Essays on Economic Incentives for the Implementation of Sustainable Construction Processes and Materials

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vorgelegt von

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List of Abbreviations

AMG	Augmented mean group
CD	Cross-sectional dependence
CE	Circular economy
CMUR	Circular Material Footprint
DCE	Discrete choice experiment
DMC	Domestic material consumption
EU	European Union
GB	Green building
GDP	Gross domestic product
GHG	Greenhouse gas
GVA	Gross value added
IIA	Independence of irrelevant alternatives
ML	Mixed logit
NA	Natural/primary aggregates
NAC	Concrete with natural/primary aggregates
PMG	Pooled mean group
pp	Percentage point(s)
RA	Recycled aggregates
RAC	Recycled aggregate concrete
RP	Resource productivity
RTR	Resource tax rate
SD	Standard deviation
WTP	Willingness to pay

Part I

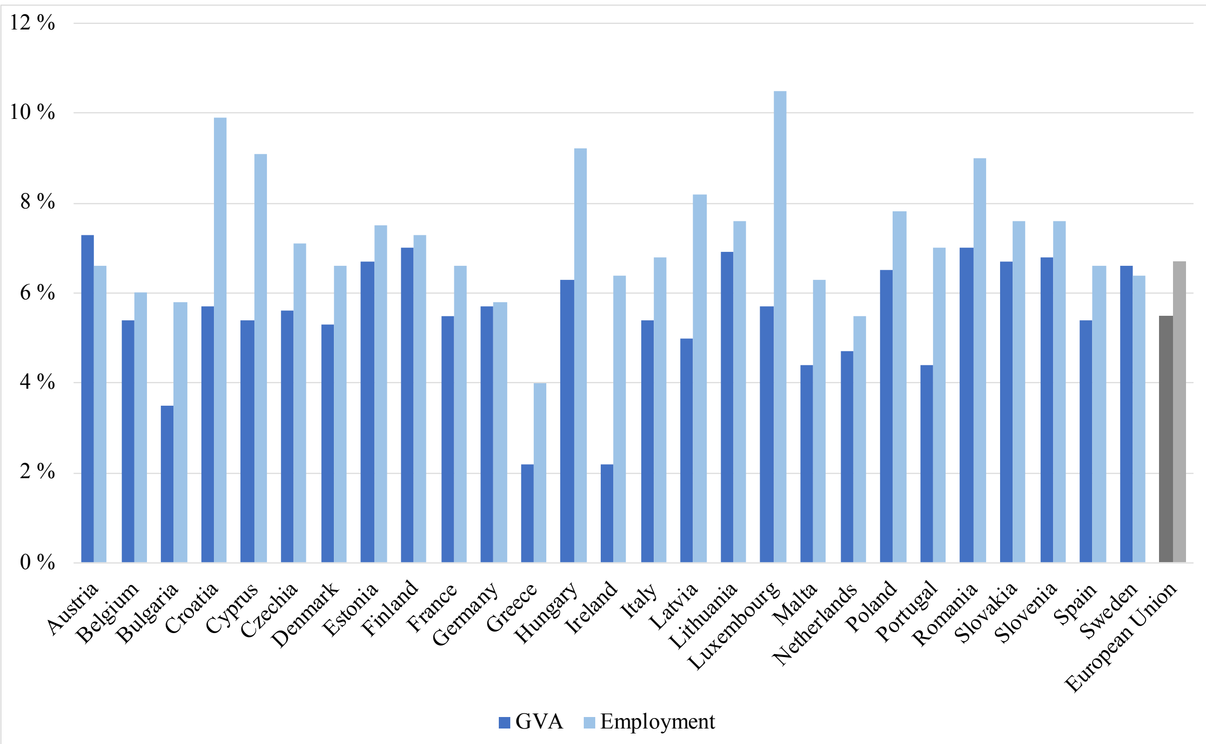
Introduction

Introduction

1 Motivation

The construction industry[1] is an underrepresented sector for sustainability efforts (e.g., only 4 % of scientific articles on sustainability cover the construction industry[2]). However, looking at the industry's size and environmental impact quickly shows the potential for targeted interventions. In 2022, it accounted for a gross value added (GVA) of 788 billion EUR, translating to 5.5 % of the European Union's (EU) total GVA. The contribution of the construction sector to overall GVA in 2022 among EU member states ranges from 2.2 % (Ireland) to 7.3 % (Austria; Eurostat, 2023c). The relevance of the construction industry is also reflected in the employment figures. In 2022, around 14 million people in the EU were employed in the construction industry, equaling 6.7 % of total employment. These shares in EU countries range between 4.0 % (Greece) and 10.5 % (Luxembourg) in 2022[3] (Eurostat, 2023a). Figure I.1 depicts the construction industry shares in GVA and employment in EU member states in 2022.

Figure I.1: Share of the construction industry in GVA and employment in EU member states in 2022

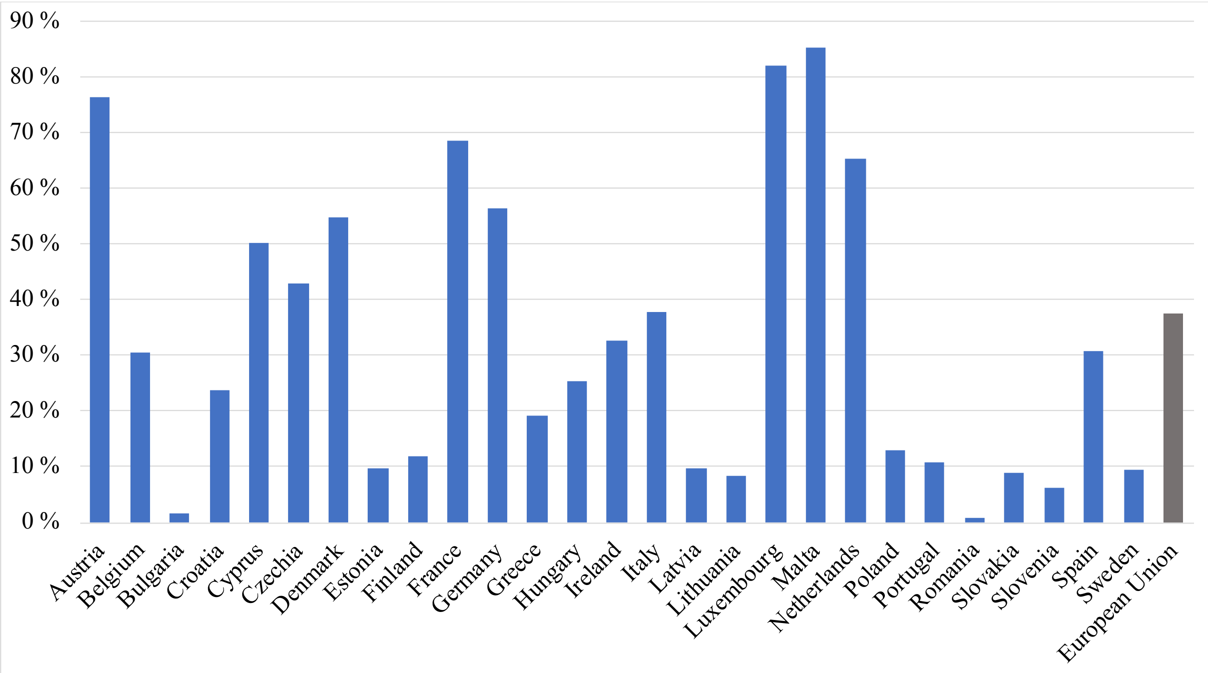


Data source: Eurostat (2023c, 2023a)
GVA = gross value added, EU = European Union

[1] When referring to the construction industry, both civil engineering and building construction are included, although the focus in some of the essays in this thesis is exclusively on the latter.
[2] The search term "sustainab*" in the article title yields 264,250 results in the Scopus database (www.scopus.com), while the search term "sustainab* AND (construction OR building)" yields 10,697 results. The search was conducted on January 23, 2024.
[3] The values stated refer to the first quarter of each year.

Apart from its economic relevance, the construction industry has a substantial ecological impact. Construction, use, and demolition of buildings account for 40 % of total energy consumption and 36 % of greenhouse gas (GHG) emissions in the EU (European Commission, 2020c). Moreover, about 50 % of all resources extracted in the EU are destined for the construction industry (European Commission, 2020b). Beyond the fact that most of these resources are not renewable and will not be available for future generations (unless they are reused or recycled), resource extraction causes substantial environmental damage. Examples are loss of biodiversity, air and water pollution, or landscape degradation (Aigbedion & Iyayi, 2007). The waste generated in the demolition and construction processes amounted to 807 million tons in the EU in 2020[4], translating to approximately 1.8 tons per capita and 37 % of total waste generated (Eurostat, 2023b). Figure I.2 displays the share of waste from the construction industry relative to total waste in 2020 in the EU member states.

Figure I.2: Share of the construction industry in total waste generation in EU member states in 2020[5]



Data source: Eurostat (2023b)
EU = European Union

According to Eurostat (2023e), the EU's recycling rate of mineral waste from construction and demolition processes – the second largest waste stream in the construction industry by weight (Eurostat, 2023b) – was 78 % in 2020. The remaining share is primarily used for backfilling or disposed of. The recycled share in Germany is 84 %[6]. However, when additionally taking the waste stream of soil and stones – the largest waste stream in the construction industry (Eurostat, 2023b) – into account, the recycling rate is much lower. Only 11 % of this waste category is

[4] More recent data is not yet available in Eurostat.
[5] The strikingly small values for Bulgaria and Romania are not an anomaly of 2020. While construction activity in these countries is relatively low compared to the European mean (Hauptverband der Deutschen Bauindustrie e.V., 2023b), the data assembly method is likely the primary reason behind these values. Data are collected through surveys that do not encompass all companies and have low response rates. Additionally, definitions and demarcations of waste categories might differ from the general understanding (Eurostat, 2022c). This argument is supported by the fact that the share of waste from mining and quarrying is exceptionally high in Bulgaria and Romania (Eurostat, 2023b).
[6] These values refer to the waste treated within the borders of the EU or Germany, respectively.

recycled (Kreislaufwirtschaft Bau, 2023). The organization *Kreislaufwirtschaft Bau* (2023) shows that of the total construction waste generated in Germany, more than half is used in backfilling and landfill construction, just over a third is recycled, and the rest is disposed of[7]. Most recycled aggregates (RA) are used in civil engineering and earthworks, while only close to a fifth is used in asphalt and concrete production. The rest is used in other applications, mainly landfill construction[8] (Kreislaufwirtschaft Bau, 2023). EU-wide, only around a tenth of all aggregates are RA, with countries differing significantly from each other (data for 2019; UEPG, n.d.). Thus, there is room for more resource efficiency in the construction industry.

A measure to lower the construction industry's environmental footprint is sustainable construction, sometimes also referred to as *green building* (GB; Zhao et al., 2019). Based on the general definition of sustainable development from the Brundtland Report, the idea is to use construction processes and materials that will help fulfill the current needs while preserving future generations' possibilities to fulfill their needs (Brundtland, 1987). In 1994, the First International Conference on Sustainable Construction was held in Tampa, Florida, after which the convenor, Charles J. Kibert, defined sustainable construction as "the practice of creating and operating a healthy built environment based on resource efficiency and ecological principles" (Kibert, 1994, p. 3). This definition can be categorized as narrow, primarily focusing on the environmental aspects of sustainability. In contrast, broad definitions follow the triple bottom line approach by incorporating social and economic factors as well (Zuo & Zhao, 2014). Throughout this thesis, the primary focus is on the environmental side of sustainability, and from this point on, this narrow understanding is referred to unless stated otherwise.

A simple internet search already shows that the topic of sustainable construction is becoming increasingly popular: The search term "sustainable construction", filtered for results of 2022, yields 72.9 million results on Google, while the same search for the year 2015 yields only 12.5 million results[9]. Bibliometric reviews confirm it is an emerging and fast-growing field (Det Udomsap & Hallinger, 2020). This trend is also reflected in the growing number of sustainability certifications annually awarded to buildings. For example, the German certification scheme, DGNB[10], handed out 1424 certifications in 2022, representing 14 % of all certifications of their 24-year existence (DGNB, 2023). Apart from environmental aspects, these certifications also consider economic, social, and technical factors. Examples of practices that are in line with sustainable construction and that are recognized by the DGNB in the environmental realm are the following: applying a life cycle assessment and basing decisions on its outcomes, reducing the GHG emissions associated with the construction process, reducing the need for potable water and reusing wastewater, limiting land consumption and additional ground sealing, and creating a strategy to retain the local biodiversity (DGNB, n.d.). Regarding material use, sustainable construction may include abstaining from using environmentally harmful materials such as heavy metals, preferably using renewable materials, and applying materials that have been extracted responsibly or come from secondary sources (DGNB, n.d.).

Currently, several barriers are still in place that hamper the implementation of sustainable construction processes and materials. These are of regulatory, economic, technical, and social nature. To overcome these barriers and tackle the construction industry's tremendous

[7] The exact values are 54.7 %, 34.9 %, and 10.4 % for backfilling and landfill construction, recycling, and disposal, respectively (Kreislaufwirtschaft Bau, 2023).
[8] The exact values are 50.3 %, 23.0 %, 19.5 %, and 7.2 % for civil engineering, earthworks, production of asphalt and concrete, and other applications, respectively (Kreislaufwirtschaft Bau, 2023).
[9] The search was conducted on October 11, 2023.
[10] German Sustainable Building Council; www.dgnb.de/en

environmental impact, the European Commission focuses on this industry as one of the critical product value chains in the Circular Economy Action Plan. The aim is to promote circularity in the construction industry through measures such as obligatory recycled contents for certain products, improving the lifespan and flexibility of buildings, integrating life cycle assessments in public procurement, and setting new material recovery targets (European Commission, 2020b). The construction industry has similarly been prioritized as one of the main sectors for a circular transition by the Ellen MacArthur Foundation. Among the ten circular investment opportunities they list, two refer to the built environment: (1) renovation and upgrade of buildings and (2) building materials reuse and recycling infrastructure (Ellen MacArthur Foundation, 2020).

Economic incentives[11] play a significant role in the transition toward a sustainable construction industry. They can counteract the barriers to GB experienced by relevant stakeholders (e.g., Choi, 2009; Darko & Chan, 2017) and correct market failures impeding the rise of sustainable practices and materials on the market (e.g., Söderholm & Tilton, 2012). Institutions and researchers call for incentives stimulating sustainable construction (e.g., Ostertag et al., 2021). This thesis analyzes economic incentives that can help to reduce the construction industry's environmental footprint. Financial and non-financial incentives are examined, and excursions to other non-incentive instruments are made. These differentiations will be elucidated in Section 2.2. To underpin the analysis, this thesis identifies the underlying issues that hinder the implementation of sustainable construction processes and materials and pinpoints the factors impacting the effectiveness of the instruments to alleviate these issues. The first two essays focus on a specific construction material (recycled aggregate concrete [RAC]) and identify the barriers and drivers for its use, construction clients' willingness to pay (WTP), and the effectiveness of potential incentives to stimulate their demand. The third essay approaches sustainable construction more generally, analyzing citizens' acceptance of GB in their municipality and instruments that could improve it. Finally, the fourth essay zooms in on a specific tax incentive and evaluates its effect in European countries. Table I.1 gives an overview of the essays in this thesis.

The following sections of this introduction outline the relevant background literature to this thesis (Chapter 2) and present its essays one by one (Chapter 3) before concluding the introduction (Chapter 4). The individual essays then constitute the remaining parts of this thesis (Part II – V).

[11] Throughout this thesis, "economic incentives" and "incentives" are used interchangeably and encompass both financial and non-financial incentives. See Section 2.2 and Figure I.4 for the precise demarcation of the term.

Table I.1: Overview of the essays of this thesis

Essay number	Title	Main topics	Method
1	Willingness to Pay for Recycled Aggregates in Concrete Among German Construction Clients	– Demand for RAC – Barriers & drivers – WTP	Survey (discrete choice experiment); logit regression analysis
2	Incentives for Construction Clients in Germany to Choose Concrete With Recycled Aggregates	– Demand for RAC – Effectiveness of incentives	Survey (factorial survey); linear regression analysis
3	Citizens' Acceptance of Sustainable Construction in Their Municipality	– Public construction – Public acceptance – WTP – Potential incentives	Survey (discrete choice experiment, factorial survey); logit & linear regression analysis
4	Resource Taxes as an Instrument to Foster Circularity? Analysis of the Effects of Resource Taxation on Circular Economy Progress in Europe	– Circular economy – Resource taxation	Secondary data analysis; panel data analysis

RAC = recycled aggregate concrete, WTP = willingness to pay

2 Relevant Literature

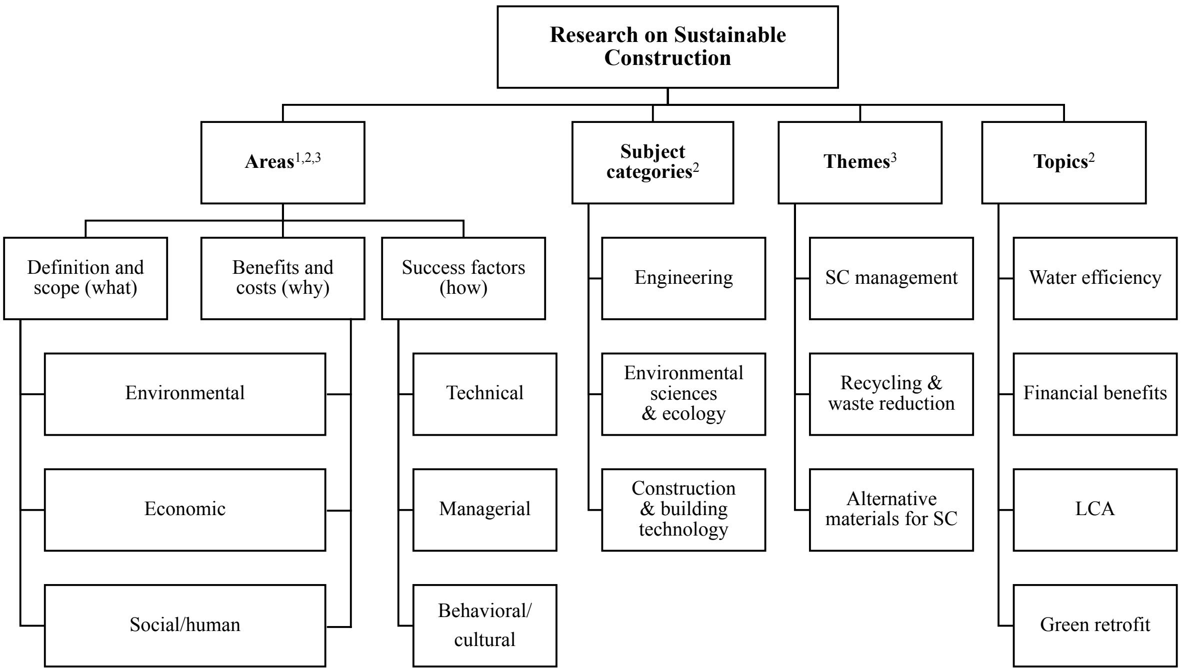
This section gives an overview of the relevant literature for this thesis. It first provides a general background on sustainable construction (Section 2.1), followed by an overview of the instruments – primarily economic incentives – for its implementation (Section 2.2). Beyond this general summary, each essay in this thesis provides a more detailed and deeper review of the literature concerned in the respective study.

2.1 Sustainable Construction

As early as 1997, Hill and Bowen (1997) provide a conceptual research paper on the principles of sustainable construction and how it can be attained. They divide the principles into four pillars: social, economic, biophysical, and technical. The process-oriented principles the authors suggest are assigned to these pillars and form a checklist for practice. The principles in their framework have mostly remained unchanged. Exemplary principles that are still advocated today are protecting and promoting human health through a healthy and safe working environment (social pillar), choosing environmentally responsible suppliers and contractors (economic pillar), maximizing resource reuse and recycling (biophysical pillar), and constructing durable, reliable, and functional structures (technical pillar). Hill and Bowen (1997) emphasize that sustainable construction starts before the actual construction phase, including the planning and design phases, and proceeds after the building has been completed.

The papers by Zuo and Zhao (2014), Zhao et al. (2019), and Det Udomsap and Hallinger (2020) are three comprehensive reviews of sustainable construction research, which are summarized in Figure I.3. It is clear from these reviews that sustainable construction is of global interest since research is conducted across the world (Det Udomsap & Hallinger, 2020; Zuo & Zhao, 2014). Zuo and Zhao (2014) identify that most of this research focuses on one of three areas: the definition and scope of sustainable construction (what), the benefits and costs (why), and ways to achieve sustainable construction (how). Within the scope (what), the environmental aspects are much more prominent than their social or economic counterparts, although attention to these is increasing. For example, the certification schemes started to include economic and social criteria in their assessment portfolios (Zuo & Zhao, 2014). Today, the DGNB assigns equal weightings to the environmental, economic, and social criteria in their assessment (DGNB, 2023). Nevertheless, Zhao et al. (2019) and Det Udomsap and Hallinger (2020) still identify social aspects of sustainable construction as a knowledge gap in the GB literature several years later. The reasons for and costs of sustainable construction (why) are divided into environmental, economic, and human aspects. Finally, the factors of success for sustainable construction (how) are technical, managerial, and behavioral or cultural (Zuo & Zhao, 2014). Zhao et al. (2019) identify the subject categories GB research has predominantly been conducted in and the most popular topics addressed (see Figure I.3). The most comprehensive review is done by Det Udomsap and Hallinger (2020), who include the period from 1994 to 2018 in their analysis. They find the three conceptual themes in the research on sustainable construction to be sustainable construction management, recycling and waste reduction, and alternative materials for sustainable construction. The latter also emerges as the dominant topic through a co-word analysis and encompasses, among others, research on concrete with alternative aggregates (referred to as *RAC* in this thesis).

Figure I.3: Overview of research on sustainable construction



SC = sustainable construction, LCA = life cycle assessment
Based on the reviews by (1) Zuo and Zhao (2014), (2) Zhao et al. (2019), and (3) Det Udomsap and Hallinger (2020)

As mentioned, numerous barriers to sustainable construction are currently hampering its widespread implementation. This section gives an overview of these barriers and the main drivers for implementing sustainable processes and materials in construction projects. Darko and Chan (2017) identify 61 barriers, indicating that the issue is multifaceted. They find the most reported ones to be a lack of information, knowledge, and awareness, additional costs, a lack of incentives, a lack of interest and demand from clients[12], and a lack of codes and

[12] Throughout this thesis, clients are defined as the ones who initiate and finance a construction project (Hartmann et al., 2008).

regulations for GB. Ahn et al. (2013) arrive at a similar collection through an expert survey. The barriers that their sample ranks highest are the cost premium, long payback periods, the tendency to stick to familiar processes, and a lack of subcontractors' knowledge and experience. The top three barriers that emerge from the survey of building surveyors by Pitt et al. (2009) are costs, a lack of demand from clients, and a lack of awareness. It becomes clear that additional costs and a lack of information, knowledge, and awareness primarily hinder sustainable construction. The so-called *split incentives* are an issue related to the former (additional costs). It refers to separating investment costs and long-term benefits across different stakeholders (e.g., the developer and tenant, respectively; e.g., Choi, 2009). This mismatch is easily comprehensible using the example of energy efficiency measures: The owner is the one to invest in a photovoltaic system or thermal insulation, but the tenant benefits from a lower energy bill. This hampers the incentive to invest in these measures, as the owner cannot be sure to find tenants willing to pay for this investment through their rent. Several other researchers also identify the latter (a lack of information, knowledge, and awareness) as problematic (AlSanad, 2015; Pitt et al., 2009; Shooshtarian et al., 2020). A related aspect is the lack of client demand (e.g., Gou et al., 2013; Hwang & Tan, 2012; Pitt et al., 2009; Rodriguez-Nikl et al., 2015) since clients cannot demand something they are not aware of and are arguably unlikely to demand something they know only little about. This issue is the basis for this thesis's first and second essays, which focus on construction clients and measures to increase their demand for sustainable construction materials. Another barrier repeatedly addressed by construction actors is the (perceived) limited availability of suppliers or materials for sustainable construction (e.g., Häkkinen & Belloni, 2011; Joachim et al., 2015; Lam et al., 2009). Finally, concern has been raised that alternative, environmentally friendly processes or materials are not accepted or positively viewed (e.g., Knappe et al., 2012; Oyedele et al., 2014; Park & Tucker, 2017). This issue will be touched upon in the third essay of this thesis, in which public acceptance of sustainable construction is examined.

Some of the same authors who study barriers to sustainable construction also consider its driving forces. Overall, however, drivers have received considerably less attention than their counterparts. Darko and his colleagues (2017) find five categories of drivers for sustainable construction: external, corporate-level, property-level, project-level, and individual-level drivers. The top cited single factors are government regulations and policies, energy conservation, reduced life cycle costs, environmental protection, and incentives. All of these are categorized as external or property-level drivers. In their survey of experts from the U.S. Green Building Council, Ahn et al. (2013) find only environment-related drivers at the top: energy conservation, indoor environmental quality improvements, environmental or resource conservation, and waste reduction. Other researchers, too, point to the importance of environmental attitudes in driving the adoption of sustainable construction practices (Diyana et al., 2013; Gou et al., 2013; Joachim et al., 2015). In contrast, the findings by Pitt et al. (2009) indicate that financial incentives, building regulations, and client awareness are the main driving forces. Given the importance of additional costs as a barrier, it may not surprise that potential financial savings encourage investment in GB attributes. Over the life cycle of a building, the savings can outweigh the initial added costs, as, for example, in the case of energy efficiency measures (Adams et al., 2017; Marker et al., 2014; Portnov et al., 2018). Finally, especially when the client (and owner) in question is an organization or business, image considerations play a significant role in the decision to construct a building sustainably (e.g., Darko et al., 2017; Diyana et al., 2013; Olubunmi et al., 2016). Identifying barriers and drivers for the specific case of construction clients' demand for RAC is a partial aim of the first two essays.

Since sustainable processes and materials are often associated with increased costs, which appear to hinder their implementation, the question of whether and to what extent construction stakeholders are willing to pay for them has been a research topic. In addition, factors that influence this WTP are identified so these can be tackled to foster sustainable construction. Khan et al. (2020), Mandell and Wilhelmsson (2011), and Portnov et al. (2018) study individuals' overall WTP for sustainable housing. They all find a positive WTP influenced by demographic factors, environmental attitudes, expected savings, and familiarity with sustainable construction. Corporations are also found to be willing to pay for green buildings, especially public authorities and those from the building and financial service industries (Wiencke, 2013).

Apart from the mentioned studies on WTP for GB, researchers investigate specific attributes and find positive estimates. Examples are the reduction of GHG emissions during the construction process (e.g., M. Park et al., 2013; Robbins & Perez-Garcia, 2005), energy-efficiency measures or energy conservation (e.g., Banfi et al., 2008; Chau et al., 2010; Yau, 2012; Zalejska-Jonsson, 2014), reducing air pollution (e.g., Chau et al., 2010; M. Park et al., 2013; Robbins & Perez-Garcia, 2005), and green materials or systems (Kwak et al., 2010; Yau, 2012a). Economic factors, such as a prospective high return or financial incentives, positively influence the WTP for these attributes (Grosskopf & Kibert, 2006; Yau, 2012a). The WTP for recycled construction material and the corresponding influential factors are the subject of the first essay of this thesis.

