	9,880	9,880	11,275	11,275
average predicted amount of greywater used per month (L)	1,293	1,763	5,865	6,145
share of available GW used	13%	18%	52%	55%

The potential amount of treated greywater that can be reused in a household is capped by two factors, *regulation of uses* and *water resource availability*. Firstly, the fact that not all uses are permitted caps the possible amount of greywater that can be reused at the total household consumption of those, as reflected in Table 6-3 under *"average monthly consumption in GW permitted uses (L)"*. Furthermore, the possible amount that can be reused is also capped by the physical availability of greywater for treatment. Not all greywater produced by a household is suitable for treatment, and available *raw* greywater before treatment is limited to that from handwashing, tooth brushing, taking a shower/bath, and laundry. Consistent with other studies (Lefebvre, 2018; Silva et al., 2019; Vuppaladadiyam et al., 2019) and information from Chile (Rodríguez et al., 2020), we assumed a 70% recovery rate of water for these uses. This provides the "*average volume of GW available per month (L)"*

Based on these three inputs, and the estimated LC model, we conducted a simulation exercise using the reweighted sample of respondents (i.e. as in Section 6.4.3), where we predicted the monthly consumption of greywater in situations where multiple uses are permitted and could be used simultaneously for each individual. The predictions are then aggregated across households. An iterative process was used, as follows:

1. For each of the permitted uses, we first assign the probability of choosing to reuse greywater as opposed to mains water, separately for each given use, calculated with the LC model, for each individual in the sample, say P_{nk} for person *n* and use k (where *k=1,…,6*, with 1=toilet flushing, 2=garden irrigation, 3=laundry, 4=washing hands, 5=shower, and 6=drinking).

2. These probabilities indicate how likely a given individual is to choose a specific use in a binary choice against mains water. In making predictions, we need deterministic outcomes, that is, whether or not a given person n will reuse greywater for use k in a specific simulation run. Use k should be acceptable to person n with a probability given by P_{nk}, and to move from probabilities to outcomes, we select as acceptable those uses where $P_{nk} > \nu_{nk}$, where ν_{nk} are separate uniformly (U[0,1]) distributed disturbances. The logic in this is easily understood by noting that, with $\nu_{nk} \sim U[0,1]$, there is a probability of P_{nk} of the draw ν_{nk} being less than this threshold. For example, if a given use has a probability of acceptability of 0.7 given by the model, then there would be 70% chance of a uniform random variable falling below that value.

3. Three conditions are tested:
    a. If none of the uses is acceptable, i.e. $P_{nk} < \nu_{nk}, \forall k$, then no greywater is consumed for that individual.
    b. If a single use is acceptable, e.g. only $P_{n1} > \nu_{n1}$, then greywater is consumed for that use, if allowed by law, and capped by both the available amount of greywater and the household consumption for that use.
    c. If multiple uses are acceptable, then they are ranked in decreasing order in terms of by how much the probability P_{nk} exceeds the random draw ν_{nk}. Uses with a higher probability given by the model will have a higher probability of being ranked first, but the random nature of probabilities is considered. The algorithm then iteratively assigns greywater for reuse, going through the ranked options, and again taking into account the regulatory and physical availability constraints mentioned in step b. The amount of greywater actually available to the household is then decreased accordingly after each use (with less greywater remaining), and the algorithm moves on to any other uses found to be acceptable in step 2. This is repeated until no further uses are allowed, or no more greywater is available for use.
4. The process in steps 2-3 is repeated a large number of times using Monte Carlo simulation (in our application, we used 250 iterations to obtain a stable solution), the results are averaged across iterations, and are then reported at the population aggregate as *"average predicted amount of greywater used per month (L)"* in Table 6-3, and also expressed as a ratio in *"share of available GW used"*.

The simulation exercise was conducted under the best conditions of appearance of greywater after treatment (transparent water, without odour). Each time, we looked separately at individuals with and without a garden, and also made separate predictions for winter and summer.

Table 6-3 first first shows that, whether or not a third use is allowed, the amount of greywater available far exceeds the actual demand in allowed uses, except in the summer for houses with a garden (e.g., 1,928L vs 8,009L in the case of houses without a garden in winter and with two permitted uses). This implies that the current law would mean that some greywater would be wasted, even if greywater reuse was universally accepted by consumers. We next turn to the predicted consumption. With or without the additional permitted use, the amount of greywater reused is below the possible maximum (e.g., 1,176L vs 1,928L in the case of houses without a garden in winter and with two permitted uses). This is a result of the heterogeneity in preferences across individuals and the fact that there is not a universal predicted uptake of greywater. The results clearly show that with the current law, the share of greywater that would be discarded is high, especially for those houses without a garden (85% discarded in winter, and 87% in summer), but also for houses with a garden in winter (78% discarded) – although 55% of greywater would be reused for houses with gardens in summer. Allowing for an additional use in the form of laundry can lead to a modest increase in the share of available greywater that is actually used. However, even though this percentage is modest, it would still lead to savings of several hundred l/month/household, which is crucial in an area with serious water security problems.

b) Scenario tests with changes in behaviour

We now use both the LC and HC models in a sensitivity analysis to determine the impact of changes in sensitivities and attitudes on the predicted uptake of greywater reuse. We consider a baseline scenario and five possible future scenarios, as follows:

Baseline - S0: This scenario corresponds to the most probable situation that can occur considering law 21,075 of 2018 regulating the domestic use of greywater, that is ideal conditions for the appearance of water (no colour and no smell) and savings in mains water associated with less use of the main drinking water system and sanitation (see figure 6-5). We compute this baseline forecast separately for the two models. As both models were calibrated on the same data, the results are expected to be very close, albeit with more heterogeneity in the LV model given the additional psychological constructs.

Scenario 1 – S1: This strategy is based on monetary incentives. We use the HC model to look at the situation of ideal greywater appearance after treatment and 30 % of savings in the water bill (associated with 20% less use of the mains system plus 10% as an additional incentive).

Scenario 2 – S2: This strategy is based on increasing educational awareness about greywater reuse and how the system could work inside the home. Using the HC model, we look at the situation of ideal greywater appearance after treatment, 10% savings in the water bill, and all individuals having previous knowledge of greywater reuse.