A last stream of research on WTP for aspects of sustainable construction addresses the WTP for environmental policies. Thus, individuals are asked whether they are willing to contribute financially to implement policies they do not directly benefit from. This concept is applied in the third essay of this thesis, in which we estimate citizens' WTP for policies aiming to foster sustainable public construction. Apart from our own, no study to date has – to the best of our knowledge – analyzed the WTP for a policy specifically for sustainable construction. Most of the existing studies focus on policies for the general reduction of GHG emissions (Alberini et al., 2018; Brännlund & Persson, 2010; Dietz & Atkinson, 2010; Longo et al., 2008; Ščasný et al., 2017). Other environmental measures studied are the reduction of air pollution, renewable energies, or energy efficiency (Alberini et al., 2018; Dietz & Atkinson, 2010; Longo et al., 2008). Consistently, positive WTP estimates are found for these environmental improvements. Brännlund and Persson (2010) find that their respondents are less willing to contribute to a policy presented as a tax than one not labeled as such. This result leads us to the following section on instruments to foster sustainable construction, focusing on the private sector.

2.2 Policy instruments and incentives (for GB)

This section gives an overview of the literature relevant to policy instruments, particularly economic incentives, to foster sustainable construction processes and materials. The focus here is on incentives, considered a subcategory of instruments. The delimitation will be presented later in this section.

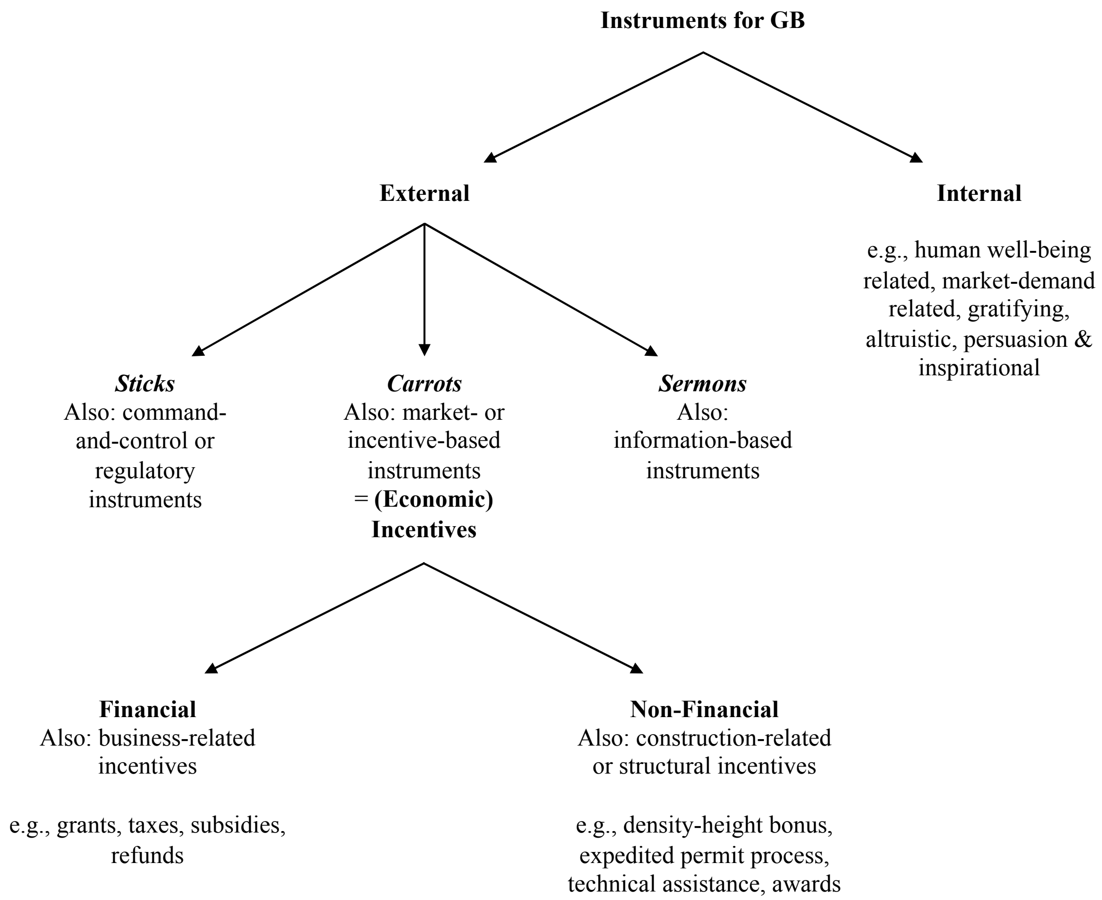
One reason why incentives may be necessary to foster sustainable construction has already been touched upon in the previous section: The lack of incentives that could, for example, compensate for investment costs is perceived as a barrier to GB (e.g., AlSanad, 2015; Darko & Chan, 2017; Häkkinen & Belloni, 2011; Hwang & Tan, 2012; Mao et al., 2015). Additionally, incentives are a way to tackle other barriers to implementing sustainable construction, such as a lack of knowledge or potential risks (Choi, 2009). Incentives can be used to "generate interest, bridge knowledge gaps, and encourage green building practices over conventional ones" (Choi, 2009, p. 120). Especially the issue of higher initial costs can be mitigated through (financial) incentives (Hwang & Tan, 2012; Park & Tucker, 2017; Samari et al., 2013; Shi et al., 2013). Financial incentives balance the costs and benefits of sustainable construction by lowering the costs of the sustainable product or raising the costs of its conventional counterpart. In the latter case, the environmental externalities that come with the conventional product are internalized (Jacob et al., 2021; Metcalf, 2009). By lowering or eliminating the cost difference, these incentives can increase the market demand for sustainable practices (Ying Liu et al., 2012).

The German Federal Environment Agency has investigated the potential of economic incentives for resource efficiency (Ostertag et al., 2021a). So far, primarily information-based instruments and support for innovations have been implemented, but their effect on the market for secondary materials has not been satisfactory. Therefore, financial incentives and their potential are explored to increase the demand for resource-efficient alternatives. Examples of considered incentives either increase the price for primary resources (e.g., through a resource tax) or lower the price for resource-efficient material (e.g., by lowering the value-added tax). Incentives targeted primarily at the construction industry, like a tax on primary resources for the construction sector and a tax on backfilling mineral construction waste, are recommended. The authors emphasize that a policy mix is likely to be most efficient.

Olubunmi et al. (2016) specifically look at incentives for GB in a systematic review. They find that incentives can be categorized into external and internal, depending on their origin. External incentives, which can be financial and non-financial, are provided by the government and imply a choice of meeting a specified standard to receive the incentive. Internal incentives, in contrast, originate in the beneficiaries themselves and reflect intrinsic motivation. The authors find that the analysis of incentive effectiveness is an ongoing research topic, but it is unclear whether external or internal incentives are more effective. The criticism in the literature reviewed by Olubunmi et al. is mainly directed at the governments' administration of external incentives. Finally, the authors point out some strategies for improvement regarding the government's approach, which includes adapting incentives to local conditions, increasing beneficiaries' awareness of existing incentives, and increasing the private sector's contribution.

The instruments that Olubunmi et al. (2016) refer to as "external" are commonly divided into market- or incentive-based instruments, also called *carrots*, and non-market-based, command-and-control, or regulatory instruments, referred to as *sticks*. Some authors add a third category of information-based instruments (e.g., Acree Guggemos & Horvath, 2003; Casabianca, 2006; Li et al., 2020), at times referred to as *sermons* (Bemelmans-Videc et al., 2011). Market-based instruments are the main focus of this work and are referred to in this thesis as (economic) incentives. They can be further divided into financial (also called *business-related*) and non-financial (also called *construction-related* or *structural*) incentives (Gündeş & Yildirim, 2015; Li et al., 2020; Olubunmi et al., 2016; Shapiro, 2011). However, it should be noted that even non-financial incentives often come with a financial benefit (Knappe et al., 2012; Olubunmi et al., 2016). For example, if the permit for the construction project is rewarded within a shorter time, the project can be completed faster, saving financial resources. Figure I.4 gives an overview of this categorization. Examples of financial incentives are grants, taxes, subsidies, and refunds (e.g., Di Filippo et al., 2019; Gou et al., 2013; Li et al., 2020; Rainwater et al., 2012). Non-financial incentives for sustainable construction include density and height bonuses, expedited permit processes, technical assistance, and awards (e.g., Choi, 2009; Darko et al., 2017; Li et al., 2020; Rainwater et al., 2012). Notably, construction-related incentives such as expedited permits and density bonuses are almost only addressed in U.S. American literature or studies that refer to the United States. At the same time, they are hardly spoken of in German literature. In Germany, the non-financial instruments in focus are information campaigns, education, certification, and consideration of environmental aspects in public tenders. Moreover, regulatory changes also seem more prominent in Germany (e.g., Dechantsreiter et al., 2015).

Figure I.4: Categorization of instruments for sustainable construction



Own presentation based on Olubunmi et al. (2016), expanded based on authors cited in the main text.

Market-based instruments – incentives – are seldom used, especially in Germany (Jacob et al., 2021). However, several researchers argue that they are more effective and efficient than regulatory instruments (Goulder & Parry, 2008; Grosskopf & Kibert, 2006; Söderholm & Tilton, 2012; Taylor, 2011). There are several criteria to rate policy instruments, among which their efficiency, cost-effectiveness, distributional equity, the transparency of the political process, the handling of revenue raised, political feasibility, and potential interaction effects between instruments (Bennear & Stavins, 2007a; Goulder & Parry, 2008). Especially regarding environmental policies, whether the instrument spurs innovation is also relevant (Di Filippo et al., 2019; Kemp & Pontoglio, 2011). Metcalf (2009) argues that the policy instrument should further show technology neutrality, meaning it should not favor one technology over another but instead target the outcome. In line with this, the most efficient instrument is considered the one that targets the environmental damage it aims to mitigate the closest (Söderholm & Tilton, 2012).

An incentive that is often discussed and applied is the tax, the topic of the fourth essay of this thesis. Applied to the construction sector, a tax could target the extraction of primary resources or the use of mineral waste for backfilling, as touched upon before. Bahn-Walkowiak et al.

(2012) plead for introducing the former: a construction minerals tax. Since a price increase on primary material is passed on through the supply chain, it affects all stakeholders. It can increase the demand for secondary materials and incentivize the conservation of buildings. According to the authors, such a tax can lead to the internalization of externalities and foster innovation efforts. This tax follows the *polluter-pays-principle* and is already applied in some European countries, like Sweden, the United Kingdom, and Czechia (e.g., European Environment Agency, 2008). Whether a tax is the optimal instrument to be applied depends, among others, on the market failures it attempts to correct (de Serres et al., 2010). The general rule also applies to natural resources: Only if a market failure is present and other environmental regulations are less efficient is a tax considered justified (Söderholm, 2011a). With that in mind, Söderholm (2011a) lists environmental motives for taxing natural resources: resource depletion (in the case of weak property rights), environmental externalities (arising downstream), and encouraging the substitution of natural aggregates with recycled ones. All of these apply in the case of utilizing primary construction material. Many researchers argue that a policy mix combining several instruments is most effective (e.g., Bennear & Stavins, 2007; de Serres et al., 2010; European Environment Agency, 2008; Mandell & Wilhelmsson, 2011). Especially when multiple market failures are at work, a single instrument will unlikely be sufficient to correct it entirely. De Serres et al. (2010), for example, state that a central element of an environmental instrument should be to put a price on the source of pollution or the excessive extraction of resources, but that information-based measures should accompany this instrument. The combination of a financial incentive such as a tax and the provision of information is often recommended (Bennear & Stavins, 2007a; de Serres et al., 2010; Mandell & Wilhelmsson, 2011a). However, careful design is needed to account for possible interaction effects between instruments (Goulder & Parry, 2008). This is also a result of the second essay of this thesis, which analyzes incentives for using RAC among construction clients.

If governments aim to support GB, its inclusion in public tenders may constitute another potential instrument. Considering environmental aspects in public tenders is an incentive often discussed in Germany. It is emphasized that public authorities are responsible as first movers and role models for private construction clients (e.g., Dechantsreiter et al., 2015; Hinzmann et al., 2019; Ruiz Durán et al., 2019). In some aspects, this responsibility has been taken on in the form of mandates, often imposed on public authorities, while incentives are directed at the private sector (Sentman et al., 2008). The public tenders for aggregates for concrete to be used in federal buildings in Germany must be invited with impartiality, meaning RA should not have a disadvantage (Baronick et al., 2019b). While this regulation does not (yet) apply to the federal states, some municipalities, like Berlin and Brandenburg, take on a leadership role in sustainable construction and voluntarily impose rules and standards like these on themselves (Baronick et al., 2019b; Sentman et al., 2008). Public mandates are an example for private construction clients and have been the first step towards more comprehensive regulations encompassing the private sector (Sentman et al., 2008). Despite a high willingness to implement these measures, only a few municipalities do so, the reasons for which are a (perceived) lack of financial and human resources and information (Chiappinelli & Zipperer, 2017; Fischer & Küper, 2021; Zu Castell-Rüdenhausen et al., 2021). The third essay of this thesis examines a potential driver for sustainable public building construction: the public's stance toward it.

3 Thesis Outline

3.1 Levels of Analysis

This thesis analyzes economic incentives for sustainable construction in four essays on three different analysis levels often applied in sociology: the micro, meso, and macro levels (Turner, 2010). The micro level describes the smallest social entities, primarily individuals, and their behavior and interactions. The first two essays are set on the micro level, focusing on the individual clients of construction projects and their purchasing behavior of RAC. The middle level of analysis, the meso level, describes groups, communities, or organizations and the social connections between parts of these groups. The third essay of this dissertation takes this level of analysis in studying cities, their citizens, and their relation to the respective municipality. The level of analysis with the broadest focus is the macro level, which describes society as a whole. This focus is adopted in the fourth essay, which analyzes countries and their political and economic influence on actors and groups of actors within them. The remainder of this chapter gives a more detailed summary of these four essays, including their research questions, methods, and main results. The essays are then presented one by one in Parts II to V.

3.2 Construction Clients' Demand Decisions for Concrete with Recycled Aggregates

The first two essays – *Willingness to Pay for Recycled Aggregates in Concrete Among German Construction Clients* and *Incentives for Construction Clients in Germany to Choose Concrete with Recycled Aggregates* – focus on construction clients' purchasing behavior of RAC. RAC is a resource-efficient building material that offers a way to lower the use of natural resources and process the waste generated by the construction industry with high value. Especially given the prospect that the amount of construction waste and the demand for aggregates will increase further with economic growth and increasing renovation rates in the EU (Pacheco et al., 2023), the market for RA is worth analyzing. According to a report by the European Commission, the most effective way to foster high-quality recycling of construction and demolition waste is to ensure a market for RA by increasing market demand through economic incentives (Pacheco et al., 2023). Clients have a decisive role in the amount of RAC used through their demand decisions. They are, therefore, considered a crucial stakeholder in the endeavor to foster the use of recycled construction materials generally and, in this case, RAC. The first essay asks what the barriers and drivers of clients' demand decision of RAC are, whether they are willing to pay for it, and what factors influence this. The second essay builds on the first one. It aims to identify the instruments that are effective in correcting the market failures that hamper the implementation of RAC on the market. Both essays differentiate client types (private individuals, organizations, and developing companies) and consider the impact of potential differences between them. To do so, a survey among construction clients in Germany is set up and conducted, including item-based questions, a discrete choice experiment (DCE), and a factorial survey. Apart from descriptive statistics, the analysis uses mixed and nested logit models for the data collected in the DCE and linear regressions for the data from the factorial survey.

The first essay finds that the barriers experienced by construction clients in demanding RAC are mostly information-based. Examples are a lack of experience or knowledge and uncertainties about the norms and regulations. Despite these barriers, positive and significant WTP estimates for RA in concrete are found with considerable differences between the three client groups. Private individuals are willing to pay the least, while organizations are willing to pay the most for an increase in the share of RA in concrete. Three main factors influencing clients' propensity to choose RAC are identified: Clients who value sustainability in construction, feel responsible for adopting sustainable practices and materials, and are familiar with the material are more likely to choose RAC over conventional concrete in the DCE. Only a subset of the sample, partly defined by these characteristics, has a WTP that matches the price premium currently observed on the market.

The results of the second essay show that all incentives that are tested – a financial grant, an expedited permit process, free technical assistance, and public recognition – and the information provision instrument are effective in at least one of the client groups. Only the financial grant appears to be effective in all three of them. With increasing values of the financial grant, the effect of information provision decreases. Overall, and in line with the pattern found in the first essay, private individuals are the least likely to choose RAC.

These two studies suggest that instruments are necessary to foster the use of RAC among all clients instead of just a selected subsample currently willing to pay the additional costs. In designing these instruments, the differences between client groups should be kept in mind: the barriers they experience, their WTP, and the effectiveness of different types of instruments. Further, policymakers should be careful in combining these instruments since they may negatively influence each other's effectiveness.

3.3 Citizens' Acceptance of Sustainable Construction in Their Municipality

The third essay of this thesis – *Citizens' Acceptance of Sustainable Construction in Their Municipality* – is joint work with my (former) colleagues Dr. Dmytro Katerusha and Dr. Morten Endrikat. It focuses on sustainable public construction in German municipalities. More than 30 % of the revenue in the German construction industry comes from public clients (Destatis, 2023). Thus, public institutions have a significant potential to lower their environmental footprint through *green public procurement* (GPP) in construction projects. In addition to lessening their impact, the indirect effect of raising awareness among the respective citizens and supporting suppliers of environmentally friendly practices or materials adds to the potential positive consequences. So far, using recycled building material, for example, is rarely allowed in public tenders, an important barrier to the widespread application of this material (Hinzmann et al., 2019; Pacheco et al., 2023). As with any public policy or change in public spending, the affected citizens' acceptance is essential for a smooth implementation. This essay asks to what extent German municipalities can expect public acceptance, on the attitude and the action dimension, toward sustainable public construction and what factors are of influence in this respect.

A survey with item-based questions, a DCE, and a factorial survey is set up and conducted in three cities and one district in Germany. We apply the same methodology for the analysis as in the first two essays: descriptive statistics, mixed and nested logit models, and linear regressions. We find consistently positive attitudes expressed in choosing policies to foster sustainable public construction over the status quo of no policy, mainly positive associations with sustainable public construction, and perceiving more benefits than drawbacks. Citizens' attitudes are driven by their trust in the municipality and their perception of benefits, personally and socially, to sustainable public construction in their city or district. As expected, additional costs negatively influence these attitudes. The results pertaining to the action dimension of acceptance are less clear: While citizens appear willing to engage when the action is a petition in favor of sustainable construction or a financial contribution, they seem undecided regarding formats such as discussion rounds or even receiving newsletters on the topic. The results suggest that their willingness to engage depends on factors such as age, interest in sustainability, and knowledge of it, especially in construction. The *default effect* is shown to be a promising tool to foster this action dimension of acceptance. All in all, the results of this essay indicate that GPP in construction would find acceptance among the public. Setting sustainable standards as the default and potentially charging a financial contribution seem feasible measures to implement sustainable construction with public acceptance.

My colleagues Dr. Dmytro Katerusha and Dr. Morten Endrikat and I set up the concept and the survey for this paper together and acquired municipalities to participate equally. I mainly collected the relevant background literature. Morten and I then worked on the analysis and interpretation together, where he primarily focused on the factorial survey, and I focused on the descriptive statistics and the DCE. Finally, I wrote the paper.

3.4 Resource Taxes as an Instrument to Foster Circularity?

The final essay of this work – *Resource Taxes as an Instrument to Foster Circularity? Analysis of the Effects of Resource Taxation on Circular Economy Progress in Europe* – is joint work with Linda Reinhart and deals with the effectiveness of regulatory instruments to foster the circular economy (CE). The CE aims to eliminate waste and keep products and materials in circulation (Ellen MacArthur Foundation, n.d.). This essay – in line with the overall topic of this thesis – focuses explicitly on resource taxes. This instrument is often discussed and proposed by researchers (e.g., Bahn-Walkowiak et al., 2010, 2012) to increase resource efficiency overall and in the construction sector specifically. However, its effectiveness regarding CE progress has not yet been tested empirically. Thus, we aim to fill this research gap with this essay asking how resource taxes impact the implementation of the CE in European countries. Due to data availability and consistency issues, we focus on general material consumption rather than construction materials. However, since the construction industry accounts for around half of the resources extracted in the EU, it is conceivable that our general results also apply to this specific sector.

Our dataset is compiled of panel data for 29 European countries from 1995 to 2021. We apply the Augmented Mean Group (AMG) estimator as the main specification and the Pooled Mean Group (PMG) estimator as a robustness check. We consistently find positive estimates for the effect of the resource tax on resource productivity, our CE indicator of choice. The chosen methods allow for identifying the effect in individual countries, which shows that the taxes are far from uniformly effective. We find evidence for a positive effect of the resource tax on resource productivity in six countries, while another six countries do not have any resource tax. Additionally, we also specify the model with alternative CE indicators. The results show an effect of resource taxation on the material footprint and the GVA from CE-related activities. At the same time, it does not seem to influence the *circular material use rate* (CMUR) or the number of patents related to recycling and secondary raw materials. The results and a number of potentially limiting factors, such as data availability issues and varying tax implementations, are discussed, and avenues for future research are suggested. Nevertheless, our results show that the resource tax is a promising tool to help countries progress toward a CE.

My colleague Linda Reinhart and I worked together on the conceptualization, data collection, and model specification. While she led the search for background information, I had the principal share in the statistical analyses. Followingly, Linda was mainly responsible for writing this paper's introduction, background, and discussion, while I primarily wrote the method and result chapters.

4 Conclusion

Throughout the research for this dissertation, positive attitudes and WTP estimates are found among individuals toward sustainable construction, whether regarding their own homes or public buildings in their surroundings. Nevertheless, barriers exist to implementing processes and materials in line with sustainable construction, rendering incentives necessary. Incentives are found to be effective on the micro, meso, and macro levels. In other words, incentives can be applied to foster sustainability in construction by individuals, municipalities, and countries. The importance of looking into the specific target group for incentives is shown. For example, incentives for construction clients are not uniformly effective. Instead, whether they can stimulate the use of sustainable construction materials largely depends on the type of construction client in question. Moreover, individual characteristics influence stakeholders' stance on sustainable construction and should be considered. Similarly, on the macro level, the same incentives do not necessarily show the same effect in different countries. Thus, policymakers should design and offer incentives tailored to the target group. In addition, the behavior or condition the incentive aims to evoke should be detailed. The research shows that a willingness to engage in favor of sustainable construction is not a uniform concept but can be divided into several forms of engagement, bringing about different levels of support. Similarly, aspired progress toward a CE should be specified as an instrument's effectiveness is shown to depend on the CE indicator used. This dissertation offers detailed insights on policy instruments to foster the implementation of sustainable construction processes and materials. It demonstrates which barriers should be tackled with incentives, which drivers and attitudes they can build on, which incentives promise to be effective for which group, and the conditions for their effectiveness. As such, it offers guidance to policymakers wishing to foster sustainable construction on the micro, meso, and macro levels.

Part II

Willingness to Pay for Recycled Aggregates in Concrete Among German Construction Clients

Willingness to Pay for Recycled Aggregates in Concrete Among German Construction Clients

Ellen Sterk

Abstract

The construction industry claims a vast quantity of natural resources and is responsible for more than half of the waste generated in Germany. Recycled aggregate concrete (RAC) is a resource-efficient alternative to conventional concrete. A central stakeholder whose preferences may significantly influence the use of RAC is the construction client. Despite their central role in this respect, little is known about clients. This study contributes to the understanding of the clients' demand decisions. It determines the willingness to pay (WTP) for recycled aggregates (RA) in concrete and examines which factors influence clients' propensity to choose RAC. Additionally, the study identifies barriers and drivers for the demand for RAC. Throughout these questions, differences between client groups are considered. In addition to item-based questions on potential barriers and drivers, a discrete choice experiment is applied to estimate the clients' WTP for a particular share of RA in concrete. Positive and significant WTP estimates are found for all client groups. Clients are willing to pay 0.26 EUR for every percentage point increase of added RA. Private individuals' WTP is the lowest, while organizations are willing to pay the most. However, even organizations' WTP does not equal the current price premium. We discuss the clients' characteristics influencing their WTP positively. The main barriers to demanding RAC are based on a lack of information. Therefore, instruments that rely on information provision are recommended to foster the use of RAC. Moreover, the significant differences in client groups should be considered in designing these instruments.

JEL classification: D12, L72, L74, Q53

Keywords: Willingness to Pay; Recycled Aggregates; Concrete; Construction Clients; Discrete Choice Experiment

1 Introduction

The construction industry is one of the most problematic sectors regarding its environmental impact. Firstly, it is highly energy-intensive: In the European Union (EU), buildings are responsible for 40 % of energy consumption and 36 % of greenhouse gas (GHG) emissions (European Commission, 2020c). Secondly, it also claims a vast quantity of natural resources (Jacob et al., 2021; Knappe et al., 2017): EU-wide, 50 % of resources extracted are processed in the construction industry (European Commission, 2020b). This share is even more striking in Germany: Of the 733 million tons of non-renewable resources extracted in Germany in 2019, 594 million tons (81 %) are non-metallic minerals, of which 550 million tons (93 %) are used in the construction industry (Destatis, 2021). In 2021, more than 150,000 building permits were awarded in Germany, with over 80 % of them pertaining to residential buildings (Destatis, 2022b). This number and its associated environmental impact are unlikely to decrease anytime soon. Population growth and urbanization require building living space (Ellen MacArthur Foundation, 2020). In Germany specifically, the federal government has set the goal to build 400,000 new residential apartments per year (*Koalitionsvertrag 2021 – 2025*, 2021), which would imply an increase of more than 20 % in the number of buildings yearly constructed of this type (Destatis, 2022b).

At the other end of the life cycle, the construction industry is responsible for more than half of all the waste generated in Germany (Destatis, n.d.). Of the 414 million tons of waste produced in 2020, more than half[13] is attributed to construction and demolition. The recovery rate of 88 % is comparably high in Germany (Destatis, n.d.), but only 12.5 % of the demand for aggregates was covered by recycled aggregates (RA) in 2018. Only slightly more than a fifth of these RA was used to produce asphalt and concrete (Kreislaufwirtschaft Bau, 2021). The majority of them is used for road filling, the need for which is decreasing (Pacheco et al., 2023) and which is commonly labeled *downcycling* (Di Maria et al., 2018; Knappe et al., 2012; Kreislaufwirtschaft Bau, 2021). Downcycling is "the practice of using unwanted material for an application of less value than its original purpose" (Allwood, 2014, p. 465). In contrast, recycling, in the stricter sense, refers to processing waste to material of equal quality. This implies keeping materials in the loop and thus closing material cycles, a political goal on a national and international level (Waste Framework Directive, 2008; *Koalitionsvertrag 2021 – 2025*, 2021). Strictly speaking, using mineral construction waste for road filling is not in line with this goal since concrete, once part of the base layer of a road, cannot be turned into concrete again. Closing the material cycle and retaining its value would mean using concrete rubble to produce new concrete (Di Maria et al., 2018). In recycled aggregate concrete (RAC), the aggregates – usually primary gravel and sand – are partly replaced by RA from construction and demolition waste. This building material is already admissible for many applications in building construction in Germany and has the same characteristics as concrete with primary or natural[14] aggregates (NAC; Knappe et al., 2013). Its advantages include closing cycles, resource efficiency, potentially shorter transport routes, and sparing landfill capacities (Knappe et al., 2012, 2017; Wizgall & Knappe, 2011). Despite these advantages, RAC is hardly used in Germany (Jacob et al., 2021; Wizgall & Knappe, 2011). While 192 million tons of gravel, sand, and natural stones were used in the production of concrete and mortar in Germany in 2020, the volume of RA employed to this end was only 0.9 million tons (Verein Deutscher Zementwerke, 2022). At the same time, the case of Switzerland demonstrates that the widespread use of RAC is feasible: 90 % of the concrete required in the Swiss building construction can be supplied with RAC (Knappe et al., 2017; Stürmer & Kulle, 2017). The following chapters will outline the reasons

[13] The exact value is 55 % (229 million tons).
[14] "Primary" and "natural" are used as synonyms throughout this thesis.

for the limited utilization of RAC in Germany and expound on the role of the construction client in this context.

The construction industry comprises many stakeholders coming together in a project. Building a simple detached house, for example, involves the client, an architect, engineers, suppliers, the municipality, and several contractors. Even more parties add to the process in projects where another building is demolished or dismantled first. The client has a unique standing among these stakeholders and is arguably the most important one (Diyana et al., 2013; Knappe & Theis, 2016; Scheibengraf & Reisinger, 2005). Construction clients are the ones "who initiate, commission, and pay for a construction project" and "formulate and communicate the requirements of a construction project to be accomplished for the intended usage of the facility" (Hartmann et al., 2008, p. 5). The construction project starts with the client's demand for a building and is then shaped by his or her expectations (Qi et al., 2010). Starting with the selection of the other stakeholders (Volk et al., 2019), clients are in charge (Knappe & Theis, 2016) and ultimately the decision-makers in any construction project (Abidin & Pasquire, 2007). They are, therefore, often seen as the "predominant player in the construction process" (Oyedele et al., 2013, p. 140) and "the most influential stakeholder on construction projects" (Onubi et al., 2020, p. 1).

Given the decisive role clients have in construction projects, they are also highly influential when it comes to adopting sustainable building practices. Several authors argue that change and innovation need to be driven by the client (Brandon, 2006; Brandon & Lu, 2008; Briscoe et al., 2004). Being the end users (or representing them), clients shape demand and thereby have a significant role in driving sustainability (Mao et al., 2015; Ozorhon, 2013; Pitt et al., 2009) and in particular the use of recycled construction material (Shooshtarian et al., 2020). According to the German Federal Environment Agency, the most efficient driver for high-quality recycling of resources is the demand for recycled material for the application in high-quality products (Janz, 2022). With this role, clients bear a great responsibility since buildings are a substantial investment in both an economic and an ecological sense. Accordingly, clients can be seen as ecological investors (Knappe & Theis, 2016).

This study investigates construction clients' consumption decisions regarding RAC. Specifically, it aims to answer the following research questions:

What are the barriers and drivers for construction clients to demand RAC?

How high is construction clients' willingness to pay for RA in concrete?

To answer these questions, an experimental survey among three groups of construction clients (private individuals, organizations, and developers[15]) is conducted. The central part of the survey is a discrete choice experiment (DCE), which is employed to determine clients' willingness to pay (WTP) and which is analyzed using a mixed logit model. The main results are the following: Information-based barriers are most prominent in all client groups, such as a lack of knowledge and uncertainty regarding the norms and regulations pertaining to RAC. In contrast, their environmental awareness drives clients to use the material. The results show that the construction clients in our sample are more likely to choose RAC than NAC, all else being equal. We find positive and significant WTP estimates in all groups, of which organizations have the highest and private individuals have the lowest WTP. Individual characteristics influencing clients' propensity to choose and pay for RAC are discussed. The paper is organized

[15] While public authorities are a highly relevant group of construction clients as well, they are willfully excluded in this study. The regulatory environment under which they operate distinguishes them from the other three groups, which is why they are considered in a separate study (see Part IV).

as follows: Chapter 2 gives an overview of the literature on the role of construction clients and their demand, potential barriers and drivers, and the WTP for green building (GB) and its features. It finishes by presenting the hypotheses derived from the literature that serve as a guiding framework for this study. Chapter 3 illustrates the method used, and Chapter 4 shows the corresponding results. These are discussed and put into context in Chapter 5. Chapter 6 concludes this paper.

2 Literature Review and Hypotheses

Research has confirmed the crucial role clients play in driving sustainable construction. Naturally, the supply of sustainable construction materials and processes is required, but it "needs to be complemented with, driven by, and shaped around a willing and committed demand site" (Khan et al., 2020, p. 1). There seems to be a consensus in the literature that clients' demand and commitment are essential to drive the implementation of sustainable building practices (Bornais, 2012; Darko et al., 2017; Diyana et al., 2013; Gou et al., 2013; Häkkinen & Belloni, 2011; Mandell & Wilhelmsson, 2011b; Pitt et al., 2009). A worldwide survey conducted by Dodge Data Analytics finds that client demand is the top trigger for GB (Dodge Data Analytics, 2016). Bornais analyzes three case studies of newly constructed green buildings in Canada and finds that "one consistent measure for success was the owners' commitment to the green building process"[16] (Bornais, 2012, p. 63). Rodriguez-Nikl and his colleagues draw a similar conclusion. They ask structural engineers about the factors that increase their likelihood of incorporating sustainable features in their designs and the actors influencing this decision. In first place, respectively, are client requirements and the group of developers and owners (Rodriguez-Nikl et al., 2015). Based on these findings, they conclude that "the client is the single most important influence on what a structural engineer can accomplish" (p. 8) in implementing sustainable design strategies. The clients' role applies to sustainable construction practices in general and to using recycled building materials in particular. The demand for recycled building materials is crucial for an increase in the recycling rate of construction and demolition waste (Pacheco et al., 2023; Schmidmeyer, 2014). According to the Ministry of the Environment, Climate Protection and Energy Sector of Baden-Württemberg, a German federal state in which RAC is more prominent, closed loops in terms of a circular economy (CE) can only be achieved if recycled products are demanded by the client (*Der Einsatz von Recyclingbaustoffen*, 2013). One of the recommendations given in a report by the European Commission studying the opportunities for RAC in Europe is to create a demand and ensure a market (Pacheco et al., 2023). As such, clients are substantive in adopting a CE (Charef & Lu, 2021). By creating the demand and making the decisions, clients are viewed as one of the key players involved in the stages of a building's life cycle who must take responsibility to achieve a waste-free construction industry (Scheibengraf & Reisinger, 2005).

Since the demand for sustainable practices and recycled material is of such significance, the lack of it explains why these practices have not yet been established. Hwang and Tan, for example, survey professionals and managers of GB projects in Singapore and find a primary barrier to be "the lack of expressed interest from clients or market demand" (Hwang & Tan, 2012, p. 324). Similarly, in a questionnaire study of building surveyors, Pitt et al. (2009) find the lack of client demand to be one of the top barriers to sustainable construction. This barrier also seems to apply to the case of RAC: Researchers point to the lack of demand in Germany for recycled material, particularly RAC, as a reason for its minimal use (Hinzmann et al., 2019;

[16] Bornais uses the terms "client" and "owner" synonymously, see p. 50.

Nobis & Vollpracht, 2015; Scheibengraf & Reisinger, 2005). Katerusha (2021) conducts a questionnaire study among executing companies in the German and Swiss construction industries focusing on concrete production. He finds that a lack of demand is a significant barrier to using RAC in Germany, only second to a lack of governmental support. This is not found to be an important barrier in Switzerland, where the use of RAC is already common. The case of Switzerland shows that RAC can be introduced to the market successfully through a corresponding demand (Knappe et al., 2012; Wizgall & Knappe, 2011). In summary, a primary barrier to incorporating sustainable practices is a lack of desire on the part of clients (Rodriguez-Nikl et al., 2015), and, to foster the use of these practices and RAC in particular, demand for it must be stimulated (Potrykus et al., 2021).

As described above, RAC is considered to have the same characteristics as NAC and can be used in almost all applications (Knappe et al., 2013). At the same time, public environmental awareness has increased (European Environment Agency, 2019; Rubik et al., 2020). Thus, the question arises why there is a lack of demand from clients for recycled building material in general and RAC in particular.

A primary barrier to the demand for sustainable building is simply the lack of awareness and knowledge of sustainable alternatives in construction (e.g., Adams et al., 2017; Gan et al., 2015; Shooshtarian et al., 2020). All but one articles that Darko and Chan review on the barriers to GB adoption point to a “lack of Information, Education and Research, Knowledge, Awareness, and Expertise” (Darko & Chan, 2017, p. 4). This barrier can be divided into a lack of awareness (simply being unaware of the existence) and a lack of information, knowledge, and experience on GB practices or materials. Unsurprisingly, not knowing of a material precludes demanding it. As such, Pitt et al. (2009) find that a lack of client awareness is among the main barriers to sustainable construction. This is reinforced by the finding that clients are among the least informed groups regarding the CE in construction (Adams et al., 2017). A lack of awareness also seems to be a problem concerning RAC specifically. One of the main barriers Stürmer and Kulle (2017) address in their report on using RAC is the insufficient familiarity of planners and clients with the material. Clients who are unaware of a product automatically lack information and knowledge about it. Nevertheless, clients who are aware of a product’s existence may still perceive a deficiency in information, knowledge, and experience. For example, Rodriguez-Nikl et al. (2015) find that the lack of information and knowledge, not only clients’ but contractors’ and structural engineers’ as well, is a primary barrier to incorporating sustainable design features. This, in combination with clients’ risk adversity, hampers the demand to implement these materials and features in their construction projects (Häkkinen & Belloni, 2011; UKGBC, 2019; Yusof et al., 2021; Zahirah et al., 2013). These barriers create a vicious circle: A lack of awareness, knowledge, and experience leads to a lack of demand, which entails a lack of supply, which then again precludes gaining experience (Wizgall & Knappe, 2011).

Related to the lack of awareness and experience is a lack of acceptance among clients, which additionally hinders their demand for recycled material (Scheibengraf & Reisinger, 2005; Shooshtarian et al., 2020). A lack of acceptance, in this case, is understood as an unwillingness to use secondary material in construction because of the perception that it is inferior. Knappe et al. (2012) devote an entire paper to enhancing the acceptance and use of secondary raw materials in construction. They attribute the low acceptance levels to the unfavorable market conditions for recycled materials and the failure of public authorities to lead by example by including these materials in their tenders. Many of these authorities acting as clients for public building projects are unwilling to use recycled material due to scepsis toward these materials. This scepsis is likely even higher for commercial or private clients (Dechantsreiter et al., 2015). According to Darko and Chan (2017), a lack of information, as described above, can also lead to low acceptance of GB. Besides, it can result from bad experiences. Knappe et al. (2012) describe that recycled materials have not always undergone adequate quality controls. The result is a bad image that sticks, even though the processing of mineral construction and demolition waste and quality control have improved in many ways. Oyedele et al. (2014) conduct a study among construction stakeholders in the United Kingdom and find that a primary barrier to using recycled construction products is the lack of a positive perception by clients based on the idea that secondary material is inferior. Since clients (and designers) determine the material used in their construction projects, this perception inhibits demand for recycled material.

The costs of building sustainably also hamper the demand for the corresponding practices and materials. Costs are found to be the number one barrier for clients in demanding sustainability in their construction projects in numerous studies (e.g., Gan et al., 2015; Lam et al., 2009; Pitt et al., 2009; Shooshtarian et al., 2020). An issue at the core of this barrier is that while the client pays for any sustainable investments, he or she is not necessarily the beneficiary. Instead, the environment and future generations are reaping the rewards (Scheibengraf & Reisinger, 2005). Especially in the case of developers, these split incentives[17] can hinder investments in sustainable construction since they act as clients but not users. When considering these investments, developers weigh the costs against the premium that the end users are willing to pay. If the market does not value these features, developers will unlikely invest the costs (Choi, 2009). Similarly, additional costs for RAC compared to NAC hinder many stakeholders from using it. Stürmer and Kulle (2017) ask architects, structural engineers, and producers of prefabricated concrete parts about reasons against using RAC. Unsurprisingly, most mention that they were unwilling to cover the extra expenses. These extra costs are a product of the costly selective demolition and elaborate processing of waste material to building products (Knappe et al., 2012; Nobis & Vollpracht, 2015). Additionally, the prices for primary material are beaten down due to revenues generated through the backfilling of mines (Knappe et al., 2012) and the external costs of primary material not being incorporated (Silva et al., 2017). The price premium for RAC compared to NAC shows a wide range. Some concrete manufacturers calculate a premium of 10 to 15 % (interviewee 10, personal communication, August 3, 2021) or even an additional 25 EUR per m^3 (interviewee 9, personal communication, August 2, 2021), which translates to around 17 %. In some regions, however, RAC is not more expensive than its primary counterpart. Especially in the German federal state of Baden-Württemberg, the supply of RA is such that concrete manufacturers can offer RAC for the same price as the conventional product (interviewee 2, personal communication, July 1, 2021). In Switzerland, where the material is established, RAC can even be offered at a lower price (interviewee 4, personal communication, July 6, 2021; Eberhard Bau AG, 2021).

Another potential barrier is the (perceived) lack of supply. The *circle of blame* explains why this can lead to a lack of demand. This concept describes the observation that suppliers would principally build sustainably but bewail that there is no demand, while the demand side would buy or lease sustainable buildings but bewail that there is no supply (Andelin et al., 2015; Keeping, 2000). For example, Gou et al. (2013) find that developers view the lack of green materials suppliers as one of the main issues hindering green construction in Hong Kong. Similarly, Lam et al. (2009) survey construction stakeholders about barriers to green specifications in construction and find the limited availability of suppliers to be an important one. The executing companies surveyed by Katerusha (2021) also rate the lack of supply as problematic in using RAC in Germany. In its product overview, a large concrete producer warns

[17] Split incentives are defined as the “separation of investor costs from user benefits” (Choi, 2009, p. 128).

that RAC is not yet comprehensively available due to its regionally limited availability (Holcim Beton und Betonwaren GmbH, 2021).

The lack of incentives is a final barrier to demand that is prominent in the GB literature. The use of natural aggregates (NA) produces externalities that are not incorporated into the price of NAC. This contributes to RAC being more expensive, which incentives could compensate for (Silva et al., 2017). For example, Zhang et al. (2012) study the implementation of green roof systems in Hong Kong and find a lack of incentives from the government toward developers, but even more prominently, those directed at clients, to be crucial impediments. The literature review by Darko and Chan (2017) similarly shows the lack of incentives as one of the most reported barriers to GB. In contrast, when these incentives are in place, they are found to drive sustainable construction, as, for example, Pitt et al. (2009), Olanipekun et al. (2017), and Adams et al. (2017) show. A lack of incentives also works as a barrier in the specific case of RAC. Katerusha (2021) asks executing companies to rank potential barriers on a scale from 1 to 100. The lack of tax incentives reaches a score of 76.5. Finally, Pacheco et al. (2023) analyze European countries and their use of RAC and find that the lack of incentives to use the material is one of the most important impediments.

The literature concerning factors that drive the demand for sustainable construction is much scarcer compared to that focusing on barriers. Nevertheless, we will discuss some recurrently mentioned drivers in the literature. Going beyond stimulating the voluntary adoption of sustainable construction practices through incentives, researchers point to policies and regulations. Gan et al. (2015) find policies and regulations to be positively correlated with Chinese construction clients implementing sustainable features. For the case of recycled construction material, Shooshtarian et al. (2020) highlight the enabling factor of "develop[ing] supportive regulations, policies, and specifications" (p. 11). Public institutions in Germany are required by law to give preference to construction products that have been recycled or prepared for reuse (Kreislaufwirtschaftsgesetz, n.d.). Similarly, the EU's Construction Products Regulation stipulates secondary material to be used in construction projects (EU Construction Products Regulation, n.d.). It seems reasonable that being obliged to fulfill specific requirements naturally creates demand. However, having these regulations in place is insufficient. Often, the problem is a lack of enforcement and monitoring (interviewee 1, personal communication, June 29, 2021; interviewee 3, personal communication, July 5, 2021). For example, while recycled material may legally not be excluded in tenders (Kreislaufwirtschaftsgesetz, n.d.), it still regularly is. However, because third parties have no legal claim, this behavior remains unchanged (interviewee 2, personal communication, July 1, 2021). In addition, many of the relevant policies fall under the federal states' responsibility in Germany, making it difficult for actors to keep an overview (interviewee 1, personal communication, June 29, 2021). In the case of RAC, additional regulations hinder its demand: The requirements are higher compared to those for NAC, and construction waste must be tested extensively for it to be introduced back into the market as a product (interviewee 5, personal communication, July 8, 2021).

For construction clients, particularly organizations or companies rather than private individuals, the importance of image or reputation takes on another significant role in the desire to build sustainably. Diyana et al. (2013) identify four main groups of drivers for green construction from the perspective of developers, of which one pertains to their image. Developers gain a competitive advantage through certifications and awards improving their reputation. Similarly, Zhang et al. (2011) investigate several case studies of GB in China and find that the responsible developers believe in the reputational advantage of implementing sustainable features. The

Australian project owners surveyed by Olanipekun et al. (2017) confirm that reputation influences their motivation for GB.

A further driver for demanding sustainable construction is moral: environmentally friendly attitudes. Olanipekun et al. (2017) study project owners' motivation for delivering GB projects and find internal factors, among which pro-environmental attitudes are most prominent, to be critical. Darko et al. (2017) distinguish five categories of drivers for GB, one of which is individual-level drivers. These include moral imperative or social conscience, personal commitment, attitudes and traditions, and self-identity. The researchers point out that these drivers can be effective, but little research has focused on them. A similar category of drivers for green construction is highlighted by Diyana et al. (2013): The category "ethical" includes social and environmental responsibilities.

Sustainable alternatives to conventional products often come with a price premium. Consumers' WTP for these alternatives has been investigated for many products and sectors, such as investments, electricity, food, vehicles, and recycled or remanufactured products in general (e.g., Gutsche & Ziegler, 2016; Hamzaoui Essoussi & Linton, 2010; Hansla et al., 2008; Longo et al., 2008). Several researchers have investigated stakeholders' acceptance of these premiums in sustainable construction and find that there generally is a positive WTP for environmentally friendly attributes (Mandell & Wilhelmsson, 2011b) in buildings. Potential homebuyers in Pakistan, for example, are found to be willing to pay an extra 11 % for sustainable housing (Khan et al., 2020). Portnov et al. (2018) use a nationwide survey in Israel and discover that a price premium between 7 and 10 % for GB is found acceptable. Wiencke (2013) surveys private and public corporations in Switzerland to investigate their WTP for green buildings. The firms' accepted price premium ranges between 1.3 and 7.9 % compared to conventional buildings.

On a smaller scale, researchers have studied to what extent construction clients, homebuyers, and tenants appear willing to pay for specific green attributes. Robbins and Perez-Garcia (2005) use a choice-based survey to investigate the WTP for features that improve the environmental performance of construction in the general population and among real estate agents. The former group is most responsive to reductions in GHG emissions, being willing to pay for the reduction of around half of what building a house emits. Their WTP for reductions in air pollution and solid waste is smaller but still positive. Compared to the general public, real estate agents are found to be much more sensitive to reductions in solid waste and much less willing to pay for reducing GHG emissions.

The WTP for RAC specifically has yet to be investigated. However, as described above, the price seems to be a barrier to its demand. One reason might be that using RAC, as opposed to installing energy efficiency measures, for example, does not directly translate into economic benefits (Zalejska-Jonsson, 2014). Katerusha (2022) surveys architects and engineers in Germany and uses the *Price Sensitivity Meter* to determine the optimal price for RAC. He finds the optimal pricing point – at which an equal share of respondents judges the product as too expensive and too cheap – to be around 14 % cheaper than NAC. The range of acceptable prices for RAC appears to lie between 83.3 and 100 % of the price of NAC.

Several factors influence clients' WTP, such as income, age, gender, and education (e.g., Chau et al., 2010; Khan et al., 2020; Park et al., 2013; Yau, 2012). The positive effect of environmental awareness on the WTP for environmentally friendly products is especially uncontroversial. It has been found for various products, such as renewable energy sources (Zografakis et al., 2010) and electric vehicles (Ziegler, 2012), but also in the building sector.

Yau (2012) finds that residents with higher environmental attitudes have a higher WTP for green housing attributes. Similarly, the respondents surveyed by Mandell and Wilhelmsson (2011) who view themselves as environmentally aware are willing to pay more for environmental housing attributes than their counterparts. Familiarity in the sense of experience with and knowledge of the environmentally friendly product is also consistently found to be advantageous for consumers' WTP (e.g., Shen, 2012; Zografakis et al., 2010). In her study on WTP for green apartments in Sweden, Zalejska-Jonsson (2014) observes that customers are only willing to pay for those attributes they understand. Similarly, Portnov et al. (2018) find that potential homebuyers who are familiar with the concept of GB are willing to pay more than those who are not. Finally, as described above, construction stakeholders often repudiate their responsibility for employing sustainable practices and materials and hold each other responsible instead (Andelin et al., 2015; Keeping, 2000). This (lack of) feeling of responsibility also seems to influence consumers' WTP: Wang (2022) finds that individuals who feel an environmental responsibility have a higher WTP for improvements to the environment.

The above overview of the current state of scientific literature on clients, their demand and WTP for sustainable building materials, and the barriers (and drivers) that impede (foster) this demand leads to the contribution of this study. The research on socioeconomic aspects of the demand for recycled material and RAC specifically is insufficient to draw informed conclusions. RAC is a specific case of sustainable construction since, for example, it does not have an apparent financial long-term benefit like energy efficiency measures. Thus, the existing research cannot necessarily be applied to RAC. This study combines the above research fields for the specific case of RAC to understand clients' consumption behavior of the material. The following sections will derive the hypotheses based on this literature.

Summarizing the literature regarding barriers, the demand for RAC among construction clients is likely impeded by factors such as unfamiliarity with the material, insufficient information or experience, limited regional availability, a lack of financial incentives for using RAC, and higher costs compared to NAC. From the literature on drivers, we deduce that demand for RAC will likely be driven by policies and regulations that prescribe its use, a positive image effect, and environmentally friendly attitudes. One of the contributions of this study is to identify the barriers and drivers construction clients face for demanding RAC by surveying them directly, which has not been done so far. This understanding is crucial to designing appropriate measures to foster the use of RAC (Pacheco et al., 2023). The following hypotheses guide this part of the study:

> **H1.1** Important barriers for clients to demand RAC are a lack of awareness and knowledge, acceptance, supply, incentives, and a higher price.

> **H1.2** Important drivers for clients to demand RAC are policies and regulations, image/reputation considerations, and environmental awareness.

These are hypothesized to be the most critical barriers and drivers since they are prominent in the literature on GB. However, additional ones are conceivable and are discussed during expert interviews. Note that some aspects can be perceived as both barriers and drivers, depending on their value. For example, the price can hinder as well as drive demand for RAC, depending on whether it is higher or lower than that of NAC. Another example is familiarity with the material: A lack of it is likely to inhibit clients' demand, but having experience with RAC, for example, can be a driving force.

So far, it is unclear whether construction clients are willing to pay more for RAC than its conventional alternative. On the one hand, they have repeatedly been found to be willing to pay for green buildings and certain specific environmentally friendly features. On the other hand, the higher price for RAC seems to be a barrier, and it has been suggested that the optimal price for RAC lies below or at most at the same level as that of NAC. Thus, the existing research is inconclusive in this regard. This study aims to resolve this issue by directly studying clients' WTP for RA in concrete.

H2 Clients' WTP for RA in concrete differs from their WTP for NA.

This study further aims to identify factors influencing clients' propensity to choose and pay for RAC. To do so, we check whether those factors that have been found to play a role in sustainable construction also apply to the specific case of RAC.

H3.1 Valuing sustainability as a criterion in construction positively influences the inclination to choose RAC and the WTP for RA in concrete.

H3.2 Clients familiar with RAC are more inclined to choose RAC and are willing to pay more for RA in concrete than clients unfamiliar with the material.

H3.3 Clients who feel responsible for considering sustainability in construction are more inclined to choose RAC and are willing to pay more for RA in concrete than clients who do not feel responsible.

So far, construction clients have been treated as one group. While all construction clients share the defining characteristic of initiating and financing a project, crucial differences between them might affect their demand for RAC. This study distinguishes private individuals, organizations, and developers and asks whether these types of clients differ regarding their barriers, drivers, and propensity to choose and pay for RAC. Given that developers function as clients on a professional basis, it can be inferred that they possess a higher level of knowledge about various construction materials, including RAC. Organizations, though not directly involved in the construction industry like developers, are likely to have commissioned multiple buildings. Consequently, they are likely to possess more experience and information compared to private individuals, who typically only build one house during their lifetime. Further, while all three groups might be intrinsically motivated to use resource-efficient materials, developers and organizations are additionally motivated by external factors such as their image and reputation (Diyana et al., 2013; X. Zhang et al., 2011). The resulting hypotheses are the following:

H4.1 Developers have the highest WTP for recycled aggregates in concrete, followed by organizations and then private individuals.

H4.2 For private individuals, informational barriers are more relevant than for developers and organizations.

H4.3 For developers and organizations, reputational aspects are more relevant drivers than for private individuals.

3 Methods

3.1 Research Strategy and Data Collection

A two-part online survey among construction clients is conducted to achieve the above research objectives. The multitude of stakeholders involved in construction projects adds to the ambiguity around the definition of the client (Gan et al., 2015; Olanipekun, Chan, et al., 2017; Rodriguez-Nikl et al., 2015). Following Hartmann et al. (2008), this study defines the client as the one who initiates and finances the construction project. In practice, the client can take several forms. Here, we distinguish between three groups that comprise our sample: private individuals, organizations, and developers. Private individuals are part of our target group if they have built a home in the previous five years, are currently in the process of building, or are planning to build soon. Organizations are represented by the employees responsible for the construction of new buildings for private and non-profit organizations. Public authorities and construction companies are excluded from the sample. Finally, the developers include property developers, investors who initiate construction projects, and housing associations.

Before the start of the survey, several interviews are conducted with industry experts to validate the information the survey questions are based on. Among the experts are concrete producers, a recycler, a researcher in the field of construction material, and representatives of German associations for GB, the concrete industry, and secondary resources. An anonymous list of interviewed experts can be found in Table II.A.1 in the appendix.

The first part of the survey consists of item-based questions, while the second part is experimental. The first part starts with the respondents being asked to give some demographic information after confirming that they belong to the target group. Next, a short description of RAC is given, and respondents are asked about their familiarity with the material. In the next block, a list of ten potential barriers is presented, each of which the respondents are asked to rate according to the extent to which they experience this factor as a barrier to using RAC. The scale ranges from "not at all" (0 %) to "totally" (100 %). Next, the same procedure follows for a list of ten potential drivers. The list of barriers and drivers is created based on a thorough literature review and the expert interviews. The respondents have the chance to mention further aspects for both barriers and drivers. The experimental part of the survey follows, which will be described below. Finally, the survey finishes with some item-based questions on sustainability's role in the construction project(s). Only the questions concerning demographic information differ considerably between the three groups. The remaining questions are only adapted in wording to suit the type of respondent. The full survey transcript can be found in Table II.A.2 in the appendix.