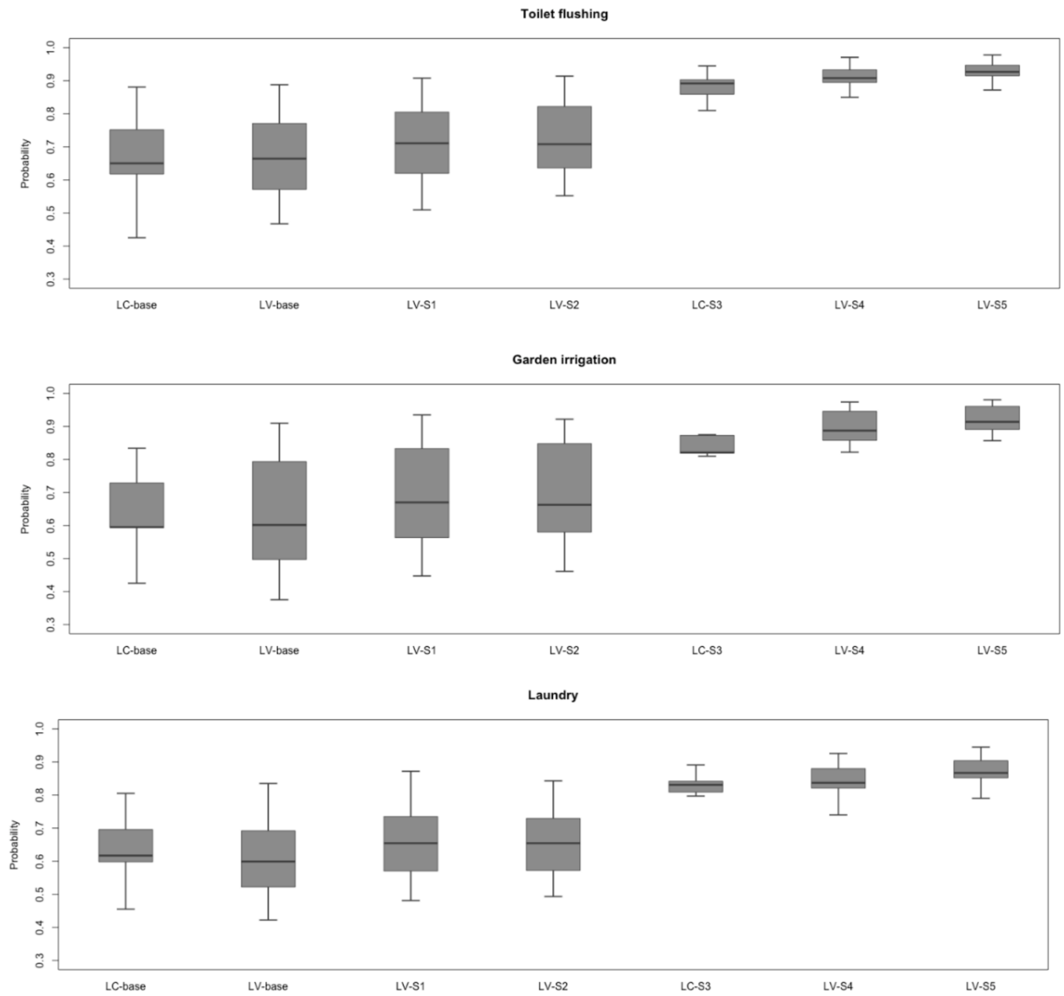
Scenario 3 – S3: This strategy is based on educational awareness with the objective of removing scepticism from the population; this could be possible if the population is shown how the system works with a real-life example (technology pilot test) and individuals can observe that the appearance of greywater after treatment is as good as that of mains water (Dolnicar et al., 2011; Smith et al., 2018). Additionally, this example considers the situation of ideal greywater appearance after treatment and 10 % of savings in the water bill. The mechanism for this scenario test is to use the LC model, and shift people out of class 2 (sceptics) into the remaining three classes, using allocations proportional to the existing class sizes.

Scenario 4 – S4: This strategy is also based on educational awareness with the objective of removing scepticism from the population but focused on increasing prior knowledge and strengthening the pro-water reuse attitudes of individuals (i.e., using the HC model). This is achieved by giving all individuals the attitudes of the most positive group in the population, for example through campaigns aimed at showing environmental benefits and social benefits with additional information. The scenario uses a mains water consumption reduction (10%) along with the optimal appearance of treated greywater.

Scenario 5 – S5: This strategy is based on combining several others together. It provides ideal greywater appearance after treatment, 30 % water bill savings (20% reduced mains use plus 10% as an additional incentive), educational awareness and a more positive attitude.

Figure 6-5 summarizes the resulting probabilities for the different scenarios. In particular, the box-plots show the probability (in a binary setting) of people preferring treated greywater reuse over the mains system for toilet flushing, garden irrigation and laundry. Each box corresponds to a management scenario to evaluate the potential uptake in the population. The two base scenarios correspond to the current probability distribution of the surveyed population estimated from the LC and HC models. These provide the point of reference for evaluating the effectiveness of each strategy. Although the distribution of both models is not exactly the same, they maintain the same magnitude for the mean.

Figure 6-5. Probability of using greywater according to different scenarios



Description	LC Base	LV Base	Scenario 1 (S1)	Scenario 2 (S2)	Scenario 3 (S3)	Scenario 4 (S4)	Scenario 5 (S5)
Model specification							
Latent class model	*				*		
Latent variable model		*	*	*		*	*
Appearance:							
- Water without colour	All scenarios						
- Water without odour	All scenarios						
Water's savings:							
10% of water bill	*	*		*	*	*	
30% of water bill			*				*
Behaviour							
- higher knowledge GWR.				*		*	*
- individuals with pro-GWR attitudes.						*	*
- change of attitude of sceptical people (class 2)					*		

The plots show that there is clear potential for increasing greywater reuse uptake through different means. In the case of reusing greywater for **toilet flushing**, predicted uptake could reach up to 0.9, which in the specific case of the analysed population corresponds to a percentage increase of up to 25% from the base. In the case of reusing water for **garden irrigation,** predicted uptake can again reach up to 0.9, but the most interesting point in this case is that by establishing strategies to achieve a higher willingness to reuse greywater, the average probability of reusing greywater could reach up to 30% increase with respect to the initial decisions (0.6 to 0.9). Finally, note that here is a high probability in the population to reuse greywater for **laundry**. However, current Chilean regulations do not allow this use. An average predicted uptake of up to 0.9 could be achieved for greywater reuse for laundry if strategies are established to promote this use.

Looking in more detail at each scenario, we note that:

- All the evaluated situations show an increase in predicted uptake, with some of them more effective than others. For the three uses, monetary incentives (S1) have almost the same impact as generating educational awareness in individuals (S2). However, although both strategies separately show an increase in predicted uptake (e.g., going from 0.65 to 0.7 for toilet flushing for both S1 and S2), this does not represent a notable increase compared to the base situation. At this point, it is important to clarify that other studies have shown that disseminating information on water reuse has a positive effect on acceptability (Hou et al., 2020). Although the results of this study support this claim, it also clarifies that the impact of changes in sensitivities/preferences depends on the intended use.
- Scenarios S3-S4 show that a change in the attitude of sceptical people and a shift towards more pro-greywater reuse attitudes could be more effective in achieving higher uptake than offering monetary incentives or strengthening the general knowledge about water reuse (scenarios S1 and S2). Note that S4 achieves higher predicted greywater reuse without offering extra monetary incentives which could be an important input to create strategies to promote water reuse. This is not addressed as an objective in this chapter. Additionally, note the fact that the interquartile range in the box-plots for these scenarios is narrower, meaning that individuals would have similarly high levels of predicted uptake.
- The strategies considered in scenarios S3-S5 show that differences in the effects vary across uses. We observe that removing consumers' scepticism about reusing greywater for toilet flushing by generating educational awareness about water or even incorporating monetary incentives would have the same impact on behaviour. Therefore, for this particular use, promoting educational awareness for toilet flushing can achieve greater uptake. In contrast, scenarios S3-S5 show a different impact on potential greywater reuse for garden irrigation. Promoting educational campaigns (S4) would be more efficient than trying to remove scepticism from the population (S3) and more economical than assigning extra monetary incentives (S5).
- If we now analyse the option of reusing water for laundry, which is proposed in this study as a suitable alternative to be incorporated into current Chilean regulations, we can see that the optimal strategy to achieve higher uptake would be to promote educational awareness campaigns and monetary incentives (S5). However, if no extra monetary incentives were offered, it could still be effective in increasing potential uptake for reusing greywater for this purpose, with an average probability between 0.8 and 0.9.

The evaluated scenarios take as an input potential changes in sensitivities or attitudes of individuals. These could be realised in practice through communication strategies (Katz et al., 2015; Tortajada and Nambiar, 2019). In particular, the study carried out by Katz et al., (2015) shows that diffusion strategies are a good tool to achieve greater acceptability. However, they highlight two elementary components: i) the need for each place to conduct its own analysis of preferences and ii) get the language right (e.g., speak as briefly and simply as possible, promote two-way communication, using graphics and videos).

6.5.Conclusions

This chapter has sought to establish a framework to analyse residential greywater reuse preferences in zones where greywater reuse is not widely implemented, and used empirical results to develop policy insights.

The first aspect that must be considered is that understanding individuals is not an easy task. This chapter has used stated preference (SP) techniques in this context, based on the notion that it is possible to obtain a reliable approximation of real-world consumer decision-making (Louviere et al., 2000). In the context of wanting to understand and disentangle the separate influences that different characteristics of a greywater service may have on potential uptake, we suggest that it is important to use advanced mathematical models that bring together economic theory and behavioural foundations from psychology. This study used advanced discrete choice models (DCM), which allowed us to quantify the influence of qualitative and quantitative attributes on potential residential greywater uptake and make a detailed analysis of it based on choice scenarios. Of course, there are other approaches that can be used, for example using the theory of planned behaviour – for a review of possible alternatives, see Smith et al. (2018)

This research has shown how changes in sensitivities or attitudes can improve the potential level of uptake, more so than economic incentives alone. We have created insights that would be useful for developing outreach strategies for residential water reuse, considering the extensive heterogeneity in users’ preferences.

An important insight obtained from this chapter involves the forecasts (4.2.1) of the volume of water that could be recovered under current regulations *vs* the volume of water that could be recovered under the scenario of allowing an additional use (laundry), which does not require direct contact with the skin or actual water intake. Our results show that this would lead to additional savings of several hundred litres per household, with clear environmental benefits, as well as a more efficient use of the greywater reuse system by reducing the gap between the amount of available treated greywater and that which is actually used. Of course, this analysis was limited to the uses studied in our survey, but the findings could be extrapolated to suggest that if individuals are willing to reuse greywater for residential uses, they could also accept it in other high-consumption urban uses such as washing cars.

By limiting the uses to those that do not require direct contact with the skin (i.e. toilet flushing and garden irrigation), the laws may be acting as a demotivator. For example, many houses do not have gardens and are therefore unable to fully exploit the potential of greywater, reducing the motivation for installing a greywater treatment system in existing dwellings. Furthermore, although toilet flushing is a major component of household water use, efficiency improvements mean that modern toilets use less than half the water of those installed over 10 years ago. This further reduces the absolute benefits from a greywater system limited to a small number of uses. Our analysis shows that increasing the number of uses for greywater could improve system efficiency and effectiveness, which should increase uptake.

The results provide important insights into potential uptake of greywater reuse technologies in Santiago. They allow the development of more effective strategies to increase the acceptability of residential greywater reuse and, thus, the number of users. However, the insights are not limited to Santiago, but should also be an important contribution to other communities that want to start establishing water reuse within cities together with new regulations. The steps outlined in the framework constitute the key components required for applying similar work elsewhere. The key distinction will arise in the data sources, the local regulations, and of course the findings in terms of behavioural patterns, which is the key aim of the modelling work.

As with any study, there are limitations and opportunities for future work. First, the empirical modelling results are based on data from hypothetical choice scenarios. There are good reasons for this, given that the lack of widespread implementation of greywater schemes limits opportunities for studying choices in a real-world setting. Great care was taken to ensure realistic choice behaviour[11] in the data (cf. Louviere et al., 2000), but nevertheless, there is scope for validating the results with real-world data post-scheme implementation, to learn lessons for future studies. Second, some of the insights are potentially specific to the study area, i.e. Santiago. Changes to the type of questions asked in surveys and/or the modelling approach may be needed in other cities, however, the broad framework outline still applies. Also, in Santiago, the work was motivated by the fact that the installation of greywater treatment facilities is going to be mandatory for new buildings – in other cities, different circumstances may apply, and the selection of study areas will also depend on whether the quantity of produced greywater would justify the investment in technology. Finally, alongside more quantitative factors such as the role of monetary incentives, our work has focussed on predicting the impact on potential uptake of changes in sensitivities and attitudes. In line with evidence in e.g. Katz et al., (2015), we have posited that these changes could be achieved through information/education campaigns. The actual extent to which this is the case, i.e. the level of impact of these campaigns, needs to be evaluated on a case by case (local) basis, which is another area for future research.

[11] See also the discussions in Amaris et al. (2020) and the importance of carefully explaining the notion of new technologies such as greywater treatment to respondents in surveys,

7. CONCLUSIONS

Water security, in terms of access and availability of water, is a global issue predicted to become worse over time, as highlighted in the scenarios foreseen for 2050 by UNESCO (2015) and OECD[12] (2012). Against this background, it becomes essential to generate public policies and to take measures that achieve a more sustainable development of cities and communities. The reuse of greywater in cities has emerged as one potential measure that can help to achieve this purpose, and cities and countries are actively developing policy schemes and regulations to facilitate it. The premise of this thesis is that the success of these policies depends on how compatible they are with consumer preferences. In particular, the key input in ensuring an effective system is an understanding of individuals' acceptability of using greywater for residential purposes.

The dissertation has sought to study residential greywater reuse preferences and generate insights into which quantitative and qualitative characteristics would lead to increasing the acceptability of water reuse as an additional source of water supply in cities. The selection of Santiago de Chile as a case study, was motivated by two factors. First, the area is increasingly experiencing water security issues, making it an ideal site for potential implementation of greywater reuse schemes. Second, the city (and the country) has recently introduced regulation in relation to residential greywater reuse, but the design of the law has not benefited from knowledge related to whether the reuse of treated greywater is acceptable to households in the area, and if so, under what circumstances.

This is not unusual, as cities and countries that want to be more sustainable by integrating greywater reuse as part of their supply sources commonly base their regulations on the experience of other cities with these new systems. Regulations must ensure that they will not cause any public health problems, so it is also common that the only residential uses allowed for greywater are those which do not require direct contact with the skin or intake, and, additionally, satisfy certain quality parameters. This could act as a demotivating factor on the acceptability of the population, since the individual must pay for the

[12] https://www.oecd.org/env/indicators-modelling-outlooks/49844953.pdf

maintenance and operation costs of the technology that would be integrated into the new constructions. This second point creates a situation where analytical work, such as that carried out in this thesis, can help with predicting the impact of this new management measure on the city, and can contribute insights into how the policies may be improved. The first aspect that must be considered is that understanding individuals is not an easy task. In the context of wanting to understand and disentangle the separate influences that different characteristics of a greywater service may have on acceptability, we need to use advanced mathematical models that bring together economic theory and behavioural foundations from psychology. While the use of such discrete choice models (DCM) is not completely new in the context of greywater research, the level of complexity allowed in the modelling work in this thesis, and the resulting detail in terms of insights generated, make important contributions to the state of the art.

The difficulty of understanding and modelling human preferences is exacerbated in a situation where data on real world behaviour is scarce, as is the case with greywater reuse in Santiago. However, this issue is not unique to the case of greywater reuse but is one that commonly arises in the context of predicting demand for new products or services. This thesis has put forward the use of stated preference (SP) techniques in this context, based on the notion that it is possible to have an approximation of a real-world decision-making processes by studying the preferences that individuals express in hypothetical scenarios; these must be based on the use of attributes that describe, as realistically as possible, the product or service of interest. The work took great care into how the scenarios were developed and described to respondents, reducing the potential for subjective interpretation of the characteristics used to describe the greywater service. The overall findings of the work are consistent with experiences of greywater reuse around the world, validating the adopted approach.

At the outset of this thesis, four hypotheses were put forward. These related to the way in which the acceptability of greywater reuse was anticipated to vary across individuals and across settings. To recap, these hypotheses were:

- **H1:** The acceptability and willingness to reuse greywater are not independent of the characteristics of the treated greywater, but vary as a function of the projected use and appearance of the water to be reused
- **H2:** Observable characteristics of individual consumers (e.g., age, education) as well as past exposure to greywater reuse are key drivers of heterogeneity in the willingness to use treated greywater.
- **H3:** There are additional variations in preferences that cannot be linked to socio-demographic attributes, but which are driven by unobserved factors.
- **H4:** Such idiosyncratic differences in preferences could in part be linked to underlying attitudes of individuals, and/or the existence of different segments of the population with very distinct preference structures.

The thesis also set out four specific objectives for the work, as follows:

- **O1:** Understand the willingness to use greywater for different residential uses, considering the variation in observable consumer characteristics across households, as well as the properties of the greywater service, in terms of qualitative appearance and monetary implications.
- **O2:** Evaluate the role of individuals' attitudes to explain the heterogeneity in greywater reuse preferences and establish which consumer characteristics contribute to the formation of these attitudes.
- **O3:** Establish whether there exist specific subgroups of the population with clearly distinct preferences, how the preferences vary across these groups, and how individuals are split across these groups, both through observable differences between consumers and through idiosyncratic variation.
- **O4:** Develop insights for policy design, including understanding geographic differences in preferences and predicting the potential uptake of greywater reuse under different future scenarios, by using the results from quantitative modelling analyses.