The second part of the survey, placed between the item-based questions, is the experimental part consisting of a DCE[18]. In DCEs, respondents are given a set of alternatives from which they are asked to choose their most desired one. These alternatives differ on a certain number of attributes, which enables the researcher to determine the influence of these attributes on the probability of choosing an alternative. DCEs are based on random utility theory and, therefore, the assumption that individuals derive utility not from whole goods but from the attributes of that good (McFadden, 1986). By including price as one of the attributes describing the alternatives, a WTP for the other attributes can be calculated. In that vein, the DCE in this study

[18] Before the DCE, respondents are randomly assigned to one of two groups: one receives information on RAC and the other does not. However, since this information provision is not of relevance for this paper, it is not further elaborated on. It is, however, discussed in detail in Part II. The treatment does not have any influence on the choices in the DCE.

has the purpose of answering the questions whether construction clients are willing to pay for increasing the share of RA in concrete (H2), whether this WTP is influenced by specific individual characteristics (H3), and whether it differs between different types of clients (H4). The alternatives in this study are different forms of RAC characterized by four attributes. The first one is the price per m^3, which is likely to influence the probability of choosing any product and RAC in particular, given that higher prices seem to be a barrier (see Chapter 2). In addition, this attribute is necessary to determine respondents' WTP for the other attributes. The price can take the values of 125 EUR, 150 EUR, and 175 EUR. These are based on the price lists of various German concrete producers. The second attribute is the share of RA contained in the concrete. It can take the values of 10 %, 55 %, and 100 %. Currently, 45 % is the maximum share that can be substituted in Germany without special approval (DAfStb, 2010). However, DCEs offer the possibility of identifying preferences in hypothetical situations, which this range of values takes advantage of. Another attribute is the CO_2 footprint per m^3 of concrete, taking values of 170 kg, 200 kg, and 230 kg. These values are based on the sustainable construction information portal Ökobaudat (Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen, 2021) and interviews with the experts. The CO_2 footprint is arguably the most salient environmental parameter of any product, activity, or sector, while RAC and its share of RA might be unfamiliar to many construction clients. This characteristic is incorporated to compare clients' responsiveness to variations in these distinct parameters. The last attribute is the certification with a CSC-R label. The Concrete Sustainability Council (CSC) certifies companies and their supply chain in the concrete industry in the categories of economic, ecological, and social sustainability, as well as management. It has an additional R-module for companies that produce RAC (Concrete Sustainability Council, 2020). Labeling of recycled concrete is one of the recommended actions in a report by the European Commission to promote the use of RAC (Pacheco et al., 2023). This attribute is binary such that it only takes the values of "yes" or "no". Since labels are a means of information provision, this attribute is included to test whether this type of instrument could help to increase the demand for RAC. These attributes are also checked with the interviewed experts. Table II.1 gives an overview of all attributes and their possible values.

Table II.1: Attributes and values of the DCE

Attribute	"Worst" value	Middle value	"Best" value	NAC
Price	175 EUR	150 EUR	125 EUR	150 EUR
RA	10 %	55 %	100 %	0 %
CO_2 footprint	230 kg	200 kg	170 kg	200 kg
CSC-R Label	No	–	Yes	No

DCE = discrete choice experiment, RA = recycling aggregates, CSC-R = Concrete Sustainability Council Recycling-module

The experiment is unlabeled, indicating that the names describing the different alternatives do not have a meaning. Respondents are given eight decision situations (*choice sets*), each showing three forms of RAC (A, B, and C) and a status-quo alternative, which is NAC. The values of this NAC do not change. They are always a price of 150 EUR per m^3, 0 % share of RA, 200 kg of CO_2 emissions per m^3, and no label (see Table II.1). The values for the price and CO_2 emissions are chosen based on literature reviews, screening price lists, and the interviews with experts. This status-quo option is added to resemble a real-life choice situation, in which respondents are not forced to choose RAC, more closely. To the same end, we include the opt-out option "I cannot answer this question". Since showing all possible choice sets to respondents – a so-called *full factorial design* – is not feasible[19], a fractional factorial design is generated using Lighthouse Studio (Sawtooth Software, 2021). The *Balanced Overlap* design option is chosen, which ensures statistical efficiency while allowing some overlap between alternatives, enabling the researcher to identify interaction effects. Twelve different versions of the experiment are created, to which respondents are allocated along the principle of drawing from an urn without replacement. This approach ensures that each version is approximately presented an equal number of times.

Respondents are asked to imagine that they are currently planning a building and must choose the concrete type to use. They are instructed to assume that all presented types, including the NAC, have the same characteristics beyond those explicitly mentioned. Respondents are given some facts about an exemplary building for orientation, including surface area, overall costs, amount of concrete necessary, and costs for this volume of concrete in absolute terms and as a percentage of overall building costs. This exemplary building is either a typical family home (private individuals) or an office building (organizations and developers). A reference in car travel kilometers is given for the magnitude of a 30 kg difference in CO_2 emissions. An exemplary choice set is shown in Table II.2. The experimental part of the survey finishes with a factorial survey, which is the focus of another paper (see Part III), to which interested readers are referred.

Table II.2: Exemplary choice set

	RAC A	RAC B	RAC C	NAC
Price per m^3	175 EUR	125 EUR	150 EUR	150 EUR
Share of RA	10 %	100 %	55 %	0 %
CO_2 footprint per m^3	230 kg	170 kg	230 kg	200 kg
Environmental label (CSC-R)	No	Yes	Yes	No
Which concrete do you choose?	○	○	○	○
○ I cannot answer this question.				

RAC = recycled aggregate concrete, RA = recycled aggregates, CSC-R = Concrete Sustainability Council Recycling-module

The survey is designed using the online platform SoSci Survey (Leiner, 2021) and made available to participants via www.soscisurvey.de. A pilot study is conducted prior to running the actual survey. Twenty-four private individuals in the target group, mainly social contacts of the researcher, completed the pilot study, and a further ten individuals started it without finishing. Additionally, one representative of the groups of organizations and developers each looked through the survey. Based on the respondents' feedback and metrics, such as the completion time, some minor changes are made to the survey design. The actual survey was available from December 2021 to mid-February 2022. Private individuals are mainly targeted via social media posts and distributors such as housing organizations or architects. Organizations and developers are invited to participate in the survey via e-mail. Contact details are assembled via publicly accessible websites and the firm database Amadeus (Bureau van Dijk, 2010).

[19] The set of all possible alternatives is formed by the Cartesian product of all attributes and levels (3 x 3 x 3 x 2 = 54). With three alternatives, there are 157,464 (54 x 54 x 54) possible choice sets.

3.2 Empirical Model

While the first research question on barriers and drivers is answered using descriptive statistics, the second (pertaining to clients' WTP) requires an empirical model. According to Louviere et al. (2010), the utility of a consumer in a choice situation can generally be formalized as follows:

$$U_{ia} = V_{ia} + \varepsilon_{ia}$$

where U_{ia} is the utility of alternative a for individual i, V_{ia} is the systematic or representative component, and ε_{ia} is the random component. The former component denotes the part of utility that the attributes of the alternatives contribute to, and that can be observed, while the latter is the part of utility contributed by the attributes that cannot be observed. The central assumption is that the individual i will choose an alternative a if and only if the utility he or she gets from that utility is larger than the utility he or she would get from the other available alternatives:

$$U_{ia} > U_{ib} \qquad all\ b\ \neq a\ \in A$$

Since the random component of utility cannot be observed, one can only make statements about probabilities. The previous two equations lead to the following probability:

$$P(a|C_i) = P[(V_{ia} + \varepsilon_{ia}) > Max(V_{ib} + \varepsilon_{ib})], \text{ for all } b \text{ alternatives in choice set } C_i$$

where a is an alternative from a set of competing options in a choice set C. In words, the probability that individual i chooses the alternative a from the given options in a choice set C is equal to the probability that the systematic and random components of utility of that alternative are larger than those of all other options in that choice set. Different choice models can be derived from this equation depending on the assumption one makes about the probability distribution of the random components ε_{ia}.

The basic choice model, the conditional logit choice or multinomial logit model by McFadden (1974), assumes that the unobserved effects are independently and identically distributed among the alternatives in the choice set. Additionally, "the ratio of the probabilities of choosing one alternative over another (given that both alternatives have a non-zero probability of choice) is [assumed to be] unaffected by the presence or absence of any additional alternatives in the choice set" (Louviere et al., 2010, p. 44) – the so-called *Independence of Irrelevant Alternatives* (IIA) assumption. In other words, introducing a further alternative should not change the relative probabilities of the alternatives already in the choice set. Technically, this means that the error terms may not be correlated. Introducing an opt-out option, as is done in this study, often violates this assumption (Dhar & Simonson, 2003). Diagnostic tests also show that the IIA assumption does not hold in our data (see Section 4.3). Therefore, this study uses a mixed logit (ML) model (McFadden & Train, 2000). The ML model allows for the coefficients of one or more of the attributes describing alternatives to be random, thus able to vary across individuals in the sample and thereby accounting for preference heterogeneity. A specific distribution of these coefficients is assumed, and the parameters of that distribution are calculated. This allows for correlations among alternatives, thereby relaxing the IIA assumption (StataCorp, 2021). The ML model separates the unobserved error component into two parts: one that contains these correlations and can follow any distribution and one that is independently and identically distributed (Train, 2009). Since the subjects in this study make a choice in several choice sets, the data can be viewed as panel data. Therefore, a time component is added to the equation. The utility an individual i gets from an alternative a at time t in the ML model can be described by

$$U_{iat} = \beta'_i\, X_{iat} + \alpha'\, W_{iat} + \delta'_a\, Z_{it} + \varepsilon_{iat}$$

where X_{iat} and W_{iat} are vectors of attributes (variables) that describe the alternatives. β'_i are the random coefficients that can vary over individuals in the sample, while α' are fixed coefficients that do not vary over individuals. Z_{it} is a vector of variables describing the individuals (the decision-makers) and δ'_a are the corresponding fixed coefficients. The command *cmxtmixlogit* in the statistical software Stata estimates α', δ'_a, and the parameters of the distribution of β'_i using maximum simulated likelihood (StataCorp, 2021).

The WTP for a particular attribute can be calculated by dividing the coefficient of the attribute of interest k by the coefficient of the price variable c (Hole, 2007):

$$WTP_k = -\frac{\beta_k}{\beta_c}$$

Likely, there is preference heterogeneity concerning the price of concrete in the sample. However, modeling the price coefficient as random with the usually assumed normal distribution implies that the WTP is the ratio of two normal distributions, which is statistically problematic (Carson & Czajkowski, 2019). A common way to deal with this issue, and the one taken here, is to fix the price parameter. The resulting WTP then follows the distribution of the attribute of interest (Sillano & de Dios Ortúzar, 2005; Train & Weeks, 2005). Because the WTP follows a distribution, we do not only report the estimated values for the WTP throughout the results but also the corresponding confidence intervals. These are calculated using the delta method implemented in the *wtp* command in Stata (Hole, 2007; StataCorp, 2021).

In order to pool the RAC alternatives and as a robustness check, the nested logit model is applied (Hensher & Greene, 2002). The nested logit model relaxes the assumptions made by the multinomial logit model by grouping similar alternatives into nests, creating a hierarchical choice. In this example, the choice is structured into a first choice between NAC and RAC and a second choice between the different versions of RAC (see Figure II.1).

The utility for a so-called *elemental mode* m that is contained within a *generic mode* g is given by

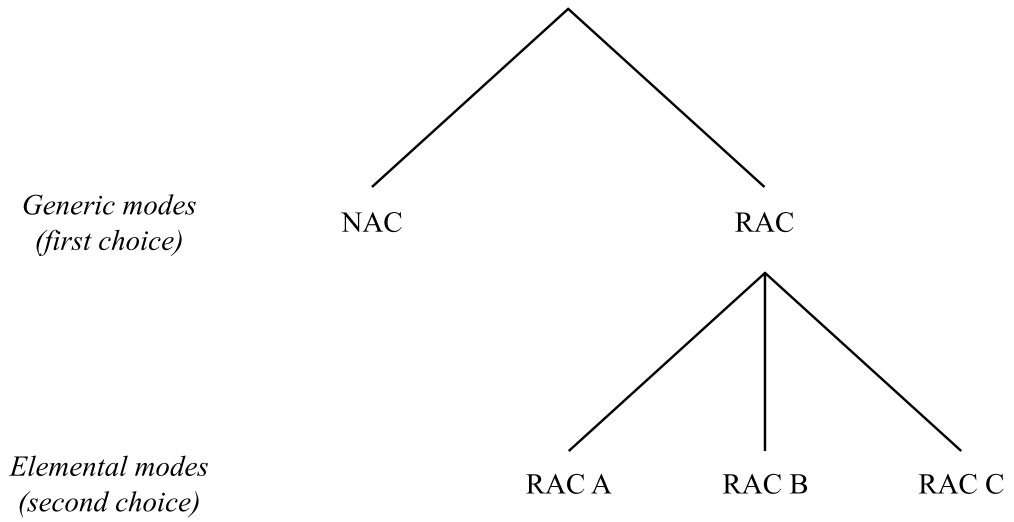
$$U_{gm} = U_g + U_{m|g}, m \in M_g, g \in G$$

or in terms of the systematic and unobserved components of utility:

$$U_{gm} = V_g + V_{m|g} + \mu_g + \varepsilon_{m|g}, m = 1, \ldots, M_g, g = 1, \ldots, G$$ (Louviere et al., 2010).

The nested logit model is fitted using the command *nlogit* in Stata (StataCorp, 2021).

Figure II.1: Hierarchical choice of concrete types



NAC = concrete with natural aggregates, RAC = recycled aggregate concrete

4 Results

4.1 Descriptive Results (Sample)

After excluding cases that quit without answering any of the substantial questions, do not belong to the target group, or did not give their consent, 834 private individuals, 624 organizational representatives, and 129 developers who started the survey remain (total: 1587). Of those, 305, 366, and 87 completed the survey, respectively (total: 758). Followingly, the attrition rate overall is relatively high (52 %). Reasons could be the relatively long time necessary to complete the survey (13 minutes on average for completed surveys and after correcting for breaks) or the complexity of the questions, especially in the DCE. Nevertheless, the discontinued surveys still contain valuable information that can be used in parts of the analysis. For example, more than half of the participants that did not finish the survey did answer the questions on barriers and drivers.

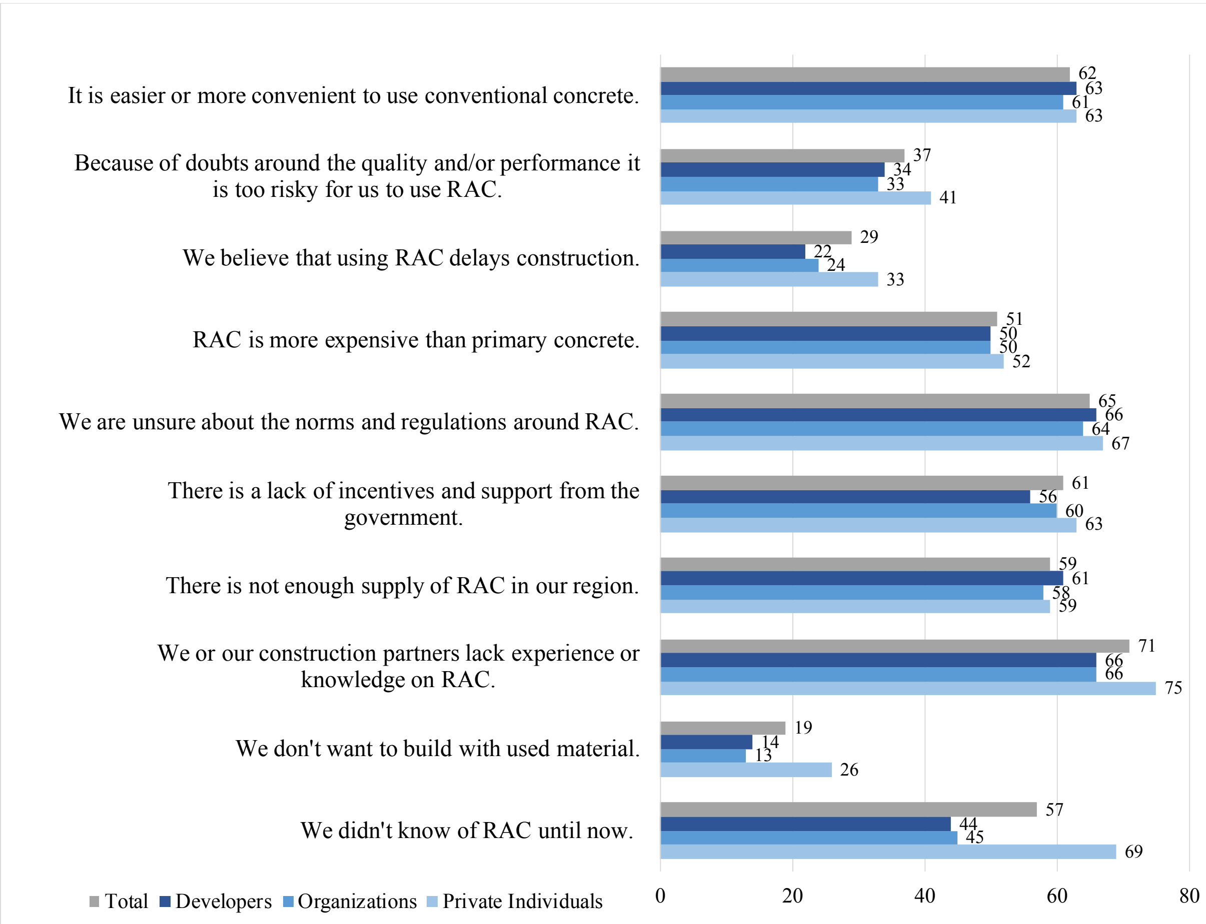
The distribution of the main demographic variables in the sample can be seen in Table II.B.1, Table II.B.2, and Table II.B.3 in the appendix. The samples of developing companies and organizations seem to represent their respective population, except concerning the organizations' turnover. This is much higher in our sample than the average among organizations in Germany. However, given that a prerequisite to participate in the study is that organizations act or have acted as construction clients, it is plausible that the sample is biased towards bigger, higher-turnover ones. A similar pattern can be seen in the sample of private individuals: Our respondents are generally younger, more highly educated, have a higher average household income, are more likely to be employed, and are more likely to be married than the general population. These differences are plausible, considering that all respondents in our sample are building, have built, or will be building a family house. Similar tendencies are found in an analysis of real estate financing by private clients in Germany (Europace, 2023).

The descriptive results regarding the role of sustainability, the familiarity with RAC, and consideration of using it can be found in Appendix B. The perceived driving forces and responsible stakeholders for considering sustainability in construction are displayed in Table II.B.4.

4.2 Barriers and Drivers

The respondents' ratings of possible barriers to the use of RAC can be found in Figure II.2. The number of observations per barrier differs, since items could be left unrated if the respondent is unable to judge it. Considering the entire sample collectively, the primary barrier is the absence of knowledge and experience with RAC on the part of the clients or their building partners. The second most important reason for not using RAC is the uncertainty surrounding norms and regulations pertaining to the material. The notion that using NAC is easier or more convenient is ranked third. Organizations and developers each viewed separately show the same pattern as the overall sample. The top three barriers for private individuals are the lack of knowledge and experience, not knowing RAC until now, and the uncertainty about norms and regulations.

Figure II.2: Barriers to the use of RAC

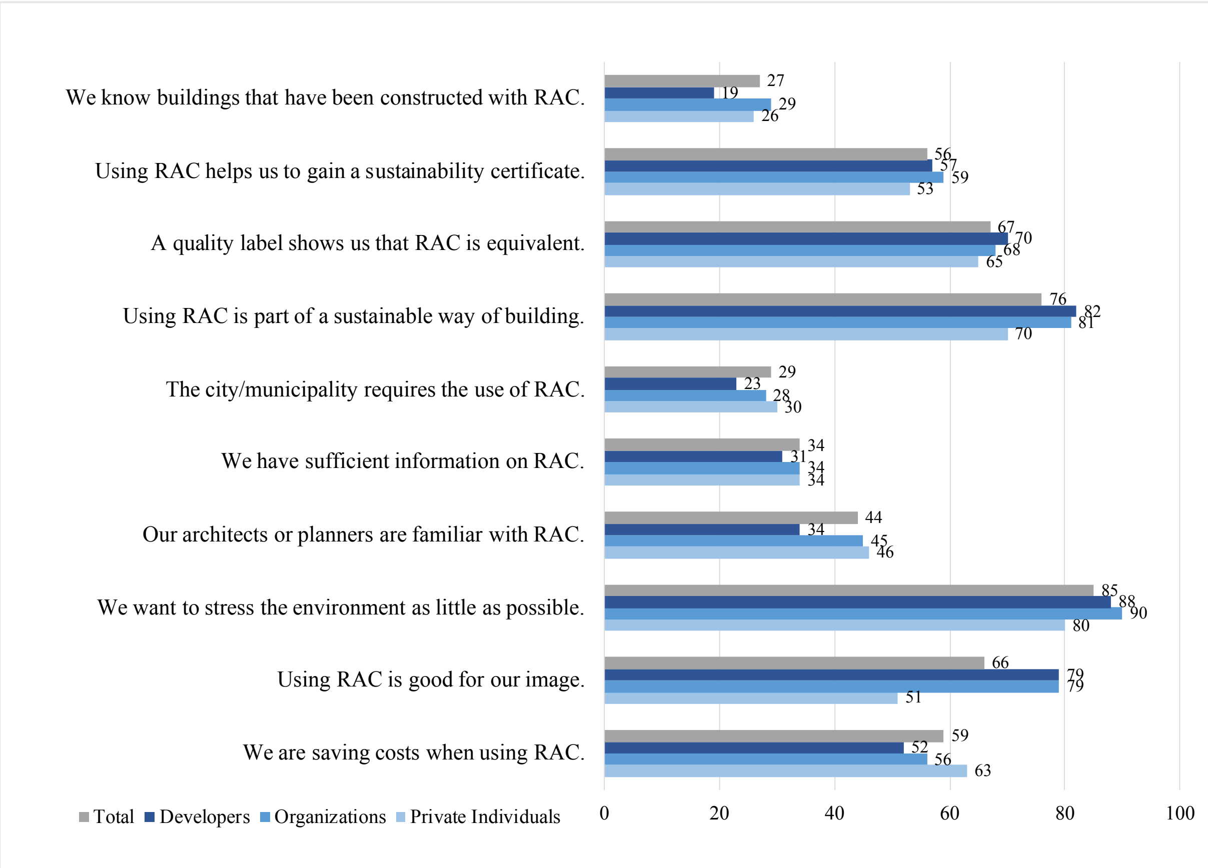


Answers are given on a scale from 0 to 100. N = 1011 – 1276.
RAC = recycled aggregate concrete

Regarding our first hypothesis (H1.1), most barriers are confirmed to be important for clients. Firstly, the lack of knowledge and experience is the most prominent barrier in all groups. Additionally, a complete lack of awareness (not knowing RAC) is the second most important barrier in the group of private individuals. As expected, developers and organizations are affected by this ignorance much less than private individuals (rank 7). Our hypothesis that informational barriers are more relevant for private individuals than for the other two groups (H4.2) is thus partly confirmed: While a lack of fundamental awareness of the existence of the material is indeed much more prominent among private individuals, all groups are held back by a lack of a deeper understanding. Given their rating (see Figure II.2), the lack of incentives, supply, and the higher price of RAC can also be considered important, but they only rank 4th, 5th, and 7th, respectively. Finally, the results do not confirm that a lack of acceptance is an issue among construction clients: the respondents rank this barrier last.

The respondents' ratings of possible drivers for the use of RAC can be found in Figure II.3. Overall, the foremost driver is the desire to minimize the impact on the environment as much as possible. The second highest rated driver is related to this environmental consciousness: the notion that RAC is part of a sustainable way of construction. A quality label certifying that RAC is equivalent to NAC ranks third. This pattern is also evident when viewing private individuals separately. However, organizations and developers rank the idea that using RAC is beneficial for their image third.

Figure II.3: Drivers for the use of RAC



Answers are given on a scale from 0 to 100. N = 890 – 1060.
RAC = recycled aggregate concrete

These results partly confirm our hypothesis regarding the main drivers for using RAC (H1.2). Environmental awareness is indeed the most important driving force for construction clients. Image and reputation considerations are also highly influential, but only for developers and organizations. This aligns with the hypothesis that reputational aspects are more relevant for these two groups than for private individuals (H4.3). Against expectations, the other driver that is hypothesized to be critical, policies and regulations, only ranks 9th. The fact that the driver of saving costs receives a similar rating to the corresponding barrier suggests that the price can be perceived both as a driver and a barrier, depending on how it compares to that of NAC. This is in line with the notion that there are regional differences in the price for RAC, which is why this factor requires a differentiated view.

4.3 Willingness to Pay

The coefficients of the alternative-specific attributes in the ML model are all highly significant and have the expected sign: While individuals are less likely to choose alternatives with a higher price and higher CO_2 values, they are more likely to choose alternatives with higher contents of RA and those that have a label (see Table II.3). The alternative-specific constant (ASC) is a dummy variable that takes the value 1 for all RAC alternatives and the value 0 for the alternative of NAC. The results indicate that respondents are more likely to choose RAC than NAC, holding the attributes constant. On average, respondents are willing to pay 0.26 EUR for every percentage point (pp) increase of added RA. This value lies in a range of possible values between 0.18 EUR and 0.33 EUR. This finding confirms our hypothesis that clients' WTP for RA differs from that for NA (H2), as they are willing to pay more for RA in concrete.

Table II.3: Main regression results

Price	– 0.0551***
	(0.00231)
RA	0.0141***
	(0.000907)
CO_2 footprint	– 0.0405***
	(0.00192)
Label	0.937***
	(0.0607)
ASC	1.632***
	(0.232)
/Normal	
SD(RA)	0.0167***
	(0.00127)
SD(CO_2 footprint)	0.0350***
	(0.0019)
SD(Label)	1.129***
	(0.0833)
SD(ASC)	2.784***
	(0.261)
N	24896

Standard errors in parentheses
$^{+}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$
Results obtained using a mixed logit model.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
RA = recycled aggregates, ASC = alternative-specific constant, SD = standard deviation

The second half of Table II.3 gives the attributes' standard deviations (SD). All values are highly significant, indicating preference heterogeneity across the sample. Moreover, this confirms that the assumption of IIA is violated in our sample, and that it is, therefore, appropriate to use a ML model.

The regression results for the separate groups, the corresponding marginal effects, and WTP estimates can be found in Table II.4, Table II.5, and Table II.6. Among the three groups, private individuals are most affected by the price of concrete. An increase of 15 % in the price for RAC decreases the probability of private individuals choosing it by 11.4 pp. However, the differences between the groups are only moderate in this respect. The share of RA most strongly affects the group of organizations. Increasing the share of RA in RAC by 20 pp translates to an increase in the probability of organizations choosing it by 3.3 pp, while the increase is only by 2.4 pp for private individuals[20]. Along the same lines, organizations are the group most willing to pay for increasing the share of RA in concrete, while private individuals' WTP is the lowest. Developers, organizations, and private individuals are willing to pay 0.27 EUR, 0.30 EUR, and 0.21 EUR for a percentage point increase in the share of RA, respectively. This order differs from the one we hypothesized to find (H4.1). As expected, private individuals have the lowest WTP, but we find organizations instead of developers to have the highest WTP. The difference between the organizations' and private individuals' WTP is significant since the respective values do not fall in the other groups' estimated range of possible values.

Table II.4: Regression results for separate client groups[21]

	(1) Developers	(2) Organizations	(3) Private Individuals
Price	-0.0528^{***}	-0.0536^{***}	-0.0569^{***}
	(0.00679)	(0.00331)	(0.00369)
RA	0.0140^{***}	0.0162^{***}	0.0118^{***}
	(0.00227)	(0.00138)	(0.00138)
ASC	3.042^{**}	1.584^{***}	1.369^{***}
	(0.948)	(0.370)	(0.314)
/Normal			
SD(RA)	0.0112^{**}	0.0162^{***}	0.0184^{***}
	(0.00348)	(0.00190)	(0.00223)
SD(ASC)	4.254^{***}	2.630^{***}	2.697^{***}
	(0.820)	(0.396)	(0.365)
N	2744	11188	10964

Standard errors in parentheses
$^{+} p < 0.10$, $^{*} p < 0.05$, $^{**} p < 0.01$, $^{***} p < 0.001$
Results obtained using mixed logit models.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
RA = recycled aggregates, ASC = alternative-specific constant, SD = standard deviation

A nested logit model is applied to estimate the effect of individual characteristics on the choice between NAC and RAC. Simply adding individual characteristics to the ML model is meaningless in the case of unlabeled experiments. Unlabeled experiments are those in which the names of the alternatives in a choice set do not carry any meaning (e.g., "RAC A", "RAC B", and "RAC C"). In contrast, labeled experiments include meaningful names of the

[20] This difference in the effect of the share of RA on organizations versus private individuals is statistically significant.
[21] Because the focus here is on the share of RA and the WTP for it, the results for the variables *CO_2 footprint* and *Label* are omitted from the regression tables from here on. The complete results for Table II.4 can be found in Table II.C.1 in the appendix.

alternatives. The most common example is the choice between means of public transport, in which the alternatives are labeled, for example, "bus", "train", and "subway" (Ben-Akiva & Bierlaire, 1999). When there is no meaningful difference between the alternatives above and beyond the varying attributes, it is also meaningless to estimate the effect of individual characteristics on the probability of choosing, for example, RAC A over RAC B. It is, however, valuable to estimate the effects of individual characteristics on the probability of choosing RAC or NAC, the nests in our nested logit model. To identify the effect that these individual characteristics have specifically on the effect of the share of recycled material on the choice probability of that type of concrete, interaction terms are added to the ML model. Thus, we use the nested logit model to identify the effect of individual characteristics on the choice of RAC generally and the ML model to identify the effect of individual characteristics on the impact of the share of RA.

Table II.5: Marginal effects of changes in the price and the share of RA

	Overall	Developers	Organizations	Private Individuals
Price (+ 15 % on RAC)	– 11.1	– 10.8	– 10.7	– 11.4
RA (+ 20 pp on RAC)	+ 2.9	+ 3.0	+ 3.3	+ 2.4

Values are given in percentage points.
RA = recycled aggregates, RAC = recycled aggregate concrete, pp = percentage points

Table II.6: WTP estimates for RA for separate client groups

	Overall	Developers	Organizations	Private Individuals
WTP RA (1 pp)	0.26	0.27	0.30	0.21
Lower limit	0.18	0.16	0.25	0.16
Upper limit	0.33	0.37	0.36	0.26

Values refer to the WTP estimates for a pp increase in the share of RA.
WTP = willingness to pay, RA = recycled aggregates, pp = percentage point

For the sample overall, individual characteristics that are of interest in the choice between NAC and RAC are to what extent sustainability is/was a criterion in construction for respondents (Sustainability), whether they had heard of RAC before (Familiarity), and whether they think that the responsibility of considering sustainability in construction lies with themselves (Responsibility). Table II.7 shows the results of both a nested logit and a ML model that includes interaction terms between these individual characteristics and the share of RA. The results show that the effects are as expected in most instances. A higher valuation of sustainability as a criterion in construction, being familiar with RAC, and a higher sense of responsibility for sustainable construction significantly increase the probability of construction clients choosing RAC and, except for the feeling of responsibility, the responsiveness to the share of RA. Our hypotheses on the value of sustainability in construction (H3.1) and on familiarity (H3.2) are thus confirmed. The hypothesis on the effect of feeling responsible (H3.3) is only partly confirmed since it does increase the probability of choosing RAC but not the responsiveness to the share of RA. Interestingly, controlling for these individual characteristics turns the sign of the alternative-specific constant in the nested logit model. This suggests that the earlier finding of clients generally being disposed to choose RAC over NAC is primarily due to them valuing sustainability, feeling responsible for considering it, and being familiar with the material. Holding these characteristics constant, respondents seem more likely to choose NAC. The alternative-specific constant does not change its sign in the ML model. Thus, the observation that the individual characteristics are responsible for clients choosing RAC over its conventional alternative cannot fully be explained by the influence of these characteristics on the effect of the share of RA. Adding to the importance of these characteristics is the finding that the main effect of the share of RA in the ML model turns insignificant when the interaction terms are added. This shows that the utility of (hypothetical) individuals who do not value sustainability at all, are unfamiliar with RAC, and do not hold themselves responsible for considering sustainability in their construction projects does not respond to variations in the share of RA.

Table II.7: Regression results with individual characteristics[22]

	(1) Nested logit	(2) Mixed logit[23]
Price	– 0.0398***	– 0.0557***
	(0.00383)	(0.00243)
RA	0.0106***	– 0.000907
	(0.00102)	(0.00273)
ASC	– 1.514***	1.460***
	(0.237)	(0.232)
	RAC (nest)	Interaction terms with RA
Sustainability	0.0158***	0.000146***
	(0.00180)	(0.0000333)
Familiarity	0.354***	0.00444*
	(0.103)	(0.00174)
Responsibility	0.516***	0.00312
	(0.103)	(0.00199)
N	22896	22896

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
RA = recycled aggregates, ASC = alternative-specific constant, RAC = recycled aggregate concrete

The marginal effects (the differences in probability) from the ML model can be calculated using the formula

$$probability = \frac{\exp(Xb)}{(1 + \exp(Xb))}$$

where Xb is the linear predictor. For a share of 10 % of RA and the case of the dummy variable *Familiarity*, for example, the difference in probability is given by

$$\frac{\exp\,(10 \cdot (-\,0.000907) + 10 * 0.00444)}{(1 + \exp(10 \cdot (-\,0.000907) + 10 * 0.00444))} - \frac{\exp\big(10 \cdot (-\,0.000907)\big)}{\big(1 + \exp\big(10 \cdot (-\,0.000907)\big)\big)}$$

[22] The complete results for Table II.7 can be found in Table II.C.2 in the appendix.
[23] In these comparative tables of the nested logit and ML models, the results for the SDs in the ML model are omitted. All coefficients are significant.

The results for the variables *Sustainability* and *Familiarity* for three different levels of the share of RA can be found in Table II.8. Since the interaction term with Responsibility is not significant, marginal effects are not calculated. The results illustrate that the positive effects of valuing sustainability and being familiar with RAC increase with an increasing share of RA. For example, at a moderate share of 55 % RA, being familiar with RAC means an increased probability of choosing this concrete by 8.5 pp. In comparison, the probability increases by 15.1 pp for an RAC with RA only (100 %). Note that these values should be treated with care since the main effect of the RA share is insignificant in the regression.

Table II.8: Marginal effects of changes in individual characteristics for different shares of RA

	10 % RA	55 % RA	100 % RA
Sustainability[24]	+ 1.9	+ 9.5	+ 14.7
Familiarity	+ 1.6	+ 8.5	+ 15.1

Values are given in percentage points.
RA = recycled aggregates

These individual characteristics also affect clients' WTP for increasing the share of RA in concrete (see Table II.9). Especially the importance clients place on sustainability as a criterion in construction and whether they are familiar with RAC significantly influence their WTP. Clients who rate the importance of sustainability lower than the median[25] are willing to pay 0.16 EUR on average. In comparison, those who rate it above the median are willing to pay 0.38 EUR per pp of RA. Similarly, clients who had never heard of RAC before are willing to pay 0.19 EUR and those who were familiar with the material (i.e., had at least heard of it before) were willing to pay 0.33 EUR for a pp increase of the share of RA. Feeling responsible for considering sustainability has a smaller, but still considerable, effect: The clients who do not feel responsible have a WTP estimate of 0.21 EUR, while those who do are estimated to be willing to pay 0.27 EUR. The respective regression results can be found in the appendix in Tables II.D.1, II.D.2, and II.D.3.

Table II.9: WTP estimates for RA for subgroups of clients based on individual characteristics

	WTP RA (1 pp)	Lower limit	Upper limit
Sustainability			
Less important	0.16	0.14	0.18
More important	0.38	0.28	0.48
Familiarity			
Not familiar	0.19	0.14	0.25
Familiar	0.33	0.28	0.38
Responsibility			
No	0.21	0.18	0.25
Yes	0.27	0.19	0.35

Based on results obtained using mixed logit models.
Values refer to the WTP estimates for a pp increase in the share of RA.
WTP = willingness to pay, RA = recycled aggregates, pp = percentage point

Looking at the client groups separately, additional individual characteristics seem to influence the propensity to choose RAC, the responsiveness to the share of RA, and the WTP. We will

[24] The change in the characteristic *Sustainability* is formalized as the change from a rating of sustainability's value lower than one SD (25.58) below the mean (73.83) to a rating higher than one SD above the mean.
[25] The median is at a score of 79.

only discuss one aspect that stands out in all three client groups. (For the influence of all individual characteristics, the interested reader is referred to Tables II.E.1to II.E.13 in the appendix.) Organizations with a higher yearly turnover are likelier to choose RAC than those with a lower turnover[26]. In contrast, turnover does not seem to influence their responsiveness to the share of RA (see Table II.E.3 in the appendix for both results). Interestingly, if we compare the WTP of organizations by turnover, we find that organizations with a lower turnover are willing to pay a significantly higher amount per pp increase in the share of RA (0.37 EUR; ll: 0.26 EUR, ul: 0.48 EUR[27]) than those with a higher turnover (0.23 EUR; ll: 0.16 EUR, ul: 0.29 EUR; the respective regression results can be found in Table II.E.4 in the appendix). This is the opposite of what we would expect, given the finding that higher-turnover organizations are more likely to choose RAC than their lower-turnover counterparts. A close look at the regression results suggests that this difference does not necessarily come from a difference in the valuation of RA (which the insignificant result in Table II.E.3 confirms) but from a difference in price sensitivity. Lower-turnover organizations appear to be much less price sensitive than higher-turnover ones. The same pattern is also observed for the group of developers (see Tables II.E.1 and II.E.2 in the appendix). In that case, however, the difference in WTP is insignificant, which could be attributable to the sample size.

For private individuals, the equivalent of turnover, the household income, is also of interest. The overall picture in this case is more consequent but not less surprising. Respondents with a lower household income are found to be likelier to choose RAC over NAC than those with a higher household income[28], and they are more responsive to an increase in the share of RA (see Table II.E.6 in the appendix). Following this line, they are significantly more willing to pay for a pp increase in the share of RA (0.34 EUR; ll: 0.22 EUR, ul: 0.45 EUR) than their counterparts (0.17 EUR; ll: 0.11 EUR, ul: 0.22; the respective regression results can be found in Table II.E.7 in the appendix).

4.4 Robustness Checks

A nested logit model is applied to validate the overall results received using the ML model. Table II.F.1 in the appendix shows the regression results. According to these results, on average, respondents are willing to pay 0.27 EUR for every pp increase of RA. The corresponding possible values range from 0.24 EUR to 0.29 EUR. The value estimated with the ML model (0.26 EUR) falls well within this range. Thus, this alternative specification supports our original estimates.

This section further summarizes the results of a series of robustness checks that use subsamples based on different criteria (see Table II.F.2 in the appendix). First, two quality indicators are used that the software SoSci Survey (Leiner, 2021) provides to identify extremely fast respondents. A value of more than 100 on the first indicator (called DEG Time) indicates low-quality data. Threshold values of 75 or even 50 are recommended for stricter filtering. Samples with values below 100 and 50 are used in models (2) and (3) in Table II.F.2. Respectively 52 and 151 participants (translating into 1,328 and 3,704 observations) are excluded. The other indicator, a relative speed index (Time RSI), is a more elaborate measure and denotes all

[26] Organizations are characterized as lower- or higher-turnover ones using a threshold of 5 million EUR. This threshold is chosen based on the distribution in the sample. It roughly divides the sample in half.

[27] The abbreviations "ll" and "ul" denote the lower and upper limits of the confidence interval for the WTP estimate, respectively.

[28] Private individuals are characterized as lower- and higher-income ones using a threshold of 4,000 EUR. This threshold is chosen based on the average household income in Germany in 2018, which was 3,661 EUR (Bundeszentrale für politische Bildung, 2020).

observations with a value of 2 or more as critical. Model (4) applies this criterion by excluding these extremely fast respondents. Thirty-nine respondents and, therefore, 1,016 observations are excluded. Another robustness check uses only the data from respondents who completed the survey. This results in a sample of 720 participants (22,388 observations; see model (5)). Finally, model (6) only uses the data from respondents who answer all choice sets of the DCE without choosing the opt-out option "I cannot answer this question" (711 participants, 22,752 observations). Overall, Table II.F.2 shows no meaningful differences between the baseline model and the robustness checks, so the results reported above can be considered robust. Table II.F.3 in the appendix shows the respective WTP estimates from these robustness checks. All models' estimates are within the limits of the other models' estimates. The estimated mean WTP for a pp increase in the share of RA is 0.26 EUR in all models except the ones that exclude unusually fast respondents (model (3)) and those that have not answered all choice sets (model (6)). The estimate in both cases is 0.25 EUR, thus differing only inconsiderably.

5 Discussion

5.1 Barriers and Drivers

The barriers and drivers for using RAC experienced by construction clients that we find in this study are partly in line with previous research. The main barrier found, the lack of knowledge and experience among clients and their construction partners, is identified as prominent in sustainable construction generally by Adams et al. (2017), Darko and Chan (2017), Gan et al. (2015), and Shooshtarian et al. (2020), for example. As Stürmer and Kulle (2017) point out, the lack of familiarity with RAC, specifically among clients, hinders demand for the product, which the current findings confirm. Especially private individuals are unfamiliar with RAC. The corresponding barrier (not knowing of RAC) ranked 2nd in this group, and more than 75 % indicate that they had never heard of RAC before. The second most prominent barrier in this study also relates to the lack of awareness: the uncertainty regarding norms and regulations. Clients' awareness and knowledge could be increased to alter their behavior and attitude toward recycled products like RAC (Hossain et al., 2020). The most straightforward way to achieve this is through the provision of information. In this vein, Banfi and her colleagues (2008) argue that barriers to investing in sustainable attributes in residential buildings can be overcome by providing information to stakeholders, such as consumers and investors. Construction clients should be sufficiently informed about the existence of recycled alternatives, their applicability, and the regulations surrounding their use. Only then can the vicious circle be interrupted such that demand increases, suppliers follow, and experience with the material can be gained, increasing demand.

The idea of information provision also relates to two critical drivers found in this study among all three groups: not wanting to harm the environment and the notion that using RAC is part of a sustainable way of construction. Only few researchers have focused on this type of internal driver (Darko et al., 2017; Diyana et al., 2013; Olanipekun, Xia, et al., 2017), though they rank highest in this study. Information asymmetry could hamper the positive influence of environmental awareness on the demand for RAC. The stakeholders in construction projects and the recycling industry have access to relevant information to different degrees (Forsythe et al., 2015; Li et al., 2020). In the case of RAC, information on how beneficial the material is in terms of its environmental impact is not readily accessible to clients. To avoid this information asymmetry and reap the advantages of the driving force of environmental awareness, a label certifying the quality and sustainability-related aspects of RAC could be helpful. Including a label as an attribute in the DCE (see Section 3.1) allows us to check this idea. We find that respondents are significantly more likely to choose a type of concrete if it has a label than if it does not (see Table II.3). Developers, organizations, and private individuals have an additional estimated WTP of 19.83 EUR[29], 17.54 EUR[30], and 15.70 EUR[31], respectively, for a m^3 of concrete with compared to one without a label (see Table II.G.1 in the appendix). Based on an average-priced type of concrete (150 EUR per m^3), this translates to 13 %, 12 %, and 10 % of the price. This aligns with previous research that find consumers willing to pay more for products, among which building materials, with eco-labels (e.g., Shen, 2012; Ward et al., 2011). The notion that labels could enhance demand is supported by the finding that a label offering evidence that RAC is of equal quality to NAC is a top driver (ranked 3rd) for the clients in our sample.

The lack of acceptance for recycled material that is found repeatedly in the literature (Knappe et al., 2012; Scheibengraf & Reisinger, 2005; Shooshtarian et al., 2020) does not emerge from this study as a barrier as much as expected. The barrier of uncertainty and doubts regarding the material's quality and performance only ranks 8th (with a score of 38 on a scale from 0 to 100). Not wanting to build with recycled material even ranks last (10th, with a score of 20). Another barrier that appears to be less of a problem than previously expected is the higher price of RAC. This barrier is not unimportant and should be tackled since it does reach a score of 52, but it only ranks 7th (out of 10). Thus, it seems like a range of other aspects hinder the creation of demand for RAC more than a higher price. The positive WTP found confirms this and will be discussed in the next section. The lack of supply of RAC (Katerusha, 2021) also plays a role in impeding its demand but is among the top four barriers only for developers. It is conceivable that the developing companies have dealt with the supply of RAC in their region more than the other two groups, especially the private individuals, since they build more by definition. The finding that around 40 % of developers have considered using RAC while less than 20 % of private individuals have supports this idea. A lack of incentives and support from the government (e.g., Darko et al., 2017) appears to be among the main barriers specifically for organizations. However, this barrier is not as prominent as in the study of executing companies by Katerusha (2021). If executing companies were supported in their production of RAC, the conditions for the client might be favorable enough for them not to need any more incentives.

The third most prominent barrier in this study is the ease and convenience of building conventionally, which has not received much interest in the literature (an exception is Joachim et al. (2015)). However, the experts interviewed agree that the construction industry is conservative and does not adopt changes or innovation easily. The current findings seem to support this idea. Tackling this barrier could imply information provision or incentives such that clients are willing to invest some effort. At the same time, choosing RAC will be just as convenient once its demand and supply have reached a certain level such that it has become a standard praxis.

While policies and regulations are found to drive sustainable construction, only a few are in place (as of now) for RAC. Municipalities can, however, prescribe specific construction approaches, as is done, for example, in the so-called *Faktor X* residential areas (Faktor X Agentur & der Entwicklungsgesellschaft indeland GmbH, n.d.). A particular factor of resource efficiency is determined there, meaning all houses must be built with only a share (e.g., half for factor 2) of the conventionally required resources. The driving force of the city or municipality prescribing the use of RAC is not ranked very high by the respondents. Since this is a

[29] ll: 11.33 EUR, ul: 28.33 EUR
[30] ll: 13.97 EUR, ul: 21.22 EUR
[31] ll: 12.21 EUR, ul: 19.20 EUR

prescription and not a voluntary agreement, it would probably be considered a driver if it was in place. The low rank, therefore, points toward these policies still being seldom.

It is not new that acting environmentally friendly is advantageous for a company's image – it is why greenwashing has become an issue (Delmas & Burbano, 2011). Unsurprisingly, the positive effect of using RAC on their image is a primary driver for organizations and developers like previously established in the literature (Diyana et al., 2013; X. Zhang et al., 2011). In both groups, the driver ranks 3rd (scoring 79 points on a scale from 0 to 100). In contrast, image considerations seem less critical to private individuals. In this group, this driver only ranks 6th (with a score of 51). Given that private individuals are not dependent on their image or reputation like companies are, this discrepancy is unsurprising. A related driver is the advantage of using RAC to gain a sustainability certificate. Since these certificates demonstrate one's environmentally friendly behavior and thereby enhance one's image (Diyana et al., 2013), they are also ranked higher by organizations and developers than by private individuals.

Finally, a group of drivers reaches surprisingly low scores. Apart from the already mentioned aspect of municipalities prescribing its use, these are the knowledge or experience among architects and construction partners, sufficient information on RAC, and awareness of buildings constructed with RAC. Likely, these aspects are not given (yet) and, therefore, cannot drive clients' demand of RAC.

5.2 Willingness to Pay

Our results show that respondents, on average, tend to choose RAC over NAC when these are equal in the attributes we model. This suggests that when confronted with two types of concrete, one RAC and the other NAC, and which have the same price, share of RA (although per definition not possible), CO_2 footprint, and environmental label, construction clients would choose the RAC. Further, all estimates for clients' WTP for an increase in the share of RA found in this study are positive and significant. An estimate of 0.26 EUR for every pp of RA more per m^3 of concrete is calculated, but rather large differences are found between the groups. Private individuals are estimated to be willing to pay 0.21 EUR on average. Assuming a one-family dwelling that needs 100 m^3 of concrete and an average price of 150 EUR per m^3, these clients would be willing to pay 945 EUR more for building their house with RAC that has a share of 45 %[32] of RA compared to one that has only NA, which translates to 6 % of the price for concrete. Organizations and developers have an estimated WTP of 0.30 EUR and 0.27 EUR for every pp increase, respectively. Assuming a large office building that requires 15,000 m^3 of concrete, these client groups would be willing to pay an extra 9 % (202,500 EUR) and 8 % (182,250 EUR). These values are in the same range as findings of WTP for GB overall found by other researchers (Khan et al., 2020; Portnov et al., 2018; Wiencke, 2013). The price premium for RAC in most parts of Germany currently lies between 10 and 17 %[33] (interviewee 9, personal communication, August 2, 2021; interviewee 10, personal communication, August 3, 2021). This difference suggests that RAC is currently only consumed by construction clients with an above-average WTP for RA. The respondents with the highest WTP for the share of RA in our sample are organizations that value sustainability in construction, feel responsible for considering it, and are familiar with RAC. The estimated WTP for this group is 0.50 EUR[34], which translates into a price premium of 15 %. Thus, while there are clients who are willing to pay the current price premium, a lot of them are not. Given that stimulating recycling is a

[32] 45 % is the maximum share currently admitted in Germany without special approval (DAfStb, 2010).
[33] The share of RA contained varies. However, since 45 % is the maximum share currently admitted, the comparison is rather conservative.
[34] ll: 0.32 EUR, ul: 0.68 EUR; the respective regression results can be found in Table II.E.14 in the appendix.

political goal in Germany (*Koalitionsvertrag 2021 – 2025*, 2021), the EU (Waste Framework Directive, 2008), and worldwide (United Nations, 2015b), increasing the use of RAC is desirable. This can be achieved by stimulating demand among the whole range of construction clients. One idea would be to subsidize the use of RAC. Our results show that demand is price sensitive (see, for example, Table II.3), and the current market price is hindering for many construction clients, which speaks to the effectiveness of financial incentives. These incentives might only be necessary temporarily since, with increasing resource scarcity, the market will presumably produce price competitiveness in the future, rendering incentives unnecessary.

We find that clients who value sustainability in construction, feel responsible for considering it, and are familiar with RAC are more likely to choose RAC. Our results suggest that these characteristics make clients choose RAC over its conventional alternative when these do not differ in the attributes we model. Individuals who do not value sustainability, feel responsible, or are familiar with the material do not respond to a change in the share of RA. In particular, environmental awareness (valuing sustainability) has been shown to have a substantial effect. Clients with this characteristic are much more likely to choose RAC and more willing to pay for the share in RA contained. This aligns with previous research on the influence of environmental attitudes (Mandell & Wilhelmsson, 2011b; Yau, 2012b). Further, our results support the finding that familiarity with the concept positively influences WTP for GB. Portnov et al. (2018) find that when potential homebuyers are familiar with the concept of GB, they are willing to pay a price premium of 1.5 pp more than those who are not. In our sample, the difference between the WTP for RAC of respondents who are and who are not familiar with the material expressed as a price premium is even higher with 4.2 pp (see Table II.9). This finding shows that mere awareness of the existence of the material is already very beneficial, which could easily be achieved on a large scale through an information campaign. The feeling of responsibility for considering sustainability is not a prominent determinant of WTP in previous studies. However, our results confirm the findings by Wang (2022) that a feeling of responsibility positively influences WTP. This also relates to the idea of a circle of blame described above (see Chapter 2): The demand and supply sides point to each other as responsible for the sparse use of, in this case, RAC (Andelin et al., 2015; Keeping, 2000). Our results indicate that this vicious circle can be broken when stakeholders (clients, in our case) take responsibility. These results can be used to design incentives to increase RAC demand efficiently.

Regarding demographic determinants of WTP, we will only briefly discuss the effect of turnover (developers and organizations) and income (private individuals). Interestingly, we find a higher WTP for organizations with a lower turnover. A similar pattern is observed for private individuals: Those with a lower household income are willing to pay more for increasing the share of RA. Previous research has more often found a positive correlation between income and WTP for sustainable housing or GB attributes (e.g., Chau et al., 2010; Mandell & Wilhelmsson, 2011; Yau, 2012). However, there have been contrary findings, too. Khan et al. (2020) find a negative correlation between income and WTP for sustainable housing attributes such as wall insulation or air quality in their sample of Pakistani homebuyers. The negative influence of income on WTP might suggest that the share of RA is considered an inferior good (Ebert, 2003). Although the environment is most often seen as a normal good (i.e., WTP increases with income), some studies find environmental goods to be inferior. For example, Huhtala (2010) finds a negative income effect on the WTP for recycling in Finland. Similarly, Vo and Huynh (2017) estimate WTP for groundwater conservation and also find that respondents with a higher income are less willing to pay for clean groundwater. Some explanations, such as context-dependency and substitutability, are offered (Dupoux & Martinet, 2022) but should be studied further.

As a comparison to the WTP for increasing the share of RA, the WTP for saving a kilogram of CO_2 emissions is calculated. Averaged over all three client groups, an estimated 0.74 EUR[35] would be accepted for a kilogram more CO_2 emissions per m^3 of concrete[36]. For the three groups separately, values of 0.62 EUR[37] (private individuals), 0.68 EUR[38] (developers), and 0.87 EUR[39] (organizations) are calculated (see Table II.G.2 in the appendix; respective regression results can be found in Table II.C.1). Projected to a ton of CO_2, private individuals, developers, and organizations would be willing to pay 620 EUR, 680 EUR, and 870 EUR to avoid its emission, respectively. With that, the respondents' WTP exceeds the current price for a ton of CO_2 equivalents by far (Ember, n.d.; The World Bank, 2022b).

Previous estimates of WTP for saving CO_2 emissions cover an extensive range (Alberini et al., 2018), the higher end of which our estimates are located at. These high estimates could be explained by heightened media attention to global warming and climate change issues at present (Achtnicht, 2012). Additionally, respondents could have seen the reduction in CO_2 emissions as being in the domain of losses rather than gains. In that case, the estimated value should be seen as a willingness to accept rather than to pay (WTP; Nguyen et al., 2021). Willingness-to-accept estimates have generally been found to be higher than their corresponding WTP estimates (Horowitz & McConnell, 2002). Nevertheless, even if these values are overestimated, our respondents are much more sensitive to changes in CO_2 footprint compared to changes in the share of RA. While they would be willing to pay much more than the current market price for CO_2, their average WTP for RA does not match the current price premium seen for RAC. This striking difference supports the idea that people are aware of climate change issues, while resource scarcity is much less prominent. A similar finding results from the study of Robbins and Perez-Garcia (2005). Comparing the general population's WTP for reductions in solid waste and GHG emissions, the researchers find that the respondents are most sensitive to the latter.

It would be valuable to determine where the money construction clients are willing to pay to conserve the environment is best spent. Based on the estimated average WTP in this study, one Euro could reduce 1.35 kg of CO_2 emissions or save around 71 kg of primary sand and gravel[40]. While both CO_2 emissions and the extraction of sand and gravel produce externalities (e.g., Bendixen et al., 2021; Cai & Lontzek, 2019), only the so-called *social cost* of carbon has been estimated. Two studies that try to quantify the costs of aggregate extraction are from the Department of the Environment, Transport and the Regions and London Economics cited in Willis and Garrod (1999). The values range from 1.06 to 9.00 GBP (British pound), depending on the study and the method used. However, these estimates are from the United Kingdom in 1998 and 1999 and are based on surveys that assess the respondents' WTA and WTP. Thus, the environmental damages and consequences of mining sand and gravel (in Germany) have yet to be objectively priced. Therefore, it is difficult, if not impossible, at this point to determine where clients' hypothetical payments are spent most efficiently.