Objectives **O1** to **O3** aimed at testing the four hypotheses, while objective **O4** aimed at facilitating the crucial step of using the insights from modelling work to evaluate existing policies and help developing better ones.

Three advanced discrete choice models based on the paradigm of random utility maximization were specified and estimated to address the research questions. These models used different approaches to explain the acceptability of water reuse and focused on different behavioural influences. Each model analysed in turn, was more complex in its treatment of heterogeneity than the previous one.

The first model, in Chapter 3, is an error components Mixed Logit model. This work focused on objective **O1**, generating insights into which characteristics of a greywater service (in terms of appearance and intended uses) influence acceptability, and how this varies as a function of the individuals' sociodemographic characteristics. The findings from this analysis supported our research hypotheses **H1** and **H2**, showing that the characteristics of both the greywater service and consumers influenced acceptability. A number of key findings are that the aesthetics of the water (colour, odour) and the savings reflected in the water bill, influence different measures for different residential uses. Consistent with expectations, the most accepted uses for treated greywater are those that require less direct contact with the skin. When the quality of appearance in terms of colour and odour gets worse, monetary incentives could be needed even for those uses that do not involve human contact. Gender, age, educational level, water expenditure level, and in particular previous knowledge about greywater reuse, are important determinants of acceptability and thus willingness to pay for greywater use; however, their importance varies according to the type of use.

The second model, in chapter 4, is a Hybrid Choice model. This work focused on objective **O2**, by incorporating psychological constructs (pro-greywater reuse attitudes). Alongside further support for hypotheses **H1** and **H2**, the key finding of this chapter supports research hypothesis **H3**, by showing that in some cases psychological constructs can be (equal or) more influential than observed characteristics in shaping the acceptability of treated greywater for different uses. In general, we found that women and consumers with lower education have a less favourable attitude towards greywater reuse. These underlying attitudes play a role in shaping the individuals' acceptability of different uses, where the influence varies across uses, and is by far the lowest for drinking.

The third model, in chapter 5, is a Latent Class model. This work focused on objective **O3**, by looking at probabilistically allocating the population into different segments according to their sensitivities to changes on the greywater service. Alongside further support for hypotheses **H1** and **H2**, the key finding of this chapter supports research hypothesis **H4**, by showing that consumers can be divided into groups with very distinct preferences (and hence different levels of acceptability). It also showed that the way in which individuals are distributed across these classes, is a function of both observed consumer characteristics and idiosyncratic differences in sensitivities. We found that one group was strongly in favour of greywater reuse (*enthusiasts*) while another was strongly opposed (*greywater sceptics*). Two other groups focused more on the characteristics of the water (*appearance conscious*) or the implied extent of use (*water expenditure conscious*).

In general, from the three models used, we understood that:

(i) the appearance of the greywater (colour and smell) after treatment matters highly. Therefore, individuals must be informed about how the system would work within their homes and what they should expect from it. In terms of water appearance, we were also able to understand that a light blue colouration of the water does not negatively affect acceptability, so it could be a useful strategy to distinguish between mains water and treated greywater.

(ii) Savings on the water bill, *per se,* help promote acceptability. However, monetary incentives could be incorporated to achieve greater uptake by individuals.

Many choice modelling applications in environmental sciences and beyond, have focused only on understanding preferences and potential demand, but not in making the transition from modelling work to actual use of the results. Notwithstanding the fact that the modelling work itself pushed the state-of-the-art in the field and generated valuable insights, a core aim of this thesis was to *use* the results from these models to generate real-world benefits. This was the aim of chapter 6, which addresses objective **O4**.

Chapter 6 brings together the evidence from the three separate modelling analyses, looking at the implications of the current regulation on acceptability, and investigating strategies to achieve higher acceptability in an efficient way. The work investigated five main scenarios. First, monetary incentives, to alleviate the monetary costs of system operation and maintenance. Secondly, educational awareness. Thirdly, removing the individuals' scepticism. Fourth, both educational awareness and monetary savings on the water bill. And, finally, a combination of all strategies.

It was possible to conclude that removing population scepticism can be as efficient to achieve higher acceptability as providing monetary incentives. With these results, it is evident that public management policies must include the population to guarantee a greater adoption of the measures. Until now, no formal campaigns had promoted water reuse as a viable source that can reach appropriate quality standards for use within the home. Pilot experiences released to the public can also help remove scepticism from the population.

Another important insight obtained from this thesis involves the forecasts (in Chapter 6) of the volume of water that could be recovered under current regulations *vs* the volume of water that could be recovered under the scenario of allowing an additional use (laundry), which does not require direct contact with the skin or intake. Our results show that this would lead to savings of several hundred litres per household, with clear environmental benefits as well as a more efficient use of the greywater reuse system, by reducing the gap between the amount of available treated greywater and that which is actually used. Of course, this analysis was limited to the uses studied in our survey, but the findings can also serve to understand that if individuals are willing to reuse greywater for residential uses, they could also accept it in other high-consumption urban uses such as car washing.

Finally, to aid policy makers, a novel approach was used to present the results in a disaggregate manner using spatial information (i.e., a cartographic illustration). In this way, we cope with the belief that analyses based on hypothetical situations may not be realistic. The maps not only show the city areas in which one could start talking about water reuse and even test pilot technologies, but can also highlight what changes to the regulation might be required to suit the needs of the local population.

This research has demonstrated, with statistical support, that greywater reuse can be acceptable to large parts of the population, but that there is extensive heterogeneity in acceptability. It also shows that allowing a range of indirect uses, can help to optimize the allocation of water uses and, therefore, reduce the demand for mains water at the household level. This dissertation contributes to expanding the concept of acceptability in water management. Still, it could also be applied to other areas that seek to integrate individuals as a fundamental element for better water resource management. Furthermore, an integrated assessment framework was adopted for acceptability analysis, proposing a new theoretical framework to design public policies about residential greywater reuse.

It should be clarified that knowing the acceptability of individuals to reuse grey water in a hypothetical setting, does not imply that a potential rejection of this new supply system would be completely avoided. However, this approximation to the real system can help explain the characteristics of the technology and how it would work and can be a first step to reduce the probability of rejection, by offering a service that adapts to people's requirements and needs.

8. REFERENCES

Abou-Zeid, M. & Ben-Akiva, M. (2014). Hybrid choice models. In S. Hess & A. Daly (eds.), Handbook of Choice Modelling. Edward Elgar Publishing, Cheltenham

Adapa, S. (2018). Factors influencing consumption and anti-consumption of recycled water: evidence from Australia. Journal of Cleaner Production 201, 624–635 .org/10.1016/J.JCLEPRO.2018.08.083

Aguas Andinas (2016). Reporte de Sustentabilidad. Retrieved from www.aguasandinas.cl (in Spanish)

Aguas Andinas (2019). Reporte integrado. Retrieved from www.aguasandinasinversionistas.cl

AIDIS & UNESCO (2016). Uso seguro del agua para el reúso (P. Tello, P. Mijailova, & R. Chamy, eds.). Retrieved from http://www.aidis.org.br/PDF/AIDIS-Uso_seguro_del_agua_26_sep.pdf

Aitken, V., Bell, S., Hills, S. & Rees, L. (2014). Public acceptability of indirect potable water reuse in the south-east of England. Water Science and Technology: Water Supply, 14, 875–885 doi.org/10.2166/ws.2014.051

Ajzen, I. (1985). From intentions to actions: a theory of planned behavior. In J. Kuhl & J. Beckmann (eds.), Action Control: From Cognition to Behaviour. Springer-Verlag, Berlin.

Ajzen, I. & Fishbein, M. (1975). A Bayesian analysis of attribution processes. Psychological Bulletin, 82, 261–277 doi.org/10.1037/h0076477

Akter, S., Krupnik, T. J., & Khanam, F. (2017). Climate change skepticism and index versus standard crop insurance demand in coastal Bangladesh. Regional Environmental Change, 17(8), 2455–2466. https://doi.org/10.1007/s10113-017-1174-9

Amaris, G., Dawson, R., Gironás, J., Hess, S. & Ortúzar, J. de D. (2020). Understanding the preferences for different types of urban greywater uses and the impact of qualitative attributes. Water Research, 116007 .org/10.1016/j.watres.2020.116007

Amaris, G., Hess, S., Gironás, J. & Ortúzar, J. de D. (2021a). Using hybrid choice models to capture the impact of attitudes on residential greywater reuse preferences. Resources, Conservation and Recycling, 164, 105171 doi.org/10.1016/j.resconrec.2020.105171

Amaris, G., Gironás, J., Hess, S. & Ortúzar, J. de D. (2021b). Capturing and analysing heterogeneity in residential greywater reuse preferences using a latent class model. Journal of Environmental Management (in press).

Bach, P. M., Rauch, W., Mikkelsen, P. S., McCarthy, D. T. & Deletic, A. (2014). A critical review of integrated urban water modelling – urban drainage and beyond. Environmental Modelling & Software, 54, 88–107 doi.org/10.1016/j.envsoft.2013.12.018

Baghapour, M.A., Shooshtarian, M.R. & Djahed, B. (2017). A survey of attitudes and acceptance of wastewater reuse in Iran: Shiraz City as a case study. Journal of Water Reuse and Desalination 7, 511–519 doi.org/10.2166/wrd.2016.117

Bahamonde-Birke, F. J., Kunert, U., Link, H. & Ortúzar, J. de D. (2017). About attitudes and perceptions: finding the proper way to consider latent variables in discrete choice models. Transportation, 44, 475–493 doi.org/10.1007/s11116-015-9663-5

Brikké, F., & Vairavamoorthy, K. (2016). Managing change to implement integrated urban water management in African cities. Aquatic Procedia, 6, 3–14 doi.org/10.1016/j.aqpro.2016.06.002

Baumann, D. D. (1983). Social acceptance of water reuse. Applied Geography, 3, 79–84 .org/10.1016/0143-6228(83)90007-3

Ben-Akiva, M., McFadden, D., Train, K., Walker, J., Bhat, C., Bierlaire, M., Bolduc, D., Boersch-Supan, A., Brownstone, D., Bunch, D.S., Daly, A., de Palma, A., Gopinath, D., Karlstrom, A. & Munizaga, M.A. (2002). Hybrid choice models: progress and challenges. Marketing Letters, 13, 163–175 doi.org/10.1023/A:1020254301302

Bennett, J. & Blamey, R. (2001). Assessing the options for the Canberra water supply: an application of choice modelling. In J. Bennett & R. Blamey (eds.), The Choice Modelling Approach to Environmental Valuation. Edward Elgar Publishing, Cheltenham.

Bliemer, M.C.J. & Rose, J.M. (2010). Construction of experimental designs for mixed logit models allowing for correlation across choice observations. Transportation Research Part B: Methodological 44, 720–734 doi.org/10.1016/j.trb.2009.12.004

Bonelli, S., Vicuña, S., Meza, F. J., Gironás, J. & Barton, J. (2014). Incorporating climate change adaptation strategies in urban water supply planning: the case of central Chile. Journal of Water and Climate Change, 5, 357 .org/10.2166/wcc.2014.037

Buyukkamaci, N., & Alkan, H. S. (2013). Public acceptance potential for reuse applications in Turkey. Resources, Conservation and Recycling, 80(1), 32–35. https://doi.org/10.1016/j.resconrec.2013.08.001

Cáceres, G., Nasirov, S., Zhang, H., & Araya-Letelier, G. (2015). Residential solar PV planning in Santiago, Chile: incorporating the PM10 parameter. Sustainability 7, 422–440 doi.org/10.3390/su7010422

Carpenter, S. R., Caraco, N. F., Correll, D. L., Howarth, R. W., Sharpley, A. N. & Smith, V. H. (1998). Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications, 8, 559–568 doi.org/10.2307/2641247

Caussade, S., Ortúzar, J. de D., Rizzi, L.I. & Hensher, D.A. (2005). Assessing the influence of design dimensions on stated choice experiment estimates. Transportation Research Part B: Methodological 39, 621–640 doi.org/10.1016/J.TRB.2004.07.006

Chen, Y., Lu, H., Li, J., Ren, L. & He, L. (2017). A leader-follower-interactive method for regional water resources management with considering multiple water demands and eco-environmental constraints. Journal of Hydrology, 548, 121–134 .org/10.1016/j.jhydrol.2017.02.015

Chen, Z., Wu, Q., Wu, G. & Hu, H.Y. (2017). Centralized water reuse system with multiple applications in urban areas: lessons from China’s experience. Resources, Conservation and Recycling 117, 125–136 doi.org/10.1016/j.resconrec.2016.11.008

Ching, L. (2015). A quantitative investigation of narratives: recycled drinking water. Water Policy, 17, 831–847 doi.org/10.2166/wp.2015.125

ChoiceMetrics (2012). Ngene user manual & reference guide. Retrieved from www.choice-metrics.com

Coombes, Y., & Devine, J. (2010). Introducing FOAM: A Framework to Analyze Handwashing Behaviors to Design Effective Handwashing Programs. https://doi.org/https://doi.org/10.1596/27924

Da Silva, L. C. C., Filho, D. O., Silva, I. R., Pinto, A. C. V. & Vaz, P. N. (2019). Water sustainability potential in a university building – case study. Sustainable Cities and Society, 47, 101489 .org/10.1016/j.scs.2019.101489

Daly, A. (2010). Cost damping in travel demand models: report of a study for the Department of Transport. Technical Report, Rand Europe, Cambridge.

Distefano, T. & Kelly, S. (2017). Are we in deep water? Water scarcity and its limits to economic growth. Ecological Economics, 142, 130–147 doi.org/10.1016/j.ecolecon.2017.06.019

Dolnicar, S., Hurlimann, A. & Grün, B. (2011). What affects public acceptance of recycled and desalinated water? Water Research 45, 933–943 doi.org/10.1016/J.WATRES.2010.09.030

Domencich, T. A., & McFadden, D. (1975). Urban Travel Demand - A Behavioral Analysis (North-Holland, Ed.).

Domnech, L. & Saurí, D. (2010). Socio-technical transitions in water scarcity contexts: public acceptance of greywater reuse technologies in the Metropolitan Area of Barcelona. Resources, Conservation and Recycling 55, 53–62 doi.org/10.1016/j.resconrec.2010.07.001

Etale, A., Fielding, K., Schäfer, A. I. & Siegrist, M. (2020). Recycled and desalinated water: consumers' associations, and the influence of affect and disgust on willingness to use. Journal of Environmental Management, 261, 110217 .org/10.1016/j.jenvman.2020.110217

Fielding, K.S., Dolnicar, S. & Schultz, T. (2019). Public acceptance of recycled water. International Journal of Water Resources Development 35, 551–586 doi.org/10.1080/07900627.2017.1419125

Fielding, K. S. & Roiko, A.H. (2014). Providing information promotes greater public support for potable recycled water. Water Research 61, 86–96. doi.org/10.1016/j.watres.2014.05.002

Fountoulakis, M.S., Markakis, N., Petousi, I. & Manios, T. (2016). Single house on-site grey water treatment using a submerged membrane bioreactor for toilet flushing. Science of the Total Environment 551–552, 706–711 doi.org/10.1016/j.scitotenv.2016.02.057

Fundación Chile - FCH. (2017). Desafíos del agua para la región Latinoamericana. Retrieved from https://fch.cl/wp-content/uploads/2017/03/DESAFIOS-DEL-AGUA-ok.pdf (In Spanish)

Franceschinis, C., Thiene, M., Scarpa, R., Rose, J., Moretto, M. & Cavalli, R. (2017). Adoption of renewable heating systems: an empirical test of the diffusion of innovation theory. Energy, 125, 313–326 .org/10.1016/j.energy.2017.02.060

Garcia-Cuerva, L., Berglund, E.Z. & Binder, A.R. (2016). Public perceptions of water shortages, conservation behaviours, and support for water reuse in the U.S. Resources, Conservation and Recycling 113, 106–115 doi.org/10.1016/j.resconrec.2016.06.006