Generally, WTP estimates from stated preference studies should be treated cautiously. The so-called *hypothetical bias* might inflate estimations, meaning that participants in these studies declare to be willing to pay more than they actually would. For example, Voelckner (2006)

[35] ll: 0.54 EUR, ul: 0.93 EUR; see Table II.3 for the regression results
[36] The CO_2 footprint is coded in kg per m^3. Therefore, the respective coefficient is negative and thus is the WTP. One could interpret this negative WTP as a willingness to accept (WTA). Here however, we conceptualize the estimates as WTP for savings in kilogram and therefore have reversed the sign.
[37] ll: 0.53 EUR, ul: 0.71 EUR
[38] ll: 0.48 EUR, ul: 0.87 EUR
[39] ll: 0.75 EUR, ul: 0.98 EUR
[40] A m^3 of concrete has around 1,850 kg of aggregates (Knappe et al., 2017).

finds that WTP estimates are higher when the price stated is only paid hypothetically than when it is real. Murphy and his colleagues (2005) conduct a meta-analysis on this issue and find a median ratio of hypothetical to actual WTP values of 1.35. Overall, they find that choice-based elicitation methods, as used in the present study, reduce bias. They conclude that hypothetical bias in stated preference studies might be less of an issue than previously assumed. In addition, the differences in WTP between types of clients are independent of the absolute values identified.

5.3 Client group differences

The substantial differences between client groups are worth noting. First, private individuals seem to experience barriers to a greater extent than organizations and developers (see Figure II.2). Additionally, they choose the base alternative, NAC, more often than the other two groups (10 % vs. 6 %). The marginal effect of increasing the share of RA is lowest for private individuals. In contrast, the marginal effect of increasing the price is highest in this group (see Table II.5). These tendencies present themselves most clearly when comparing the groups' WTP for increasing the share of RA. Organizations' WTP per additional pp of RA is almost 1.5 times that of private individuals. Although the difference is smaller, developers also have a substantially higher WTP than private individuals (see Table II.6). Some of this discrepancy is ascribable to observed differences between the groups, such as their familiarity with RAC (66 % of developers and 64 % of organizations but only 23 % of private individuals are familiar with RAC). However, even after controlling for familiarity, organizations and developers are still significantly more likely to choose RAC than private individuals (see model (1) of Table II.D.4 in the appendix). Another difference is to what extent the groups value sustainability: Private individuals score 68 points, while developers and organizations score 74 and 77 points, respectively. Controlling for both familiarity and sustainability explains the difference between private individuals and organizations with respect to their likelihood of choosing RAC (see model (2) of Table II.D.4 in the appendix). The difference between developers and private individuals persists, however. These two groups differ somewhat concerning the extent to which they feel responsible for considering sustainability (81 % (developers) vs. 75 % (private individuals)). Notwithstanding, a marginally significant difference remains between the two groups even after controlling for this feeling of responsibility (see model (3) of Table II.D.4 in the appendix).

The higher WTP for an increased share of RA from organizations and developers thus is mainly attributable to the familiarity with RAC, the feeling of responsibility, and valuing sustainability in construction. The remaining difference could be explained by the factors these groups are motivated by. As illustrated by the main driving forces, all groups seem intrinsically motivated to protect the environment. Diyana et al. (2013) identify these ethical considerations as one group of motivations for GB. Another one is financial drivers, which are currently not applicable in the case of RAC but would affect organizations, developers, and private individuals to the same extent. However, the remaining two categories of motivation, image and business strategy thoughts, only apply to organizations and developing companies. As the ranking of the respective driver in this study shows, private individuals are much less driven by image concerns. Thus, while organizations and developing companies are motivated to choose recycled material by both intrinsic and extrinsic aspects, private individuals are only affected by the former. This might explain why this group is least likely to demand and willing to pay for RAC. Additional incentives that address private individuals specifically would be needed to tackle this issue. An example could be a subsidy granted to individuals about to build their family home for applying RAC where possible.

Our results also show that private individuals lack awareness of RAC more than the other two groups. Thus, information-based instruments that inform construction clients of the possible alternatives to primary material should be targeted specifically at this group. In contrast, specific information regarding the application of RAC, for example, can be directed at clients more generally since a lack of knowledge hampers all groups. The notable difference in the effect of image and reputation considerations between the groups offers another way to efficiently design incentives: incentives based on this driver should be tailored to organizations and developers, while private individuals should be incentivized to use RAC through different mechanisms. These are just some examples of how different client groups should be treated differently. The barriers and drivers, the choice patterns, the responsiveness to different attributes in the choice situations, and the WTP all show significant differences between the studied groups. Thus, a one-size-fits-all approach to stimulate demand is unlikely to be efficient. Policies should instead be designed taking these differences into account.

6 Conclusion

RAC offers a way to reduce the use of primary resources on the one hand and minimize construction and demolition waste on the other. It can be used in almost any application and is considered qualitatively equivalent to its primary counterpart. Nevertheless, it is hardly used in Germany, which, to a significant part, is due to a low demand. This study sets out to investigate the barriers and drivers for construction clients to demand RAC, whether they are willing to pay for it, which factors are of influence, and how different client groups differ in this respect. The main findings are the following: Construction clients perceive barriers that arise from a lack of information as the most severe. These are a lack of awareness, knowledge, and experience, and uncertainty about norms and regulations. In contrast, they are driven by their environmental consciousness. A quality label further stimulates private individuals to demand RAC, while a positive image effect motivates organizations and developers. All groups are willing to pay for RA in concrete, with private individuals showing the lowest and organizations showing the highest WTP per pp increase. Valuing sustainability in construction, being familiar with RAC, and feeling responsible for sustainable construction all positively affect the WTP. These characteristics also seem to underlie the finding that clients are generally more likely to choose RAC over NAC when these do not differ in their attributes, such as price. Additionally, demographic characteristics like turnover/income have an influence, and there are substantial differences between client groups.

Although we find a positive WTP for RAC, the average value does not match the current price premium. We find clients in our sample willing to pay this premium, but to close resource loops and minimize waste, as is politically strived for, a broader demand needs to be stimulated. Information provision could help to fulfill this goal. Especially in the form of a quality and sustainability label, objective information on RAC could tackle some of the main barriers we find and take advantage of the aspects that drive construction clients toward using recycled material. In that sense, information could increase clients' environmental awareness and familiarity with the product, factors we discover to be positively influential. Apart from information, potential financial incentives could be effective, particularly for private individuals since they are the most price-sensitive group. State subsidies could at least temporarily be installed to stimulate demand. The appeal of a positive and "green" image could be taken advantage of to increase demand among organizations and developers. Municipalities could, for example, award companies using RAC with a publicly advertised certificate. These are just a few examples of potential measures to implement to increase the demand for RAC. Further research should study which of these are effective and under what conditions. One aspect of policy design that this study has demonstrated the importance of is tailoring measures to the client groups. The differences we have observed should not be ignored if policies are to be as effective and efficient as possible.

7 Appendix

Appendix A

Interviews and Survey

Table II.A.1: Overview of interviewed experts

Interview number	Interviewed expert	Date	Means
1	CEO for the section of minerals in a union for secondary resources	29.06.2021	video call
2	R&D manager in a recycling company	01.07.2021	video call
3	employee of the German green building council	05.07.2021	video call
4	CEO of a concrete producing company	06.07.2021	video call
5	managing director of economic affairs in a concrete association	08.07.2021	video call
6	construction project manager and city councilor	12.07.2021	video call
7	regional director in a building material producing company	21.07.2021	phone call
8	product manager in a concrete producing company	27.07.2021	video call
9	quality director in a concrete producing company	02.08.2021	e-mail
10	sales manager in a building material producing company	03.08.2021	video call
11	professor for building materials research	03.08.2021	video call

CEO = chief executive officer, R&D = research and development

Table II.A.2: Full survey transcript

Question	Wording	Response options
Start		
Consent (filter question)	*Information on the survey and data protection.*	→ I give my consent and wish to participate in this survey. (Survey continues.) → I do not want to participate in this survey. (Survey is terminated.)
Target group – P (filter question)	This survey is targeted at individuals who have built a house in the previous 5 years, are currently building one, or are planning to build one in the near future. Confirm here that you are part of the target group.	→ I built a house in the previous 5 years. → I am currently building a house. → I am planning to build a house in the near future (ca. 1 year). → I do not belong to the target group. (Survey is terminated.)
Target group – D (filter question)	This survey is targeted at project developers and (employees from) developing companies, who act as clients in construction projects. Housing associations and investors who initiate and finance the project also belong to the target group. Confirm here that you are part of the target group.	→ I am a project developer. → I work at a developing company. → I am an investor and initiate projects. → I work at a housing association. → I am unsure whether I belong to the target group, because: *Text* (Survey continues in all of the above.) → I do not belong to the target group of this study. (Survey is terminated.)
Target group – O (filter question)	This survey is targeted at employees in construction management in organizations/companies, that are <u>not</u> themselves construction or developing companies. Note: The position does not have to carry the name 'construction management'. Meant are all employees that are involved in the construction of new buildings for their organization/company. *Example.* Organizations can be private as well as non-	→ I work in the field of construction management for an organization/company, that is not itself a construction or developing company. → I am unsure whether I belong to the target group, because: *Text* (Survey continues in all of the above.) → I do not belong to the target group of this study. (Survey is terminated.)

	profit. Local authorities (federal state, states, municipalities) are not part of the target group of this study. Confirm here that you are part of the target group.	
Socio-demographic information (P)		
Gender	Which gender are you?	→ female → male → other → not specified
Age	How old are you?	→ 18 – 25 → 26 – 35 → 36 – 45 → 46 – 55 → 56 – 65 → older than 65
Education	Which educational status do you have?	→ no degree → Certificate of Secondary Education → General Certificate of Secondary Education → completed apprenticeship → vocational diploma → general qualification for university entrance → graduate degree → other: *Text*
Employment	Which of the following describes your employment status best?	→ employed, full time → employed, part time → without employment, searching → without employment, not searching → studying → retired → incapable of work → other: *Text*
Income	How high is your monthly net household income?	→ less than 500 EUR → 500 EUR to less than 1000 EUR → 1000 EUR to less than 2000 EUR → 2000 EUR to less than 3000 EUR → 3000 EUR to less than 4000 EUR → 4000 EUR to less than 5000 EUR → 5000 EUR to less than 6000EUR → 6000 EUR to less than 7000 EUR → 7000 EUR to less than 8000 EUR → more than 8000 EUR → not specified
Family status	What is your current family status?	→ married or civil partnership → widowed or civil partner deceased → divorced or civil partnership terminated → living together → living separately → single → other: *Text*
Children	How many children do you have?	→ 0 → 1 → 2 → 3 → more than 3

Socio-demographic information (D & O)		
Founding year	What year was your company (D)/organization (O) founded? Give a rough estimate if you are unsure.	*Text*
Employees	How many people does your company (D)/organization (O) employ?	→ less than 10 → 10 – 49 → 50 – 249 → 250 – 499 → 500 – 999 → 1000 – 2499 → 2500 – 4999 → 5000 – 9999 → 10.000 or more → I don't know.
Type of business (only for O)	What type of business is your organization?	→ private → non-profit → public → I don't know.
Sector (only for O)	Which sector does your organization belong to?	→ primary (basic production) → secondary (industry and commerce) → tertiary (service) → non-profit → I don't know.
Turnover	How much turnover did your company (D)/organization (O) roughly generate in 2020?	→ up to 250.000 → up to 1 million EUR → up to 5 million EUR → up to 10 million EUR → up to 20 million EUR → up to 50 million EUR → more than 50 million EUR → I don't know.
Customers (only for D)	Which of the following describes your customers and the respective projects best? More than one option can be selected.	→ private individuals (one-family homes) → companies (e.g., office and logistic buildings) → public authorities (e.g., schools, hospitals, administrative buildings) → investors → others: *Text*
State	Which state is your company (D)/organization (O) mostly active in?	*List of all German states.* → in more than one state → in all of Germany
Role of sustainability	Which role does sustainability play in your company (D)/organization (O)?	*Slider from 0 (a very small one) to 100 % (a very big one)*
Sustainability goals	Has your company (D)/organization (O) set specific sustainability goals?	→ Yes → No → I don't know.
The building & RAC		
Residential area (only for P)	What district does or will your house be located in?	Text → I don't know (yet).
Location (only for P)	Which describes the location of your house best?	→ urban → intermediate → rural → I don't know
Familiarity RAC	Have you ever heard of RAC before?	→ yes → no → I am unsure.

Usage of RAC	Have you (*D:* in your company; *O:* in your organization) considered using RAC for the construction… … of your house? (P) … of buildings for your company? (D) … of buildings? (O)	→ Yes, and I (P)/we (D & O) will use it if possible./Yes, and I (P)/we (D & O) have. → Yes, and we use RAC sometimes. *(Only for D & O)* → Yes, but I am (P)/we are (D & O) unsure. → Yes, and I will not use it./Yes, and I have not used it. (P)/Yes, and we do not use it. (D & O) → No, I (P)/we (D & O) have not (yet). → This decision is/was not mine (P)/ours (D & O).
Barriers & drivers		
Barriers	Please rate to what extent you (O: in your department/organization) experience the following aspects as a barrier to the use of RAC for the construction … … of your house. (P) … of buildings. (D & O) *All barriers listed.*	*Slider from 0 (not at all) to 100 % (totally)*
Other barriers	Are there other aspects that you experience as a barrier to the use of RAC?	*Text*
Drivers	Please rate to what extent you (O: in your department/organization) experience the following aspects as a driving force to the use of RAC for the construction … … of your house. (P) … of buildings. (D & O) *All drivers listed.*	*Slider from 0 (not at all) to 100 % (totally)*
Other drivers	Are there other aspects that you experience as a driver to the use of RAC?	*Text*
Treatment		
Information treatment (randomized half of the sample)	Please read the following information carefully. *Information presented.*	→ I have read the information carefully.
Discrete choice experiment		
Discrete choice experiment	*Explanation.* *Orientation example (different ones for P and D/O).* Which concrete would you choose? *6 choice sets with differing attribute levels (see text).*	→ RAC A → RAC B → RAC C → primary concrete → I cannot answer this question.
Factorial survey		
Factorial survey	*Explanation.* *Situation description (vignette).* How likely is it that you would choose RAC under these conditions?	*Slider from 0 ("extremely unlikely") to 100 % ("extremely likely")*
Sustainability & construction		
Construction partners (only for P & O)	How are/did you build(ing) your house? (P)/How are your buildings usually constructed? (O)	→ with an architect (P)/with external architects (O) → buying from a developer → with a general contractor → through separate tenders → differently: *Text*

Sustainability	To what extent does the following statement apply to … … you? (P) … your company? (D) … your organization? (O) In the construction of my house, sustainability is/was) an important criterion. (P)/In the construction of buildings, sustainability is an important criterion. (D & O)	*Slider from 0 (not at all) to 100 % (totally)*
Driving Force	Who is (*P:* was) the driving force behind considering sustainability in construction of … … buildings? (D & O) More than one option can be selected. Skip this question if sustainability is/was not a criterion.	→ me/us (P)/us as developers (D)/us (the organization; O) → the architect *(only for P & O)* → the developer *(only for P & O)* → the construction company → the requester *(only for D)* → others: *Text*
Responsibility	Who do you consider responsible for considering sustainability in construction? More than one option can be selected.	→ me/us (P)/us as developers (D)/us (the organization; O) → the architect *(only for P & O)* → the developer *(only for P & O)* → the construction company → the requester *(only for D)* → the state → others: *Text*

RAC = recycled aggregate concrete, D = developers, O = organizations, P = private individuals

Appendix B

Descriptive Results

Table II.B.1: Descriptive results (developers)

	Count	Share
Target Group		
I work at a developing company.	58	44.96 %
I am an investor and I initiate construction projects.	19	7.75 %
I am a project developer.	41	14.73 %
I work at a cooperative building company.	1	31.78 %
I am unsure whether I belong to the target group.	10	0.78 %
Total	129	100.00 %
Founding Year		
Min. (earliest)	1878	
Max. (most recent)	2020	
Mean	1990	
Total	122	100.00 %
Federal State of Main Activity (top 3)		
Baden-Württemberg	31	27.93 %
North Rhine-Westphalia	21	18.92 %
Bavaria	20	18.02 %
Total	111	100.00 %
Yearly turnover		
<= 250.000 EUR	4	3.48 %
250.000 < x <= 1 million EUR	17	14.78 %
1 million < x <= 5 million EUR	42	36.52 %
5 million < x <= 10 million EUR	14	12.17 %
10 million < x <= 20 million EUR	15	13.04 %
20 million < x <= 50 million EUR	6	5.22 %
> 50 million EUR	17	14.78 %
Total	115	100.00 %
Employees		
< 10	76	59.84 %
10 – 49	33	25.98 %
50 – 249	10	7.87 %
250 – 499	1	0.79 %
500 – 999	2	1.57 %
1000 – 2499	2	1.57 %
2500 – 4999	0	0 %
5000 – 9999	2	1.57 %
> 10000	1	0.79 %
Total	127	100.00 %
Customers		
Private individuals (single family homes)	79	61.72 %
Organizations (office- or logistic buildings)	32	25.00 %
Public authorities (schools. hospitals. etc.)	8	6.25 %
Investors	59	46.09 %
Others (e.g., private individuals with apartment buildings)	26	20.31 %
Total	128	100.00 %

Table II.B.2: Descriptive results (organizations)

	Count	Share
Target Group		
I work in the area of construction management for an organization that is not a construction or developing company	550	88.28 %
I am unsure whether I belong to the target group.	73	11.72 %
Total	623	100.00 %
Founding Year		
Min. (earliest)	1090	
Max. (most recent)	2021	
Mean	1974	
Total	566	100.00 %
Federal State of Main Activity (Top 3)		
North Rhine-Westphalia	116	21.52 %
Baden-Württemberg	90	16.7 %
Bavaria	59	10.95 %
Total	539	100.00 %
Type of Business		
Private	436	72.91 %
Public	73	12.21 %
Non-Profit	89	14.88 %
Total	598	100.00 %
Yearly turnover		
<= 250.000 EUR	92	18.81 %
250.000 < x <= 1 million EUR	88	18 %
1 million < x <= 5 million EUR	74	15.13 %
5 million < x <= 10 million EUR	62	12.68 %
10 million < x <= 20 million EUR	60	12.27 %
20 million < x <= 50 million EUR	46	9.41 %
> 50 million EUR	67	13.7 %
Total	489	100.00 %
Employees		
< 10	176	29.48 %
10 – 49	86	14.41 %
50 – 249	209	35.01 %
250 – 499	37	6.2 %
500 – 999	36	6.03 %
1000 – 2499	29	4.86 %
2500 – 4999	11	1.84 %
5000 – 9999	9	1.51 %
> 10000	4	0.67 %
Total	597	100.00 %
Industry Sector		
Primary	27	4.6 %
Secondary	121	20.61 %
Tertiary	366	62.35 %
Non-Profit	73	12.44 %
Total	587	100.00 %

Table II.B.3: Descriptive results (private individuals)

	Count	Share
Target Group		
I built a house within the past 5 years.	315	37.77 %
I am currently building a house.	331	39.69 %
I am planning to build a house in the near future (ca. 1y).	188	22.54 %
Total	834	100.00 %
Gender		
Female	410	50.12 %
Male	400	48.9 %
Other	3	0.37 %
No statement	5	0.61 %
Total	818	100.00 %
Age		
18 – 25	29	3.56 %
26 – 35	430	52.83 %
36 – 45	217	26.66 %
46 – 55	79	9.71 %
56 – 65	36	4.42 %
> 65	23	2.83 %
Total	814	100.00 %
Education		
No degree	0	0.0 %
Certificate of Secondary Education	18	2.21 %
General Certificate of Secondary Education	67	8.22 %
Completed apprenticeship	95	11.66 %
Vocational diploma	94	11.53 %
General qualification for university entrance	112	13.74 %
Graduate degree	415	50.92 %
Other	14	1.72 %
Total	815	100.00 %
Employment		
Working, full time (40 hours)	572	70.27 %
Working, part time (< 40 hours)	150	18.43 %
Without employment, seeking work	1	0.12 %
Without employment, not seeking work	10	1.23 %
Retired	24	2.95 %
Incapable of work	1	0.12 %
In education, student	11	1.35 %
Other (e.g., parental leave)	45	5.53 %
Household Income		
< 500 EUR	1	0.12 %
500 <= x < 1000 EUR	3	0.37 %
1000 <= x < 2000 EUR	22	2.74 %
2000 <= x < 3000 EUR	86	10.7 %
3000 <= x < 4000 EUR	126	15.67 %
4000 <= x < 5000 EUR	213	26.49 %
5000 <= x < 6000 EUR	150	18.55 %
6000 <= x < 7000 EUR	76	9.45 %
7000 <= x < 8000 EUR	44	5.47 %
> 8000 EUR	45	5.6 %
No statement	38	4.73 %
Total	804	100.00 %
Marital Status		
Married or registered partnership	546	67.16 %
Widowed or registered partner deceased	2	0.25 %
Divorced or registered partnership terminated	9	1.11 %
Separated	2	0.25 %

Single	48	5.9 %
In a permanent relationship	204	25.09 %
Other	2	0.25 %
Total	813	100.00 %
Number of Children		
0	340	41.92 %
1	179	22.07 %
2	217	26.76 %
3	56	6.91 %
> 3	19	2.34 %
Total	811	100.00 %

Regarding sustainability's role in developing companies, the mean indication (on a scale from 0 to 100) is 71.91 (SD: 24.72), and 41.18 % have sustainability goals in place. For organizations, the mean indication is at 77.03 (SD: 22.17), and around half of them (47.92 %) say they have specific sustainability goals. The difference in sustainability's role between developers and organizations is significant (t = 2.27, p = 0.024). Regarding the respondents' familiarity with RAC, 41 % of them (P: 22 %, O: 61 %, D: 63 %)[41] state that they had heard of RAC before, while 54 % did not (P: 72 %, O: 35 %, D: 33 %) and the rest was unsure. The differences in this distribution between groups are significant ($\mathcal{X}^2$ (4, N = 1465) = 237.38, p = 0.000). Most respondents (72 %; P: 82 %, O: 66 %, D: 59 %) state that they had not considered using RAC (yet). The respondents who had considered it before either use it whenever possible (6 %; P: 6 %, O: 5 %, D: 3 %), use it sometimes (4 %; P: –, O: 7 %, 8 %), are still unsure (13 %; P: 7 %, O: 17 %, D: 20 %), or decided against using it (5 %; P: 5 %, O: 5 %, D: 10 %). This distribution differs significantly between groups ($\mathcal{X}^2$ (8, N = 1108) = 79, p = 0.000).

The mean answer to the question to what extent sustainability is/was a criterion in construction on a scale from 0 to 100 is 73 (P: 68, O: 77, D: 74) with a standard deviation of 26 (P: 26, O: 24, D: 26). The difference between private individuals and organizations is significant (t = –4.77, p = .000). The driving force behind considering sustainability that was most often selected are the respondents themselves. When choosing who they think is responsible for considering sustainability in construction, private individuals, organizations, and developers choose themselves most frequently, too. A detailed overview of the chosen driving stakeholders and stakeholders responsible for considering sustainability can be found in Table II.B.4.

[41] The abbreviations "D", "O", and "P" represent developers, organizations, and private individuals, respectively. They are used throughout this section.

Table II.B.4: Perceptions about driving forces and responsibility for sustainability

	Driving	Responsible
We/us		
Developers	76 %	81 %
Organizations	72 %	74 %
Private Individuals	73 %	75 %
Total	73 %	75 %
The architect		
Organizations	51 %	71 %
Private Individuals	14 %	42 %
Total	33 %	58 %
The developer		
Organizations	22 %	46 %
Private Individuals	14 %	48 %
Total	18 %	47 %
The construction company		
Developers	7 %	40 %
Organizations	7 %	31 %
Private Individuals	19 %	50 %
Total	12 %	40 %
The applicant		
Developers	16 %	34 %
The state		
Developers	–	65 %
Organizations	–	58 %
Private Individuals	–	60 %
Total	–	60 %
Others		
Developers	18 %	16 %
Organizations	15 %	10 %
Private Individuals	6 %	2 %
Total	11 %	7 %

Appendix C

Complete Regression Results

Table II.C.1: Regression results for separate client groups displaying all attributes

	(1) Developers	(2) Organizations	(3) Private Individuals
Price	-0.0528^{***}	-0.0536^{***}	-0.0569^{***}
	(0.00679)	(0.00331)	(0.00369)
RA	0.0140^{***}	0.0162^{***}	0.0118^{***}
	(0.00227)	(0.00138)	(0.00138)
CO_2 footprint	-0.0359^{***}	-0.0465^{***}	-0.0353^{***}
	(0.00525)	(0.00296)	(0.00281)
Label	1.047^{***}	0.940^{***}	0.893^{***}
	(0.194)	(0.0881)	(0.0929)
ASC	3.042^{**}	1.584^{***}	1.369^{***}
	(0.948)	(0.370)	(0.314)
/Normal			
SD(RA)	0.0112^{**}	0.0162^{***}	0.0184^{***}
	(0.00348)	(0.00190)	(0.00223)
SD(CO_2 footprint)	0.0309^{***}	0.0368^{***}	0.0332^{***}
	(0.00454)	(0.00302)	(0.00286)
SD(Label)	1.271^{***}	1.036^{***}	1.169^{***}
	(0.239)	(0.117)	(0.137)
SD(ASC)	4.254^{***}	2.630^{***}	2.697^{***}
	(0.820)	(0.396)	(0.365)
N	2744	11188	10964

Standard errors in parentheses
$^{+} p < 0.10$, $^{*} p < 0.05$, $^{**} p < 0.01$, $^{***} p < 0.001$
Results obtained using mixed logit models.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
RA = recycled aggregates, ASC = alternative-specific constant, SD = standard deviation

Table II.C.2: Regression results with individual characteristics displaying all attributes

	(1) Nested logit	(2) Mixed logit
Price	– 0.0398***	– 0.0557***
	(0.00383)	(0.00243)
RA	0.0106***	– 0.000907
	(0.00102)	(0.00273)
CO_2– footprint	– 0.0285***	– 0.0415***
	(0.00272)	(0.00203)
Label	0.733***	0.959***
	(0.0736)	(0.0651)
ASC	– 1.514***	1.460***
	(0.237)	(0.232)
	RAC (nest)	Interaction terms with RA
Sustainability	0.0158***	0.000146***
	(0.00180)	(0.0000333)
Familiarity	0.354***	0.00444*
	(0.103)	(0.00174)
Responsibility	0.516***	0.00312
	(0.103)	(0.00199)
N	22896	22896

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
RA = recycled aggregates, ASC = alternative-specific constant, RAC = recycled aggregate concrete

Appendix D

Individual Characteristics – Overall Sample

Table II.D.1: Regression results for subsamples based on the reported importance of sustainability

	Sustainability	
	Less important	More important
Price	– 0.0641***	– 0.0462***
	(0.00381)	(0.00283)
RA	0.0103***	0.0176***
	(0.00112)	(0.00137)
CO_2 footprint	– 0.0329***	– 0.0471***
	(0.00252)	(0.00281)
Label	0.859***	1.007***
	(0.0856)	(0.0887)
ASC	1.490***	1.895***
	(0.312)	(0.407)
/Normal		
SD(RA)	0.0129***	0.0184***
	(0.00169)	(0.00182)
SD(CO_2 footprint)	0.0299***	0.0374***
	(0.00253)	(0.00277)
SD(Label)	1.011***	1.192***
	(0.118)	(0.124)
SD(ASC)	2.885***	2.910***
	(0.516)	(0.420)
N	11708	12804

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using mixed logit models.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
RA = recycled aggregates, ASC = alternative-specific constant, SD = standard deviation

Table II.D.2: Regression results for subsamples based on the familiarity with RAC

	Familiarity	
	No	Yes
Price	-0.0593^{***}	-0.0502^{***}
	(0.00346)	(0.00308)
RA	0.0115^{***}	0.0166^{***}
	(0.00119)	(0.00136)
CO_2 footprint	-0.0354^{***}	-0.0450^{***}
	(0.0026)	(0.00282)
Label	1.030^{***}	0.883^{***}
	(0.0917)	(0.0842)
ASC	1.652^{***}	1.564^{***}
	(0.365)	(0.301)
/Normal		
SD(RA)	0.0144^{***}	0.0174^{***}
	(0.00196)	(0.00177)
SD(CO_2 footprint)	0.0322^{***}	0.0357^{***}
	(0.0026)	(0.00275)
SD(Label)	1.212^{***}	1.040^{***}
	(0.128)	(0.114)
SD(ASC)	3.153^{***}	2.316^{***}
	(0.398)	(0.323)
N	11564	12560

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using mixed logit models.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
RA = recycled aggregates, ASC = alternative-specific constant, SD = standard deviation

Table II.D.3: Regression results for subsamples based on the feeling of responsibility

	Feeling of Responsibility	
	No	Yes
Price	-0.0525^{***}	-0.0574^{***}
	(0.00437)	(0.00287)
RA	0.0113^{***}	0.0157^{***}
	(0.00158)	(0.00113)
CO_2 footprint	-0.0315^{***}	-0.0452^{***}
	(0.00298)	(0.00253)
Label	0.800^{***}	0.993^{***}
	(0.100)	(0.0783)
ASC	1.960^{***}	1.325^{***}
	(0.549)	(0.257)
/Normal		
SD(RA)	0.0134^{***}	0.0168^{***}
	(0.00232)	(0.00150)
SD(CO_2 footprint)	0.0252^{***}	0.0378^{***}
	(0.00338)	(0.00231)
SD(Label)	0.655^{***}	1.252^{***}
	(0.162)	(0.101)
SD(ASC)	3.792^{***}	2.090^{***}
	(0.59)	(0.299)
N	5740	17920

Standard errors in parentheses

$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Results obtained using mixed logit models.