Gaudry, M.J.I., Jara-Diaz, S.R. & Ortúzar, J. de D. (1989). Value of time sensitivity to model specification. Transportation Research Part B: Methodological 23, 151–158 doi.org/10.1016/0191-2615(89)90038-6

Gfk. (2019). Estilo de vida de los nuevos grupos socioeconómicos en Chile. (In Spanish)

Gibson, F.L. & Burton, M. (2014). Salt or sludge? Exploring preferences for potable water sources. Environmental and Resource Economics 57, 453–476 doi.org/10.1007/s10640-013-9672-9

Goodwin, D., Raffin, M., Jeffrey, P., & Smith, H. M. (2018). Informing public attitudes to non-potable water reuse – the impact of message framing. Water Research 145, 125–135 doi.org/10.1016/j.watres.2018.08.006

Greene, W. H. & Hensher, D. A. (2003). A latent class model for discrete choice analysis: contrasts with mixed logit. Transportation Research Part B: Methodological, 37, 681–698 doi.org/10.1016/S0191-2615(02)00046-2

Gu, Q., Chen, Y., Pody, R., Cheng, R., Zheng, X. & Zhang, Z. (2015). Public perception and acceptability toward reclaimed water in Tianjin. Resources, Conservation and Recycling 104, 291–299 doi.org/10.1016/j.resconrec.2015.07.013

Guthrie, L., De Silva, S. & Furlong, C. (2017). A categorisation system for Australia's integrated urban water management plans. Utilities Policy 48, 92–102 doi.org/10.1016/j.jup.2017.08.007

Gustafsod, P. E. (1998). Gender Differences in Risk Perception: Theoretical and Methodological erspectives. Risk Analysis, 18(6), 805–811. https://doi.org/10.1111/j.1539-6924.1998.tb01123.x

Halkos, G. & Matsiori, S. (2014). Exploring social attitude and willingness to pay for water resources conservation. Journal of Behavioral and Experimental Economics, 49, 54–62 .org/10.1016/j.socec.2014.02.006

Harris-Lovett, S. R., Binz, C., Sedlak, D. L., Kiparsky, M. & Truffer, B. (2015). Beyond user acceptance: a legitimacy framework for potable water reuse in California. Environmental Science and Technology, 49, 7552–7561 .org/10.1021/acs.est.5b00504

Hartley, T.W. (2006). Public perception and participation in water reuse. Desalination 187, 115–126 doi.org/10.1016/j.desal.2005.04.072

Hensher, D. A., Rose, J. M. & Greene, W. H. (2015). Applied Choice Analysis. Second Edition, Cambridge University Press, Cambridge.

Hess, S. (2014). Latent class structures: Taste heterogeneity and beyond. In S. Hess & A.J. Daly (Eds.), Handbook of Choice Modelling. Edward Elgar, Chentelham doi.org/10.4337/9781781003152.00021

Hess, S. & Palma, D. (2019). Apollo: a flexible, powerful and customisable freeware package for choice model estimation and application. Journal of Choice Modelling 32, 100170 doi.org/10.1016/j.jocm.2019.100170

Hess, S., Spitz, G., Bradley, M. & Coogan, M. (2018). Analysis of mode choice for intercity travel: application of a hybrid choice model to two distinct US corridors. Transportation Research Part A: Policy and Practice, 116, 547–567 doi.org/10.1016/j.tra.2018.05.019

Hess, S., Train, K.E. & Polak, J.W. (2006). On the use of a Modified Latin Hypercube Sampling (MLHS) method in the estimation of a Mixed Logit model for vehicle choice. Transportation Research Part B: Methodological, 40, 147-163 doi.org/10.1016/j.trb.2004.10.005

Hess, S. & Daly, A. (eds.) (2014). Handbook of Choice Modelling. Edward Elgar Publishing, Cheltenham doi.org/10.4337/9781781003152

Hess, S., Daly, A., Dekker, T., Cabral, M. O. & Batley, R. (2017). A framework for capturing heterogeneity, heteroskedasticity, non-linearity, reference dependence and design artefacts in value of time research. Transportation Research Part B: Methodological, 96, 126–149 .org/10.1016/j.trb.2016.11.002

Hou, C., Fu, H., Liu, X. & Wen, Y. (2020). The effect of recycled water information disclosure on public acceptance of recycled water—evidence from residents of Xi'an, China. Sustainable Cities and Society, 61, 102351 .org/10.1016/j.scs.2020.102351

Hoyos, D. (2010). The state of the art of environmental valuation with discrete choice experiments. Ecological Economics, 69, 1595–1603 doi.org/10.1016/j.ecolecon.2010.04.011

Hoyos, D., Mariel, P. & Hess, S. (2015). Incorporating environmental attitudes in discrete choice models: an exploration of the utility of the awareness of consequences scale. Science of the Total Environment, 505, 1100–1111 .org/10.1016/j.scitotenv.2014.10.066

Hurlimann, A. & Dolnicar, S. (2016). Public acceptance and perceptions of alternative water sources: a comparative study in nine locations. International Journal of Water Resources Development, 32, 650–673 .org/10.1080/07900627.2016.1143350

Ilemobade, A. A., Olanrewaju, O. O. & Griffioen, M. L. (2013). Greywater reuse for toilet flushing at a university academic and residential building. Water SA, 39, 351–360 doi.org/10.4314/wsa.v39i3.2

Instituto Nacional de Estadísticas INE (2018). Memoria del Censo 2017. Instituto Nacional de Estadísticas, Santiago. Retrieved from www.censo2017.cl/memoria/, accessed online 7 April 2020 (in Spanish)

Jäger-Waldau, A. (2019). PV Status Report 2019, EUR 29938 EN. Publications Office of the European Union, Luxembourg, ISBN 978-92-76-12608-9, doi:10.2760/326629, JRC118058

Jefferson, B., Palmer, A., Jeffrey, P., Stuetz, R. & Judd, S. (2004). Grey water characterisation and its impact on the selection and operation of technologies for urban reuse. Water Science and Technology, 50, 157–164. doi.org/10.2166/wst.2004.0113

Jimenez, B. & Asano, T. (2008). Water reuse: an international survey of current practice, issues and needs. In Water Intelligence Online. Retrieved from http://library.wur.nl/WebQuery/titel/1887028 si esto es un libro, faltan editores , editorial y ciudad

Katz, S. M., Tennyso, P. A., & Snyder, K. (2015). Public outreach for potable reuse: Bringing the public to a new level of acceptance. Journal - American Water Works Association, 107(11), 46–53. https://doi.org/10.5942/jawwa.2015.107.0160

Khan, S.J. & Anderson, R. (2018). Potable reuse: experiences in Australia. Current Opinion in Environmental Science & Health 2, 55–60 doi.org/10.1016/J.COESH.2018.02.002

Kim, Y., Park, I., & Kang, S. (2018). Age and gender differences in health risk perception. Central European Journal of Public Health, 26, 54–59. https://doi.org/10.21101/cejph.a4920

Kotzé, P. (2018). Guidelines pave the way for safe use of greywater. Water Wheel, 17, 20–23.

Laland, K. N., Brown, G. & Brown, G. R. (2011). Sense and Nonsense: Evolutionary Perspectives on Human Behaviour. Oxford University Press, Oxford .org/10.1007/s11191-013-9602-9

Lambert, L. A. & Lee, J. (2018). Nudging greywater acceptability in a Muslim country: comparisons of different greywater reuse framings in Qatar. Environmental Science and Policy 89, 93–99. doi.org/10.1016/j.envsci.2018.07.015

Lefebvre, O. (2018). Beyond NEWater: an insight into Singapore's water reuse prospects. Current Opinion in Environmental Science & Health 2, 26–31 doi.org/10.1016/J.COESH.2017.12.001

Leng, J. & Goldstein, D. R. (2010,). Impact of aging on viral infections. Microbes and Infection, 12, 1120–1124. doi.org/10.1016/j.micinf.2010.08.009

Leong, C. (2016). The role of emotions in drinking recycled water. Water, 8, 548 doi.org/10.3390/w8110548

Li, F., Wichmann, K. & Otterpohl, R. (2009). Review of the technological approaches for grey water treatment and reuses. Science of the Total Environment, 407, pp. 3439–3449. doi.org/10.1016/j.scitotenv.2009.02.004

Liu, J., Wang, Y., Yu, Z., Cao, X., Tian, L., Sun, S. & Wu, P. (2017). A comprehensive analysis of blue water scarcity from the production, consumption, and water transfer perspectives. Ecological Indicators, 72, 870–880. doi.org/10.1016/j.ecolind.2016.09.021

Louviere, J. J., Hensher, D. A. & Swait, J. D.(2000). Stated Choice Methods: Analysis and Application. Cambridge University Press, Cambridge. doi.org/10.1017/cbo9780511753831.008 en general los libros no llevan DOI

Lu, Z., Mo, W., Dilkina, B., Gardner, K., Stang, S., Huang, J. C. & Foreman, M.C. (2019). Decentralized water collection systems for households and communities: household preferences in Atlanta and Boston. Water Research 167, 115134 doi.org/10.1016/j.watres.2019.115134

Mankad, A. & Tapsuwan, S. (2011). Review of socio-economic drivers of community acceptance and adoption of decentralised water systems. Journal of Environmental Management, 92, 380–391. doi.org/10.1016/j.jenvman.2010.10.037

Mariel, P. & Meyerhoff, J. (2016). Hybrid discrete choice models: gained insights versus increasing effort. Science of the Total Environment, 568, 433–443 .org/10.1016/j.scitotenv.2016.06.019

Mason, L.R., Arwood, C. & Shires, M.K. (2018). Seasonal patterns and socio-economic predictors of household rainwater and greywater use. Urban Water Journal, 15, 109–115 .org/10.1080/1573062X.2017.1401098

Massoud, M.A., Kazarian, A., Alameddine, I. & Al-Hindi, M. (2018). Factors influencing the reuse of reclaimed water as a management option to augment water supplies. Environmental Monitoring and Assessment, 190. doi.org/10.1007/s10661-018-6905-y

Mekonnen, M.M. & Hoekstra, A.Y. (2016). Four billion people facing severe water scarcity. Science Advances, 2, e1500323. doi.org/10.1126/sciadv.1500323

Meza, F.J., Vicuña, S., Jelinek, M., Bustos, E. & Bonelli, S. (2014). Assessing water demands and coverage sensitivity to climate change in the urban and rural sectors in central Chile. Journal of Water and Climate Change 5, 192–203 doi.org/10.2166/wcc.2014.019

Ministerio del Interior y Seguridad Publica. (2014). Análisis de la situación hídrica en Chile, propuestas y políticas. Gobierno de Chile. Retrieved from http://aih-cl.org/articulos/Analisis-de-la-situacion-hidrica-en-Chile-Gobierno-de-Chile-(mayo-2014).pdf

Minton, J., Murray, C. C., Meads, D., Hess, S., Vargas-Palacios, A., Mitchell, E., … Twiddy, M. (2017). The Community IntraVenous Antibiotic Study (CIVAS): a mixed-methods evaluation of patient preferences for and cost-effectiveness of different service models for delivering outpatient parenteral antimicrobial therapy. Health Services and Delivery Research, 5(6), 1–272. https://doi.org/10.3310/hsdr05060

Mukherjee, M. & Jensen, O. (2020). Making water reuse safe: a comparative analysis of the development of regulation and technology uptake in the US and Australia. Safety Science, 121, 5–14. doi.org/10.1016/j.ssci.2019.08.039

Muthukumaran, S., Baskaran, K. & Sexton, N. (2011). Quantification of potable water savings by residential water conservation and reuse - a case study. Resources, Conservation and Recycling, 55, 945–952. doi.org/10.1016/j.resconrec.2011.04.013

Oh, K.S., Leong, J.Y.C., Poh, P.E., Chong, M.N. & Von Lau, E.E. (2018). A review of greywater recycling related issues: challenges and future prospects in Malaysia. Journal of Cleaner Production 171, 17–29 doi.org/10.1016/j.jclepro.2017.09.267

Ormerod, K. J., Redman, S., & Kelley, S. (2019). Public perceptions of potable water reuse, regional growth, and water resources management in the Reno-Sparks area of northern Nevada, USA. City and Environment Interactions, 2, 100015. https://doi.org/10.1016/j.cacint.2019.100015

Ortúzar, J. de D. & Willumsen, L.G. (2011). Modelling Transport. Fourth Edition, John Wiley & Sons, Chichester.

Ortúzar J de D, Cherchi, E., & Rizzi, L. I. (2014). Transport research needs. In S. H. & A. Daly (Ed.), Handbook of Choice Modelling (pp. 688–698). Retrieved from https://ideas.repec.org/h/elg/eechap/14820_29.html

Oteng-Peprah, M., de Vries, N. & Acheampong, M.A. (2020). Households' willingness to adopt greywater treatment technologies in a developing country – exploring a modified theory of planned behaviour (TPB) model including personal norm. Journal of Environmental Management, 254, 109807 doi.org/10.1016/j.jenvman.2019.109807

Pedro-Monzonís, M., Solera, A., Ferrer, J., Estrela, T. & Paredes-Arquiola, J. (2015). A review of water scarcity and drought indexes in water resources planning and management. Journal of Hydrology, 527, 482–493. doi.org/10.1016/j.jhydrol.2015.05.003

Pham, T.T.N., Ngo, H.H., Guo, W., Dang, H.P.D., Mainali, B., Johnston, A. & Listowski, A. (2011). Responses of community to the possible use of recycled water for washing machines: a case study in Sydney, Australia. Resources, Conservation and Recycling, 55, 535–540 doi.org/10.1016/j.resconrec.2011.01.004

Probe Research Inc. (2017). Water Issues Public Opinion Poll. Retrieved from www.sdcwa.org/sites/default/files/2017 SDCWA Poll Complete Report.pdf

Rodríguez, C., Sánchez, R., Lozano-Parra, J., Rebolledo, N., Schneider, N., Serrano, J. & Leiva, E. (2020). Water balance assessment in schools and households of rural areas of Coquimbo region, north-central Chile: potential for greywater reuse. Water, 12, 2915 .org/10.3390/w12102915

Rose, J. M. & Bliemer, M. C. J. (2014). Stated choice experimental design theory: the who, the what and the why. In S. Hess & A. J. Daly (Eds.), Handbook of Choice Modelling (pp. 152–177), editorial, ciudad. doi.org/10.4337/9781781003152.00013

Rose, J.M., Hensher, D.A., Caussade, S., Ortúzar, J. de D. & Jou, R.C. (2009). Identifying differences in willingness to pay due to dimensionality in stated choice experiments: a cross country analysis. Journal of Transport Geography 17, 21–29 doi.org/10.1016/J.JTRANGEO.2008.05.001

Roshan, A. & Kumar, M. (2020). Water end-use estimation can support the urban water crisis management: a critical review. Journal of Environmental Management, 268, 110663. doi.org/10.1016/j.jenvman.2020.110663

Rungie, C., Scarpa, R. & Thiene, M. (2014). The influence of individuals in forming collective household preferences for water quality. Journal of Environmental Economics and Management 68, 161-174 doi.org/10.1016/j.jeem.2014.04.005

Ryan, A. M., Spash, C. L. & Measham, T. G. (2009). Socio-economic and psychological predictors of domestic greywater and rainwater collection: evidence from Australia. Journal of Hydrology, 379, 164–171. doi.org/10.1016/j.jhydrol.2009.10.002

Saldias, C., Speelman, S., Van Huylenbroeck, G. & Vink, N. (2016). Understanding farmers' preferences for wastewater reuse frameworks in agricultural irrigation: lessons from a choice experiment in the western cape, South Africa. Water SA, 42, 26–37 doi.org/10.4314/wsa.v42i1.04

Scarpa, R., Thiene, M. & Hensher D.A. (2012). Preferences for tap water attributes within couples: an exploration of alternative mixed logit parameterizations. Water Resources Research 48, W01520, doi:10.1029/2010WR010148, 2012

Schaafsma, M., Brouwer, R., Liekens, I., & de Nocker, L. (2014). Temporal stability of preferences and willingness to pay for natural areas in choice experiments: a test-retest. Resource and Energy Economics 38, 243–260 doi.org/10.1016/j.reseneeco.2014.09.001

Serpell, A., Kort, J. & Vera, S. (2013). Awareness, actions, drivers and barriers of sustainable construction in Chile. Technological and Economic Development of Economy 19, 272–288 doi.org/10.3846/20294913.2013.798597

Schmuck, H. (2000). "An Act of Allah": Religious Explanations for Floods in Bangladesh as Survival Strategy. International Journal of Mass Emergencies and Disasters, 18, 85–96.