The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.

RA = recycled aggregates, ASC = alternative-specific constant, SD = standard deviation

Table II.D.4: Regression results including the effect of client groups

	(1)	(2)	(3)
Price	-0.0352^{***}	-0.0400^{***}	-0.0399^{***}
	(0.00361)	(0.00382)	(0.00382)
RA	0.00949^{***}	0.0107^{***}	0.0106^{***}
	(0.000959)	(0.00102)	(0.00102)
CO_2 footprint	-0.0251^{***}	-0.0286^{***}	-0.0285^{***}
	(0.00254)	(0.00271)	(0.00272)
Label	0.663^{***}	0.736^{***}	0.733^{***}
	(0.0696)	(0.0735)	(0.0735)
ASC	– 0.0431	-1.337^{***}	-1.567^{***}
	(0.205)	(0.233)	(0.238)
RAC (nest)			
Client Groups[42]			
Developers	0.393^{*}	0.386^{+}	0.377^{+}
	(0.185)	(0.201)	(0.201)
Organizations	0.332^{**}	0.171	0.191
	(0.112)	(0.120)	(0.120)
Familiarity	0.326^{**}	0.272^{*}	0.268^{*}
	(0.109)	(0.117)	(0.118)
Sustainability		0.0174^{***}	0.0154^{***}
		(0.00184)	(0.00180)
Responsibility			0.518^{***}
			(0.103)
N	24124	22896	22896

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using nested logit models.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
RA = recycled aggregates, RAC = recycled aggregate concrete

42 Private individuals are the base category.

Appendix E

Regression Results in the Separate Client Groups

Table II.E.1: Regression results with socio-demographic variables (developers)

	(1) Nested logit	(2) Nested logit	(3) Mixed logit
Price	-0.0416^{***} (0.0119)	-0.0418^{***} (0.0127)	-0.0525^{***} (0.00742)
RA	0.0115^{***} (0.00324)	0.0119^{**} (0.00374)	0.249^{+} (0.132)
CO_2 footprint	-0.0281^{***} (0.00797)	-0.0276^{**} (0.00851)	-0.0362^{***} (0.00614)
Label	0.874^{***} (0.255)	0.851^{**} (0.269)	0.995^{***} (0.183)
ASC	0.0853 (0.735)	-30.83^{*} (12.08)	2.939^{**} (1.124)
	RAC (nest)		Interaction terms with RA
Founding year		0.0161^{**} (0.00620)	-0.000120^{+} (0.0000655)
Yearly turnover		1.604^{**} (0.562)	0.00557 (0.00502)
Employees		– 0.254 (0.523)	-0.0111^{*} (0.00542)
Role of sustainability	– 0.000283 (0.00566)	-0.0218^{*} (0.00953)	0.0000971 (0.0000997)
Sustainability goals	0.503 (0.455)	0.757 (0.555)	– 0.00265 (0.00589)
N	2560	2272	2272

Standard errors in parentheses
$^{+}\ p < 0.10$, $^{*}\ p < 0.05$, $^{**}\ p < 0.01$, $^{***}\ p < 0.001$
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
RA = recycled aggregates, ASC = alternative-specific constant, RAC = recycled aggregate concrete

Table II.E.2: Regression results for subsamples (developers) separated based on turnover

	Yearly turnover	
	< 5 million EUR	> 5 million EUR
Price	– 0.0502***	– 0.0543***
	(0.0101)	(0.00944)
RA	0.0141***	0.0127***
	(0.00350)	(0.00350)
CO_2 footprint	– 0.0298***	– 0.0399***
	(0.00795)	(0.00794)
Label	0.731**	0.994***
	(0.240)	(0.259)
ASC	3.564+	2.015*
	(2.019)	(0.828)
/Normal		
SD(RA)	0.00931	0.0155*
	(0.00655)	(0.00614)
SD(CO_2 footprint)	0.0316***	0.0313***
	(0.00637)	(0.00918)
SD(Label)	1.068**	0.991**
	(0.371)	(0.322)
SD(ASC)	5.310+	1.704***
	(2.882)	(0.459)
N	1272	1184

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using mixed logit models.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
RA = recycled aggregates, ASC = alternative-specific constant, SD = standard deviation

Table II.E.3: Regression results with socio-demographic variables (organizations)

	(1) Nested logit	(2) Nested logit	(3) Mixed logit
Price	-0.0358^{***}	-0.0354^{***}	-0.0537^{***}
	(0.00527)	(0.00613)	(0.00381)
RA	0.0116^{***}	0.0106^{***}	-0.0173
	(0.00165)	(0.00181)	(0.0599)
CO_2 footprint	-0.0314^{***}	-0.0313^{***}	-0.0492^{***}
	(0.00458)	(0.00538)	(0.00358)
Label	0.676^{***}	0.662^{***}	0.957^{***}
	(0.103)	(0.120)	(0.103)
ASC	-0.463	-3.630^{*}	1.649^{***}
	(0.386)	(1.559)	(0.397)
	RAC (nest)		Interaction terms with RA
Type of business[43]			
Non-profit		0.489	-0.00718^{+}
		(0.374)	(0.00431)
Public		-1.096^{***}	-0.00338
		(0.257)	(0.00587)
Founding year		0.00177^{*}	0.0000135
		(0.000742)	(0.0000292)
Yearly turnover		0.835^{**}	-0.00349
		(0.317)	(0.00473)
Employees		-0.578^{+}	-0.000496
		(0.309)	(0.00514)
Role of sustainability	0.0103^{**}	0.00841^{*}	0.000126
	(0.00346)	(0.00385)	(0.0000801)
Sustainability goals	-0.0669	-0.147	0.000252
	(0.181)	(0.219)	(0.00336)
N	10380	8276	8276

Standard errors in parentheses
$^{+}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
RA = recycled aggregates, ASC = alternative-specific constant, RAC = recycled aggregate concrete

[43] Private organizations are the base category.

Table II.E.4: Regression results for subsamples (organizations) based on turnover

	Yearly Turnover	
	< 5 million EUR	> 5 million EUR
Price	-0.0465^{***}	-0.0643^{***}
	(0.00483)	(0.00575)
RA	0.0173^{***}	0.0146^{***}
	(0.00226)	(0.00221)
CO_2 footprint	-0.0447^{***}	-0.0522^{***}
	(0.00437)	(0.00509)
Label	1.020^{***}	0.940^{***}
	(0.134)	(0.146)
ASC	2.507^{**}	0.869^{*}
	(0.857)	(0.362)
/Normal		
SD(RA)	0.0165^{***}	0.0156^{***}
	(0.00288)	(0.00285)
SD(CO_2 footprint)	0.0330^{***}	0.0396^{***}
	(0.00440)	(0.00508)
SD(Label)	1.009^{***}	1.021^{***}
	(0.173)	(0.216)
SD(ASC)	3.380^{***}	1.702^{***}
	(0.837)	(0.349)
N	4508	4596

Standard errors in parentheses
$^{+}\ p < 0.10$, $^{*}\ p < 0.05$, $^{**}\ p < 0.01$, $^{***}\ p < 0.001$
Results obtained using mixed logit models.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
RA = recycled aggregates, ASC = alternative-specific constant, SD = standard deviation

Table II.E.5: Regression results for subsamples (organizations) based on type

	Type of Business		
	Private	Non-Profit	Public
Price	– 0.0530***	– 0.0513***	– 0.0587***
	(0.00394)	(0.00815)	(0.00784)
RA	0.0164***	0.0153***	0.0173***
	(0.00170)	(0.00328)	(0.00353)
CO_2 footprint	– 0.0476***	– 0.0387***	– 0.0467***
	(0.00349)	(0.00730)	(0.00787)
Label	0.947***	1.026***	0.827***
	(0.101)	(0.283)	(0.224)
ASC	1.160***	4.979**	1.725+
	(0.351)	(1.647)	(0.928)
/Normal			
SD(RA)	0.0154***	0.0151***	0.0195***
	(0.00218)	(0.00326)	(0.00539)
SD(CO_2 footprint)	0.0357***	0.0354***	0.0395***
	(0.00335)	(0.00655)	(0.0107)
SD(Label)	0.949***	1.505***	0.798*
	(0.139)	(0.308)	(0.364)
SD(ASC)	1.962***	5.535***	3.426***
	(0.427)	(1.250)	(0.859)
N	8076	1564	1500

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using mixed logit models.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
RA = recycled aggregates, ASC = alternative-specific constant, SD = standard deviation

Table II.E.6: Regression results with socio-demographic variables (private individuals)

	(1) Nested logit	(2) Mixed logit
Price	-0.0397^{***}	-0.0583^{***}
	(0.00613)	(0.00382)
RA	0.00890^{***}	0.0149^{*}
	(0.00139)	(0.00333)
CO_2 footprint	-0.0234^{***}	-0.0363^{***}
	(0.00354)	(0.00295)
Label	0.672^{***}	0.922^{***}
	(0.108)	(0.101)
ASC	0.467	1.434^{***}
	(0.349)	(0.348)
	RAC (nest)	Interaction terms with RA
Male	-0.283^{*}	-0.00213
	(0.144)	(0.00259)
Age	0.113	0.00536^{+}
	(0.164)	(0.00302)
Graduate degree	0.722^{***}	0.00610^{*}
	(0.151)	(0.00283)
Household income	-0.392^{*}	-0.00753^{*}
	(0.161)	(0.00317)
Children	-0.529^{**}	-0.00304
	(0.167)	(0.00307)
N	10108	10108

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
RA = recycled aggregates, ASC = alternative-specific constant, RAC = recycled aggregate concrete

Table II.E.7: Regression results for subsamples (private individuals) based on income

	Household Income	
	< 4000 EUR	> 4000 EUR
Price	-0.0461^{***}	-0.0623^{***}
	(0.00587)	(0.00468)
RA	0.0155^{***}	0.0103^{***}
	(0.00270)	(0.00159)
CO_2 footprint	-0.0257^{***}	-0.0406^{***}
	(0.00428)	(0.00368)
Label	1.076^{***}	0.823^{***}
	(0.189)	(0.115)
ASC	1.908^{**}	1.315^{***}
	(0.679)	(0.351)
/Normal		
SD(RA)	0.0181^{***}	0.0161^{***}
	(0.00371)	(0.00246)
SD(CO_2 footprint)	0.0278^{***}	0.0350^{***}
	(0.00496)	(0.00347)
SD(Label)	1.286^{***}	1.131^{***}
	(0.245)	(0.188)
SD(ASC)	2.806^{***}	2.565^{***}
	(0.685)	(0.458)
N	3204	7124

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using mixed logit models.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
RA = recycled aggregates, ASC = alternative-specific constant, SD = standard deviation

Table II.E.8: Regression results for subsamples (private individuals) based on gender

	Gender	
	Female	Male
Price	-0.0473^{***}	-0.0680^{***}
	(0.00458)	(0.00581)
RA	0.0109^{***}	0.0130^{***}
	(0.00175)	(0.00209)
CO_2 footprint	-0.0318^{***}	-0.0399^{***}
	(0.00344)	(0.00444)
Label	1.023^{***}	0.789^{***}
	(0.139)	(0.130)
ASC	1.772^{***}	1.109^{**}
	(0.520)	(0.404)
/Normal		
SD(RA)	0.0143^{***}	0.0226^{***}
	(0.00241)	(0.00359)
SD(CO_2 footprint)	0.0279^{***}	0.0395^{***}
	(0.00357)	(0.00442)
SD(Label)	1.203^{***}	1.110^{***}
	(0.187)	(0.227)
SD(ASC)	2.594^{***}	2.722^{***}
	(0.693)	(0.544)
N	4912	6024

Standard errors in parentheses
$^{+} p < 0.10$, $^{*} p < 0.05$, $^{**} p < 0.01$, $^{***} p < 0.001$
Results obtained using mixed logit models.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
RA = recycled aggregates, ASC = alternative-specific constant, SD = standard deviation

Table II.E.9: Regression results for subsamples (private individuals) based on age

	Age	
	18 – 35	> 35
Price	– 0.0572***	– 0.0564***
	(0.00497)	(0.00532)
RA	0.00998***	0.0144***
	(0.00172)	(0.00223)
CO_2 footprint	– 0.0319***	– 0.0400***
	(0.00335)	(0.00477)
Label	0.769***	1.111***
	(0.110)	(0.167)
ASC	1.843***	0.815+
	(0.460)	(0.486)
/Normal		
SD(RA)	0.0169***	0.0197***
	(0.00260)	(0.00356)
SD(CO_2 footprint)	0.0291***	0.0390***
	(0.00330)	(0.00484)
SD(Label)	0.981***	1.390***
	(0.189)	(0.221)
SD(ASC)	2.883***	2.387**
	(0.533)	(0.727)
N	6064	4900

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using mixed logit models.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
RA = recycled aggregates, ASC = alternative-specific constant, SD = standard deviation

Table II.E.10: Regression results for subsamples (private individuals) based on education

	Graduate Degree	
	No	Yes
Price	– 0.0547***	– 0.0607***
	(0.00584)	(0.00462)
RA	0.00982***	0.0142***
	(0.00194)	(0.00197)
CO_2 footprint	– 0.0309***	– 0.0398***
	(0.00404)	(0.00398)
Label	0.901***	0.911***
	(0.137)	(0.133)
ASC	0.860*	1.912***
	(0.376)	(0.561)
/Normal		
SD(RA)	0.0163***	0.0197***
	(0.00283)	(0.00277)
SD(CO_2 footprint)	0.0333***	0.0347***
	(0.00413)	(0.00376)
SD(Label)	1.101***	1.255***
	(0.218)	(0.192)
SD(ASC)	2.549***	2.866***
	(0.523)	(0.675)
N	4552	6220

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using mixed logit models.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
RA = recycled aggregates, ASC = alternative-specific constant, SD = standard deviation

Table II.E.11: Regression results for subsamples (private individuals) based on number of children

	Children	
	No	Yes
Price	– 0.0552***	– 0.0579***
	(0.00586)	(0.00464)
RA	0.0112***	0.0121***
	(0.00200)	(0.00186)
CO_2 footprint	– 0.0323***	– 0.0371***
	(0.00395)	(0.00396)
Label	0.924***	0.860***
	(0.138)	(0.125)
ASC	1.869***	1.105*
	(0.538)	(0.456)
/Normal		
SD(RA)	0.0168***	0.0190***
	(0.00294)	(0.00337)
SD(CO_2 footprint)	0.0302***	0.0351***
	(0.00437)	(0.00387)
SD(Label)	1.118***	1.213***
	(0.212)	(0.189)
SD(ASC)	2.862***	2.663***
	(0.555)	(0.653)
N	4604	6360

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using mixed logit models.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
RA = recycled aggregates, ASC = alternative-specific constant, SD = standard deviation

Table II.E.12: WTP estimates for RA for various subgroups (private individuals)

	WTP RA (1 pp)	Lower limit	Upper limit
Gender			
Female	0.23	0.16	0.31
Male	0.19	0.13	0.25
Age			
18 – 35	0.17	0.11	0.23
> 36	0.26	0.17	0.34
Household income			
< 4000 EUR	0.34	0.22	0.45
> 4000 EUR	0.17	0.11	0.22
Graduate degree			
Yes	0.23	0.17	0.30
No	0.18	0.11	0.25
Children			
Yes	0.21	0.14	0.28
No	0.20	0.13	0.27

Based on results obtained using mixed logit models.
Values refer to the WTP estimates for a pp increase in the share of RA.
WTP = willingness to pay, RA = recycled aggregates, pp = percentage point

Table II.E.13: Marginal effects of changes in education and income (private individuals) for different shares of RA

	10 % RA	55 % RA	100 % RA
Graduate degree (no/yes)	+ 1.5	+ 6.6	+ 7.5
Income (</> 4000 EUR)	– 1.9	– 9.4	– 14.0

Values are given in pp.
Results from the sample of private individuals
RA = recycled aggregates

Table II.E.14: Regression results for selected sample with high WTP

Price	-0.0377^{***}
	(0.00493)
RA	0.0189^{***}
	(0.00262)
CO_2 footprint	-0.0523^{***}
	(0.00577)
Label	0.934^{***}
	(0.150)
ASC	2.017^{**}
	(0.741)
/Normal	
SD(RA)	0.0171^{***}
	(0.00271)
SD(CO_2 footprint)	0.0375^{***}
	(0.00524)
SD(Label)	0.793^{***}
	(0.210)
SD(ASC)	2.332^{***}
	(0.651)
N	3488

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using a mixed logit model.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
The sample consists of organizations who value sustainability ($\geq \bar{x}$), feel responsible, and are familiar with RAC.
WTP = willingness to pay, RA = recycled aggregates, ASC = alternative-specific constant, SD = standard deviation

Appendix F

Robustness Checks

Table II.F.1: Robustness check: main regression results using a nested logit model

Price	– 0.0343***
	(0.00349)
RA	0.00913***
	(0.000919)
CO_2 footprint	– 0.0244***
	(0.00245)
Label	0.631***
	(0.0661)
ASC	0.315
	(0.194)
N	24896

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using a nested logit model.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
RA = recycled aggregates, ASC = alternative-specific constant

Table II.F.2: Robustness checks displaying all attributes

	(1) Basis	(2) DEG Time 100	(3) DEG Time 50	(4) Time RSI	(5) Finished	(6) DCE Complete
Price	– 0.0551***	– 0.0559***	– 0.0594***	– 0.0562***	– 0.0555***	– 0.0590***
	(0.00231)	(0.00238)	(0.00251)	(0.00238)	(0.00244)	(0.00256)
RA	0.0141***	0.0144***	0.0153***	0.0141***	0.0144***	0.0150***
	(0.000907)	(0.000926)	(0.00101)	(0.000923)	(0.000936)	(0.000982)
CO_2 footprint	– 0.0405***	– 0.0412***	– 0.0442***	– 0.0414***	– 0.0414***	– 0.0436***
	(0.00192)	(0.00197)	(0.00218)	(0.00197)	(0.00204)	(0.00213)
Label	0.937***	0.920***	0.950***	0.930***	0.928***	0.953***
	(0.0607)	(0.0625)	(0.0666)	(0.0612)	(0.0645)	(0.0665)
ASC	1.632***	1.470***	1.362***	1.438***	1.601***	1.420***
	(0.232)	(0.219)	(0.217)	(0.208)	(0.226)	(0.224)
/Normal						
SD(RA)	0.0167***	0.0163***	0.0176***	0.0168***	0.0157***	0.0170***
	(0.00127)	(0.00134)	(0.00135)	(0.00130)	(0.00123)	(0.00133)
SD(CO_2 footprint)	0.0350***	0.0353***	0.0373***	0.0350***	0.0347***	0.0359***
	(0.0019)	(0.00198)	(0.00209)	(0.00196)	(0.00201)	(0.00202)
SD(Label)	1.129***	1.099***	1.144***	1.096***	1.097***	1.174***
	(0.0833)	(0.0857)	(0.0902)	(0.0856)	(0.0895)	(0.0904)
SD(ASC)	2.784***	2.472***	2.286***	2.424***	2.498***	2.526***
	(0.187)	(0.242)	(0.236)	(0.217)	(0.240)	(0.274)
N	24896	23568	21192	23880	22388	22752

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using mixed logit models.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
RSI = relative speed index, DCE = discrete choice experiment, RA = recycled aggregates, ASC = alternative-specific constant, SD = standard deviation

Table II.F.3: WTP estimates for RA based on robustness checks

	Basis	DEG Time 100	DEG Time 50	Time RSI	Finished	DCE Complete
WTP RA (1 pp)	0.26	0.26	0.26	0.25	0.26	0.25
Lower limit	0.18	0.19	0.19	0.18	0.20	0.19
Upper limit	0.33	0.33	0.32	0.3	0.32	0.32

Values refer to the WTP estimates for a pp increase in the share of RA.
RSI = relative speed index, DCE = discrete choice experiment, WTP = willingness to pay, RA = recycled aggregates, pp = percentage point

Appendix G

WTP estimates for CO_2 footprint and Label

Table II.G.1: WTP estimates for a sustainability label for separate client groups

	Developers	Organizations	Private Individuals
WTP CSC-R Label	19.83	17.54	15.70
Lower limit	11.33	13.97	12.21
Upper limit	28.33	21.11	19.20

Values refer to the WTP estimates of having a label versus not having a label.
WTP = willingness to pay, CSC-R = Concrete Sustainability Council Recycling-module

Table II.G.2: WTP estimates for saving CO_2 emissions for separate client groups

	Developers	Organizations	Private Individuals
WTP CO_2 footprint (1 kg)	0.68	0.87	0.62
Lower limit	0.48	0.75	0.53
Upper limit	0.87	0.98	0.71

Values refer to the WTP estimates for saving a kg of CO_2 emissions.
WTP = willingness to pay

Part III

Incentives for Construction Clients in Germany to Choose Concrete With Recycled Aggregates

Incentives for Construction Clients in Germany to Choose Concrete With Recycled Aggregates

Ellen Sterk

Abstract

Recycled aggregate concrete (RAC) offers a way to reduce the extraction of natural resources and to close material loops in line with political goals. However, market failures may hamper the efficient use of RAC in construction. Various policy instruments can be used in this situation to stimulate construction clients' demand for RAC and to correct market failures. This study aims to answer the question of which instruments are potentially effective and how different client groups differ in their responsiveness to these instruments. The results show that all tested instruments have a positive effect in at least one of the client groups, but only financial incentives work in all groups. While information provision is shown to positively affect the likelihood of choosing RAC (at least in some client groups), its effectiveness decreases with an increasing financial grant. Finally, client groups also differ in their likelihood of choosing RAC over conventional concrete. Conceiving sustainability as an essential criterion in construction projects increases this likelihood. This study offers a guideline for policymakers to design instruments to stimulate the use of recycled construction material.

JEL classification: H30, L72, L74, L78, Q53

Keywords: Policy Instruments; Recycled Aggregates; Concrete; Construction Clients; Factorial Survey

1 Introduction

The need to close material cycles and, to this end, increase recycling has left the discussion table of scientists and climate activists and has entered the general public's awareness. It is also a political goal on a national and international level (Waste Framework Directive, 2008; *Koalitionsvertrag 2021 – 2025*, 2021; United Nations, 2015b). An industry with considerable potential in this regard is the construction industry. It claims around 75 % of the non-renewable resources extracted in Germany (Destatis, 2021) and produces more than half of the waste generated (Destatis, n.d.). One product that can help lower these numbers in line with the political goals is recycled aggregate concrete (RAC). In this material, the natural aggregates (NA) that are a component of conventional concrete (NAC) – usually gravel and sand – are partly replaced by recycled aggregates (RA) from construction and demolition waste. Fewer primary resources are needed, less waste is produced, and landfill capacities are spared (Knappe et al., 2012, 2017; Wizgall & Knappe, 2011). RAC is already admissible for many applications in building construction in Germany and is considered to have the same characteristics as NAC (Knappe et al., 2013). Nevertheless, it is hardly used in Germany (Jacob et al., 2021; Wizgall & Knappe, 2011).

Arguably, two main market failures are at work that hamper resource efficiency generally and the use of RAC in particular: external costs and information asymmetry (Jacob et al., 2021). Both will be elaborated on in the following sections. It is commonly accepted that market failures should be counteracted with policy interventions (Söderholm & Tilton, 2012). A report by the European Commission recommends using economic instruments to establish cost competitiveness for RAC and create a market for it (Pacheco et al., 2023). Which policy instruments are likely to increase the likelihood of construction clients using RAC has not yet been quantitatively tested. This study aims to fill this gap by answering the following research question:

Which policy instruments can increase construction clients' likelihood to demand RAC?

We answer this question using a factorial survey and a sample of three different groups of construction clients: private individuals, organizations, and developing companies[44]. While they all initiate and finance construction projects, they are different in ways that might influence their demand behavior. The tested instruments are a financial grant, an expedited permit process, free technical assistance, public recognition, and information provision[45]. The results show that all tested instruments are effective for at least one of the client groups. Only a financial grant increases the likelihood of choosing RAC in all three groups. While organizations exhibit responsiveness to all instruments, developers and private individuals are influenced by only a subset of them. Regarding a proposed mix of financial and informational instruments, we find that providing information is only effective when a concomitant financial grant is relatively low. Developers are the group most likely to choose RAC overall. Finally, considering sustainability an essential criterion in construction increases the likelihood of choosing RAC. The results offer guidance to policymakers to shift demand from primary to recycled building material.

[44] While public authorities are a highly relevant group of construction clients as well, they are willfully excluded in this study. The regulatory environment under which they operate distinguishes them from the other three groups, which is why they are considered in a separate study (see Part IV).

[45] Note that the financial grant, expedited permit process, free technical assistance, and public recognition are referred to as "incentives", while the term "(policy) instruments" includes all of the former as well as the provision of information.

The paper is organized as follows: Chapter 2 gives an overview of the literature on market failures in the context of RAC and potential policy instruments to counteract these. It finishes with the presentation of hypotheses derived from the literature that inform the direction of this study. Chapter 3 illustrates the method used, and Chapter 4 shows the corresponding results. These are discussed and put into context in Chapter 5. Chapter 6 concludes this paper.