Shaikh, I. N. & Ahammed, M. M. (2020). Quantity and quality characteristics of greywater: a review. Journal of Environmental Management, 261, 110266. doi.org/10.1016/j.jenvman.2020.110266

Sillano, M. & Ortúzar, J. de D. (2005). Willingness-to-pay estimation with mixed logit models: some new evidence. Environment and Planning A: Economy and Space 37, 525-550 doi.org/10.1068/a36137

Silva, L. C. C. da, Filho, D. O., Silva, I. R., Pinto, A. C. V. e., & Vaz, P. N. (2019). Water sustainability potential in a university building – Case study. Sustainable Cities and Society, 47, 101489. https://doi.org/10.1016/j.scs.2019.101489

Smith, H.M., Brouwer, S., Jeffrey, P. & Frijns, J. (2018). Public responses to water reuse – understanding the evidence. Journal of Environmental Management 207, 43–50 doi.org/10.1016/J.JENVMAN.2017.11.021

Smith, H.M., Brouwer, S., Jeffrey, P. & Frijns, J. (2018). Public responses to water reuse – understanding the evidence. Journal of Environmental Management, 207, 43–50 doi.org/10.1016/J.JENVMAN.2017.11.021

Su, W., Liu, M., Zeng, S., Štreimikienė, D., Baležentis, T., & Ališauskaitė-Šeškienė, I. (2018). Valuating renewable microgeneration technologies in Lithuanian households: A study on willingness to pay. Journal of Cleaner Production, 191, 318–329 .org/10.1016/j.jclepro.2018.04.199

Subramanian, P. S. G., Raj, A. V., Jamwal, P., Connelly, S., Yeluripati, J., Richards, S., Ellis, R., and Rao, L. (2020). Decentralized treatment and recycling of greywater from a school in rural India. Journal of Water Process Engineering, 38, 101695. https://doi.org/10.1016/j.jwpe.2020.101695

Tchetchik, A., Kaufman, D., & Blass, V. (2016). Perceived scarcity, habits, environmental attitudes, and price sensitivity: How do they interact with preferences towards greywater systems? Built Environment, 42(2), 273–293. doi.org/10.2148/benv.42.2.273

Tortajada, C., & Nambiar, S. (2019). Communications on Technological Innovations: Potable Water Reuse. Water, 11(2), 251. https://doi.org/10.3390/w11020251

Train, K.E. (2009). Discrete Choice Methods with Simulation. Cambridge University Press, Cambridge.

Valdés-Pineda, R., Pizarro, R., García-Chevesich, P., Valdés, J. B., Olivares, C., Vera, M. & Helwig, B. (2014). Water governance in Chile: availability, management and climate change. Journal of Hydrology, 519, 2538–2567 doi.org/10.1016/j.jhydrol.2014.04.016

Veronesi, M., Chawla, F., Maurer, M. & Lienert, J. (2014). Climate change and the willingness to pay to reduce ecological and health risks from wastewater flooding in urban centers and the environment. Ecological Economics, 98, 1–10. doi.org/10.1016/j.ecolecon.2013.12.005

Vicuña, S., Gil, M., Melo, O., Donoso, G. & Merino, P. (2018). Water option contracts for climate change adaptation in Santiago, Chile. Water International, 43, 237–256 .org/10.1080/02508060.2017.1416444

Vij, A. & Walker, J. L. (2016). How, when and why integrated choice and latent variable models are latently useful. Transportation Research Part B: Methodological, 90, 192–217. doi.org/10.1016/j.trb.2016.04.021

Vuppaladadiyam, A. K., Merayo, N., Prinsen, P., Luque, R., Blanco, A. & Zhao, M. (2019). A review on greywater reuse: quality, risks, barriers and global scenarios. Reviews in Environmental Science and Biotechnology, 18, 77–99 doi.org/10.1007/s11157-018-9487-9

Wallsten, T. S. & Budescu, D. V. (1983). State of the art—encoding subjective probabilities: a psychological and psychometric review. Management Science, 29, 151–173. doi.org/10.1287/mnsc.29.2.151

Wang, C., Hou, Y. & Xue, Y. (2017). Water resources carrying capacity of wetlands in Beijing: analysis of policy optimization for urban wetland water resources management. Journal of Cleaner Production, 161, 1180–1191 .org/10.1016/j.jclepro.2017.03.204

Wang, X. R., Hui, E. C. M. & Sun, J. X. (2017). Population migration, urbanization and housing prices: evidence from the cities in China. Habitat International, 66, 49–56 .org/10.1016/j.habitatint.2017.05.010

Wanjiru, E., & Xia, X. (2018). Sustainable energy-water management for residential houses with optimal integrated grey and rain water recycling. Journal of Cleaner Production, 170, 1151–1166. https://doi.org/10.1016/j.jclepro.2017.09.212

Wester, J., & Broad, K. (2021). Direct potable water recycling in Texas: case studies and policy implications. Journal of Environmental Policy and Planning, 23(1), 66–83. https://doi.org/10.1080/1523908X.2020.1798749

Wester, J., Timpano, K.R., Çek, D. & Broad, K. (2016). The psychology of recycled water: factors predicting disgust and willingness to use. Water Resources Research 52, 3212–3226 doi.org/10.1002/2015WR018340

Wester, J., Timpano, K.R., Çek, D., Lieberman, D., Fieldstone, S.C. & Broad, K. (2015). Psychological and social factors associated with wastewater reuse emotional discomfort. Journal of Environmental Psychology 42, 16–23 doi.org/10.1016/J.JENVP.2015.01.003

Wilcox, J., Nasiri, F., Bell, S. & Rahaman, M.S. (2016). Urban water reuse: a triple bottom line assessment framework and review. Sustainable Cities and Society 27, 448–456 doi.org/10.1016/J.SCS.2016.06.021

Woltersdorf, L., Zimmermann, M., Deffner, J., Gerlach, M. & Liehr, S. (2018). Benefits of an integrated water and nutrient reuse system for urban areas in semi-arid developing countries. Resources, Conservation and Recycling 128, 382–393 doi.org/10.1016/j.resconrec.2016.11.019

Wu, B. (2019). Membrane-based technology in greywater reclamation: a review. Science of the Total Environment, 656, 184–200 .org/10.1016/j.scitotenv.2018.11.347

Yang, H. D. & Yoo, Y. (2004). It's all about attitude: revisiting the technology acceptance model. Decision Support Systems, 38, 19–31 .org/10.1016/S0167-9236(03)00062-9

Yi, L., Jiao, W., Chen, X. & Chen, W. (2011). An overview of reclaimed water reuse in China. Journal of Environmental Sciences, 23, 1585–1593 .org/10.1016/S1001-0742(10)60627-4

Yuriev, A., Dahmen, M., Paillé, P., Boiral, O. & Guillaumie, L. (2020). Pro-environmental behaviors through the lens of the theory of planned behavior: a scoping review. Resources, Conservation and Recycling, 155, 104660 .org/10.1016/j.resconrec.2019.104660

Zhang, Z. & Balay, J. W. (2014). How much is too much? Challenges to water withdrawal and consumptive use management. Journal of Water Resources Planning and Management, 140, 01814001 .org/10.1061/(asce)wr.1943-5452.0000446