2 Literature Review and Hypotheses

As stated above, one market failure that hampers the use of RAC is the external cost related to NAC production. The extraction of natural resources generates externalities that are not taken into account by construction clients or factored into the price of NAC (European Commission, 2008). Firstly, mining sand and gravel causes greenhouse gas (GHG) emissions. In Germany, 40 % of GHG emissions are ascribable to the extraction and first processing of natural resources (Lutter et al., 2022). These emissions can be reduced by recycling construction and demolition waste instead of mining natural resources (Marzouk & Azab, 2014). Resource extraction is further problematic since it entails damage to flora and fauna, pollution of groundwater and soil, and noise and dust disturbance, to name a few impacts (Wijayasundara et al., 2018b). The International Resource Panel (2019) finds that over 90 % of water stress and biodiversity loss are ascribable to the extraction of resources. Moreover, it leads to resource depletion, the costs of which are quantified in the concept of *scarcity rents*. Scarcity rents represent the opportunity costs of extracting a unit of resources today instead of conserving it for the future. It indicates the costs of depleting a resource now such that its benefits are not available to future generations (Farzin, 1992). Naturally, using RA instead of NA does not entail these issues. While the processing of waste into aggregates also produces emissions, the use of RA has been shown to have a lower environmental impact (e.g., Ding et al., 2016; Knoeri et al., 2013; Serres et al., 2016; Stürmer & Kulle, 2017). For example, Colangelo et al. (2021) conduct a life cycle assessment comparing several mixtures of concrete with varying shares of RA to NAC. The impacts are considered in three areas: human health, ecosystem quality, and resource scarcity (RIVM, 2011). The results show that RAC is better from an environmental perspective, and the benefits increase with an increasing share of RA. Mostert et al. (2021) reach similar conclusions as they evaluate the demolition and construction of a city hall using RAC. They find a reduced footprint regarding material, water (for the case of dry processing), and climate due to reduced emissions from transport and energy use. However, the researchers emphasize that a project's environmental footprint can only be assessed on a case-by-case basis. In line with this, the transport distance is repeatedly found to be decisive for the environmental impact of aggregates (Ding et al., 2016; Ghisellini et al., 2018; Knoeri et al., 2013). Notwithstanding, using NA produces externalities not accounted for in the price of NAC. Wijayasundara et al. (2018b) identify avoiding landfilling construction and demolition waste, the extraction of natural resources, and transportation of waste and by-products as the main benefits of RA in this regard. They quantify these external costs and find a net benefit between 9 and 28 % of the price of NAC. In a different study, the same authors show that internalizing these benefits would decrease the price of RAC with a share of 30 % of RA by 4 to 6 %. This reduction increases linearly with an increase in the share of RA and renders the use of RAC compared to NAC economically profitable (Wijayasundara et al., 2018a).

If the market depicted the external costs connected to material scarcity and damaging environmental impacts, the price for NA would rise, lowering demand and triggering the use of RA instead. However, reality shows that in the case of environmental externalities, "the costs of harm do not affect prices unless the costs are added due to policy" (Allwood et al., 2011, p. 376). This statement aligns with the findings by Henckens et al. (2016): The researchers study whether the geological scarcity of minerals is reflected in their price development and find that this is not the case. Thus, instead of trusting market forces to ensure resource conservation, they recommend installing policy measures to increase the price of scarce materials. Policies "level the playing field" (Wilson, 1996, p. 389) by internalizing externalities so that these do not compromise the position of RAC on the market. These instruments either increase the price of primary materials (e.g., environmental taxes) or lower the price of recycled materials (e.g., subsidies; European Environment Agency, 2008a; Li et al., 2020).

Besides externalities, information asymmetry additionally worsens the market situation for RAC. In this case, it is especially at play in the form of adverse selection. Adverse selection describes the situation in which one party, usually the seller, has more information about the product than the other party, usually the buyer. Generally, not all stakeholders in construction projects or the recycling industry have the same degree of access to relevant information (Forsythe et al., 2015; Li et al., 2020). For example, clients, especially laypersons, must trust their contractors and suppliers to deliver the best possible material that lives up to their promises. Even the contractors ordering (recycled) material most likely do not know about the quality of the RA supplied by the recycler and used by the producer. In the case of RAC, construction clients do not have ready access to information about the quality or environmental impact of the material. Analogous to the famous example of lemons in the automobile market (Akerlof, 1970), this implies that sellers who offer a high quality are unable to attain an adequate price since the quality is unobserved and sellers with lower-quality products are favored (Nicolli et al., 2012). Adverse selection is especially likely to be significant in the construction and recycling industry because the transactions are infrequent (especially for clients who are private individuals; Nicolli et al., 2012) and there are numerous stakeholders involved (Forsythe et al., 2015). Selling predominantly low-quality aggregates would result in a negative perception of RAC and a diminished demand.

There is a widespread belief that policy intervention is essential to counteract market distortions, and this perspective also applies to construction materials. Söderholm and Tilton (2012), for example, argue that policy instruments are desirable if market failures impact clients' purchasing decisions of material. Information asymmetry and environmental externalities are among the market failures they list for this case. Public policy instruments are commonly divided into *sticks*, *carrots*, and sometimes *sermons*[46] (Bemelmans-Videc et al., 2011). Sticks, also called *command-and-control* instruments, refer to mandatory regulations by the government, which oblige people to act by the specified rules. Carrots, in contrast, imply adding or removing resources as a form of incentive, such that the person concerned can choose whether to use the measure. They are also referred to as *market-based* instruments. An example is the financial incentives mentioned before. The final category, sermons, describes information instruments. These aim to stimulate "good" or avoid "bad" behavior by influencing the actors through knowledge transfer and persuasion.

This paper focuses on incentives (carrots) and information provision (sermons), the former of which can be categorized in several ways. Several authors and institutions propose categories for green building (GB) incentives. For example, Olubunmi et al. (2016) distinguish between external and internal incentives. External incentives are provided by the government and entail specific conditions that must be met. They are further subdivided into financial and non-financial. Internal incentives refer to people's intrinsic motivation or interest in the activity, such as a positive influence on health or inspiration from leadership[47]. The U.S. Green Building

[46] Figure I.4 in this thesis's introduction gives an overview of these categories.

[47] Note that Olubunmi et al. (2016) use the term "incentives" differently than is done in this thesis. We only understand the external instruments which are carrots (rather than sticks or sermons) as incentives.

Council (2014) differentiates structural, financial, and other incentives. Structural incentives offer benefits in the construction process, such as an increased admissible floor area ratio. Financial incentives are direct benefits in the form of a tax credit or grant. Finally, assistance from the municipality falls under other incentives.

Among these categories, incentives (carrots), especially financial ones, have received the most attention among scholars. Several authors argue for their implementation instead of regulations (sticks). Financial market-based instruments (as part of environmental policy) "provide a stimulus to consumers and producers to change their behaviour towards more eco-efficient use of natural resources" (European Environment Agency, 2006, p. 5). They can be tradable permits, environmental taxes, environmental charges, environmental subsidies and incentives, and liability and compensation schemes. The main argument for these instruments is that they are efficient and cost-effective (Duran et al., 2006; Grosskopf & Kibert, 2006; Jaffe & Stavins, 1995). They leverage the diversity of economic actors, as each one can decide whether to pay for the environmental harm they cause or modify their production processes to prevent such harm, depending on which is the less expensive option (European Environment Agency, 2006; Mandell & Wilhelmsson, 2011b). In contrast, regulations, such as environmental standards, are often costly and inefficient. The diversity in economic activities makes the same technology or process appropriate in one firm and inappropriate in another. Moreover, these instruments do not offer any incentive to improve one's environmental footprint beyond the requirements (Stavins, 2003). In the specific case of recycling construction and demolition waste, too, market-based instruments have been proposed as the optimal solution. Duran et al. (2006) develop a model using surveys, interviews, and existing data to determine the conditions that make recycling economically feasible. They find viability is given when landfilling is more expensive than offering the waste for recycling and using NA is more expensive than using RA. The authors conclude that (financial) market-based instruments – taxes and subsidies in this case – rather than command-and-control approaches, are the best way to reach these conditions.

Financial incentives are found to be effective in stimulating demand from construction clients (e.g., AlSanad, 2015; Darko et al., 2017; Diyana et al., 2013; Iheanyichukwu Joachim et al., 2014). For example, Pitt et al. (2009) ask building surveyors to rank potential drivers for sustainable construction and find financial incentives to be the most important. Adams et al. (2017) also identify financial incentives to use secondary material as an enabler to implement a circular economy in the construction industry. Particularly among clients, as opposed to researchers, consultants, and contractors, this factor is given a high ranking. Similarly, Portnov et al. (2018) survey potential homebuyers regarding their preference for public policy measures for GB. They find two forms of financial incentives at the top: tax reduction and subsidized loans and grants. In the same vein, a lack of financial incentives is often found to hinder the advancement of sustainable construction and the use of secondary materials. Several researchers identify a lack of (financial) incentives as one of the main barriers to GB (e.g., Adams et al., 2017; Chan et al., 2009; Häkkinen & Belloni, 2011). For example, Darko and Chan (2017) review 36 articles on barriers and challenges to the adoption of GB. They find that a lack of incentives is among the top barriers, as reported by 21 articles. Incentives seem to play a role in the use of RAC, too. Katerusha (2021) surveys concrete-producing companies and asks them to rate potential barriers on a scale from 1 ("not relevant at all") to 100 ("very relevant"). The median score for a lack of tax incentives is 76.5. The European Commission recommends taxing natural aggregates and using the revenue to subsidize RAC in a report by Pacheco et al. (2023). In earlier research (see Part II), we ask construction clients about their perception of potential barriers to using RAC. The lack of incentives ranks 4th out of 10.

Other incentives – non-financial ones – have received less attention. The structural incentives listed by the U.S. Green Building Council (2014) are an expedited review/permitting process and density and height bonuses. The former implies a prioritization of permits by the municipality that comply with specific GB standards. This can save time and costs on the side of the construction client while no costs are involved for the municipality. The latter structural incentive refers to an increase in the allowed floor area ratio or similar metrics. The American Institute of Architects (Rainwater et al., 2012) lists these as commonly implied incentives by local U.S. governments. Other incentives include technical or marketing assistance. Technical assistance is provided through training and support with planning and certification, especially for developers. Marketing assistance (in the form of publicity) builds on a GB certification's positive influence on the client's reputation or image (Rainwater et al., 2012; U.S. Green Building Council, 2014). Lacetera and Macis (2010) show the effectiveness of this latter type of incentive in the setting of pro-social behavior. They find that symbolic prizes encourage blood donations, especially when awarded publicly.

The third category of public policy instruments – sermons (information provision) – are also of interest for stimulating the demand for RAC. First, information-based instruments are the most straightforward solution for information asymmetries. As explained above, potential buyers of RAC do not have access to the same information as recycling and producing companies. Sermons could help to level out this imbalance. Secondly, in a previous paper, we find that the main barriers to construction clients demanding RAC are based on a lack of information: a lack of knowledge, not knowing the material, and uncertainty regarding the norms and regulations (see Part II). Raising clients' awareness of RAC (and recycled materials generally) and its properties and possibilities for application through information could tackle these issues. Finally, knowing and understanding an environmentally friendly construction product or practice has been found to increase clients' willingness to pay (WTP) for it (e.g., Portnov et al., 2018; Zalejska-Jonsson, 2014). Our previous study shows this for the case of RAC. Respondents familiar with the material are more likely to choose RAC and are willing to pay more for increasing the share of RA. Familiarity is conceptualized as having heard of RAC before. This indicates that simply being aware of the material's existence is already highly beneficial, which can be accomplished through information provision.

One potentially effective type of sermon to tackle information asymmetry is a third-party label or certification, as proposed by Bennear and Stavins (2007). As such, a label certifying RAC's quality- and sustainability-related aspects could be helpful. In support of this, we find that a label proving that RAC is equal to NAC in quality is a top driver for clients to demand RAC in a previous study. We also test their WTP for an environmental label and find it to be positive (see Part II). This aligns with other research that finds consumers willing to pay more for products, among which building materials, with eco-labels (e.g., Shen, 2012; Ward et al., 2011). Another conceivable sermon is an information campaign transferring knowledge. For example, Zhang et al. (2016) ask Chinese residents for their WTP for green housing, then show them information cards displaying the performance of green and non-green housing on some indoor environmental indicators, and then ask them again. The WTP of those participants who currently do not live in an environmentally friendly building increases significantly. The authors argue that there is no meaningful increase in participants living in green buildings because they likely already know the information provided. A similar result is found by Khan et al. (2020), who ask potential homebuyers in Pakistan about their attitude toward sustainable housing before and after being exposed to information on the subject. They find that this information positively affects their respondents' willingness to change from conventional to sustainable housing as well as their WTP for the latter. Mandell and Wilhelmsson (2011) also argue for information campaigns to increase the demand for sustainable housing. They assume that clients who understand themselves to be environmentally aware are better informed about their behavior's impact on the environment. They find that these clients have a larger WTP for sustainable housing and conclude that information campaigns raising environmental awareness among the relevant actors are justified.

To sum up, two types of market failures impede the use of RAC: environmental externalities and information asymmetry. According to Bennear and Stavins (2007), these two market failures are jointly ameliorating, meaning that correcting one of them also lessens the negative impacts of the other. For example, the authors name energy labels as a measure that provides consumers with information on energy usage and costs and lowers energy consumption. A mix of instruments is considered more efficient when several market failures are at work (Bennear & Stavins, 2007; de Serres et al., 2010; European Environment Agency, 2006; Wilson, 1996). Specifically, at least one measure should be applied per market failure (Goulder & Parry, 2008). Regarding environmental externalities and information asymmetry, a combination of some (financial) incentive, such as a tax, and information disclosure requirements, such as a third-party label, is recommended (Bennear & Stavins, 2007a). Mandell and Wilhelmsson (2011) suggest a similar mix to be most efficient. As described above, they find higher WTP estimates for environmentally aware clients, which speaks to implementing information campaigns. However, this effect is primarily found for environmental attributes that require only small investments. Therefore, information should be combined with economic incentives to stimulate the demand for a broader range of attributes.

The above overview suggests that policy instruments could stimulate the demand for RAC. RAC keeps resources in the loop, one of the main principles of a circular economy (CE). The concept of a CE has been criticized for having various meanings. However, it is most often understood as combining the principles of reduce, reuse, and recycle with the goals of economic prosperity and environmental quality (Kirchherr et al., 2017). Researchers agree that "the transition to a circular built environment is key to achieving a resource-effective and sustainable society" (van Stijn & Gruis, 2020, p. 636). However, there seems to be a lack of policy interventions to support this transition (Hossain et al., 2020). Both Hossain et al. (2020) and Osobajo et al. (2022) conduct literature reviews on CE in the construction industry, and both find that there has been limited research on policy interventions that can help establish this transition. Thus, more research is needed to identify which policy instruments could help establish a CE in the construction industry. Specifically, as Osobajo et al. (2022) suggest, quantitative methods should be applied, given that 92 % of the articles reviewed by the authors are based on qualitative methods. Furthermore, there is a need for studies that evaluate policy mixes in specific industries (Rosenow et al., 2016), and to the best of our knowledge, none of these studies have been conducted for the case of RAC. This paper aims to combine these research endeavors by quantitatively analyzing the potential effectiveness of policy instruments (and their mix) for the application of construction products and principles that are in line with the concept of a CE and does so by using the specific case of RAC. The following sections will derive the hypotheses that guide this study from the literature presented above.

Many incentives have been proposed and partly applied to stimulate the demand for GB. The market failures at work impeding the use of RAC suggest that these incentives could also be beneficial in this case. However, whether these could be effective or which ones are likely to have the greatest impact has not yet been tested. This research aims to fill this gap, focusing on various policy instruments: a financial grant, an expedited permit process, free technical assistance, public recognition, and information provision. The respective hypotheses are the following:

H1.1 A financial grant increases the likelihood of clients demanding RAC.

H1.2 An expedited permit process increases the likelihood of clients demanding RAC.

H1.3 Free technical assistance from the municipality increases the likelihood of clients demanding RAC.

H1.4 Public recognition increase the likelihood of clients demanding RAC.

H1.5 Information provision increases the likelihood of clients' demanding RAC.

Up until this point, construction clients have not yet been further distinguished. Generally, they are defined as the ones who initiate and finance a construction project (Hartmann et al., 2008). However, construction clients differ in ways that might systematically affect their attitude towards and propensity to choose RAC and their responsiveness to incentives. Our previous work confirms that client groups differ in their consumption behavior of RAC (see Part II), and they will also be distinguished here. The three groups are developers, organizations, and private individuals. The study aims to answer whether these groups differ in terms of their likelihood to choose RAC over NAC and their responsiveness to potential incentives. In our earlier study, we find that private individuals experience barriers to using RAC to a greater extent and have a lower WTP for it than the other two groups. Moreover, they choose NAC rather than RAC more often in a discrete choice experiment (see Part II). We expect to find a similar pattern in the factorial survey applied in this study.

H2 Private individuals are less likely to demand RAC than organizations and developers.

We expect variations in the responsiveness of client groups to the different policy instruments. Private individuals appear to be more price sensitive regarding RAC (see Part II), likely making them more responsive to financial incentives, such as grants, than organizations or developers. Regarding an expedited permitting process, it is unclear which of the client groups is likely to be most affected since the length of the process is not necessarily dependent on the type of building, and the saying “time is money” holds for all groups. Whether technical assistance is attractive to clients depends on their knowledge of and experience with RAC. Since it is the developers’ profession to construct buildings, one can assume they have more technical expertise, potentially including RAC. Therefore, we expect this incentive to be the least effective in the group of developers. Developers and organizations (but not private individuals) are motivated to use environmentally friendly products and practices by reputation and image considerations (Diyana et al., 2013; X. Zhang et al., 2011). Our previous work supports this notion, as being driven to use RAC by a positive effect on one’s image is ranked higher by organizations and developers than by private individuals (see Part II). Followingly, public recognition is assumed to be most effective in these groups. Finally, we expect that providing information on RAC has the most considerable effect on private individuals. This group is the least knowledgeable and experienced regarding construction materials, including RAC, since most private clients are only construction clients once in their lives. In contrast, most organizations in our sample are responsible for several buildings, and developers act as construction clients daily. Thus, we assume that private individuals are the least informed about RAC, which our previous study confirms: Only a little more than a fifth of them had ever heard of RAC before (compared to roughly two-thirds in both other groups). In addition, not knowing the material shows to be the second most significant barrier to its use in this group (see Part II). Furthermore, Zhang et al. (2016) also find that their information treatment on the environmental factor of green buildings only works for those clients who are not themselves living in and therefore knowledgeable about green buildings. Accordingly, we expect private individuals to be most responsive to the provision of information. The resulting hypotheses are the following:

H3.1 A financial grant increases the likelihood of demanding RAC more for private individuals than organizations and developers.

H3.2 An expedited permit process increases the likelihood of different client groups demanding RAC differently.

H3.3 Free technical assistance from the municipality increases the likelihood of demanding RAC more for private individuals and organizations than for developers.

H3.4 Public recognition increases the likelihood of demanding RAC more for organizations and developers than for private individuals.

H3.5 Information provision increases the likelihood of demanding RAC more for private individuals than organizations and developers.

3 Methods

3.1 Research Strategy and Data Collection

Several interviews are conducted with industry experts to validate the practicability of the incentives we test in this study. Then, a two-part online survey among construction clients is conducted, distinguishing between three client groups: developers, organizations, and private individuals. The survey starts with item-based questions on demographics, familiarity with RAC, and barriers and drivers for their use. As a first experimental treatment, respondents are then randomly assigned to one of two groups: The treatment group receives a text with detailed information about RAC and its advantages, while the control group does not receive this information. Then, a discrete choice experiment follows. This experiment is the focus of previous work (see Part II) and will not be discussed here. This paper focuses on the subsequent factorial survey described below. The questionnaire concludes with some item-based questions on sustainability's role in the clients' construction project(s). Only the questions concerning demographic information differ considerably between the three groups. The other questions are at most adapted in wording to suit the type of respondent. For details on the inclusion criteria, interviews, barriers and drivers, and the full survey transcripts, the interested reader is referred to our preceding article (see Part II).

Factorial surveys date back to Rossi (1951) and combine the advantages of surveys and experimental research. In factorial surveys, hypothetical situation descriptions (so-called *vignettes*) are presented to the participants. Based on this situation, they are then asked how likely they would be to act in a certain way. Several aspects of these descriptions are varied in their levels, which allows the researcher to identify their influence on the choice.

In this study, the factorial survey aims to test the effectiveness of potential incentives to increase construction clients' demand for RAC (H1.1 – H1.4 and H3.1 – H3.4). Participants are asked to imagine that they are currently building their house with an architect, are awarding individual contracts, and that they must decide between using RAC or using NAC. They should assume that RAC can be used in all applications and does not differ from NAC in quality or performance. Finally, they are asked to assume that RAC is around 10 % more expensive than

NAC, everything else equal. Then, a vignette is presented. The vignette describes potential incentives that the client gets when building with RAC. These are a financial grant, prioritized treatment of the building permit, free technical assistance, and public recognition. The grant can take the values of 0 % (no grant), 50 %, 100 %, and 150 %, describing how much of the additional costs for RAC compared to NAC it covers. The other three aspects are binary, so they can only take the values of "yes" (provided) or "no" (not provided). The following is an exemplary vignette (the variable aspects are highlighted in bold):

> If you build your house with RAC, you will receive a grant, which covers **half of the extra expenses** for RAC compared to conventional concrete (**50 %**). Your building permit using RAC will **not be treated with priority** by the municipality. You will receive **free technical assistance** or counsel from the municipality regarding the application of RAC. If you build with RAC, the city **will publicly recognize** you and your house (e.g., through an award or a posting on the website or in the newspaper).

The question following the vignette is how likely participants are to choose RAC under these conditions. The answer scale ranges from 0 ("extremely unlikely") to 100 ("extremely likely").

With four varying aspects, one with four and the other with two levels, 32 vignettes can be created. To avoid cognitive fatigue, only one vignette is presented to every participant. The study by Auspurg et al. (2009) finds that the first judgment is reliable and is confirmed by the following in the case of several vignettes per respondent. This result speaks to the validity of presenting only one vignette. The vignettes are selected based on the principle of random selection from an urn without replacement. This ensures that each vignette is presented to a roughly equal number of participants.

For details on the pilot study and the survey administration, please refer to Part II.

3.2 Analysis

The data are analyzed using the following linear regression model:

$$\text{likelihood to choose RAC} = \beta_0 + \beta_1 \text{ grant} + \beta_2 \text{ prioritization} + \beta_3 \text{ assistance} + \beta_4 \text{ recognition} + \beta_5 \text{ information} + \beta' Z_i + \epsilon$$

where β_0 is the constant, β_{1-5} are the coefficients belonging to the policy instruments, and Z_i is a vector of the respondents' individual characteristics. Finally, ϵ is the error term. The model is conceptualized as an ordinary least squares regression and analyzed using the statistical software *Stata*. Since our sample has different subgroups, we are likely to face heteroscedasticity. This is tested using White's test for homoskedasticity against unrestricted forms of heteroskedasticity (White, 1980). We find different error term variances in the regression models that combine all three client groups and, therefore, apply standard errors robust to heteroscedasticity. These are known as the Huber/White/sandwich estimate of variance (Huber, 1967; White, 1980). While White's test does not indicate the presence of heteroscedasticity in all regression models, we opt for robust standard errors in all regressions for a conservative approach.

4 Results

All in all, 1587 construction clients took part in our survey, of which 758 completed it. The factorial survey is answered by 802 respondents. 11 %, 47 %, and 42 % of those are developers, organizations, and private individuals, respectively. The groups in our sample are representative of the respective groups in the population of construction clients. For details on the sample, the interested reader is directed to our preceding article (see Part II).

In the baseline specification with only the policy instruments as independent variables and all three client groups taken together, four of the five instruments have a positive and significant effect on the likelihood of choosing RAC (see model (1) in Table III.1). These are the financial grant, the building permit being treated with priority, free technical assistance, and information provision. Being publicly recognized or promoted when building with RAC does not seem to affect the overall sample. Thus, four (H1.1, H1.2, H1.3, H1.5) of our five hypotheses are confirmed regarding the entire sample of construction clients. Comparing the general likelihood of the three groups to choose RAC, we find our hypothesis (H2) confirmed. Developers and organizations are generally more likely to choose RAC than private individuals. The difference to developing companies is nearly twice as large as the difference to organizations: The mean likelihood to choose RAC is 12 and 7 percentage points (pp) higher for developers and organizations than for private individuals, respectively[48].

For the specific mix of market failures at work in the case of RAC (environmental externalities and information asymmetry), the combination of a financial incentive and an information-based instrument has been proposed. Information provision has been claimed to be "rather a complement than a substitute to economic policy instruments if one strives for more substantial changes in behaviour" (Mandell & Wilhelmsson, 2011, p. 16). Therefore, we also test the effectiveness of the grant and the provision of information in combination. To do so, we include an interaction term of these two variables in our regression model. Model (2) in Table III.1 shows the results. The estimated coefficient is negative, meaning that the effect of information decreases with an increasing grant. Table III.2 gives the corresponding marginal effects. As can be seen, respondents who receive information and are not offered any grant are almost 13 pp more likely to choose RAC than respondents who do not receive any information and are not offered a grant. This effect is reduced when information is combined with a grant. Given a grant covering 50 % of the additional costs of RAC compared to NAC, individuals who receive the information are 8.5 pp more likely to choose RAC than those who do not. The effect declines to 4 pp when a grant of 100 % is offered. Finally, at the maximum value of the grant, when the additional costs are more than compensated for, the effect of information seems to vanish completely (and the effect becomes insignificant).

[48] The groups score mean values of 62 (private individuals), 69 (organizations), and 75 (developers) on a scale from 0 ("extremely unlikely") to 100 ("extremely likely").

Table III.1: Main regression results

	(1)	(2)
Grant	0.203^{***}	0.250^{***}
	(0.0180)	(0.0258)
Prioritization	7.221^{***}	7.326^{***}
	(1.949)	(1.943)
Assistance	8.297^{***}	8.188^{***}
	(1.962)	(1.955)
Publicity	1.400	1.646
	(1.956)	(1.950)
Information	6.151^{**}	12.97^{***}
	(1.963)	(3.473)
Information x Grant		-0.0902^{*}
		(0.0358)
Client groups[49]		
Developers	12.28^{***}	12.33^{***}
	(3.094)	(3.077)
Organizations	6.614^{**}	6.805^{**}
	(2.109)	(2.102)
_cons	36.48^{***}	32.83^{***}
	(2.878)	(3.206)
N	802	802

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using the ordinary least squares estimator.
The dependent variable is the likelihood to choose RAC.

Table III.2: Marginal effects of the provision of information for different levels of a grant

Grant	Marginal effect of information provision
0 %	12.97^{***}
50 %	8.46^{***}
100 %	3.95^{+}
150 %	− 0.56

When examining the client groups separately, differences between them become apparent (see Table III.3). In the group of developers, all coefficients of the policy instruments show a positive sign. However, only the financial grant and information provision have a statistically significant effect on their likelihood of choosing RAC. Note that in the case of information provision, the coefficient is only marginally significant. In contrast, all instruments positively and significantly affect the group of organizations. Finally, in the group of private individuals, the financial grant, prioritized treatment, and technical assistance have a positive and significant effect. The coefficient for being publicly recognized when building with RAC even has a negative sign, although this effect is not statistically significant. Including the interaction term

[49] Private individuals are the base category.

of a financial grant and information does not notably change these results. The interaction term itself is only significant in the group of organizations. The results including the interaction term can be found in Table III.A.1 in the appendix.

Table III.3: Regression results for separate client groups

	(1) Developers	(2) Organizations	(3) Private Individuals
Grant	0.200***	0.164***	0.246***
	(0.0438)	(0.0262)	(0.0285)
Prioritization	1.778	5.948*	9.982**
	(5.474)	(2.754)	(3.154)
Assistance	7.090	7.359**	9.380**
	(5.310)	(2.776)	(3.160)
Publicity	1.784	5.664*	– 3.409
	(5.507)	(2.767)	(3.160)
Information	10.14^{+}	6.720*	4.706
	(5.357)	(2.789)	(3.151)
_cons	50.00***	44.74***	34.42***
	(7.720)	(3.868)	(4.024)
N	87	378	337

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using the ordinary least squares estimator.
The dependent variable is the likelihood to choose RAC.

Table III.4 shows the marginal effects of changes in the policy instruments on the likelihood of choosing RAC in the overall sample and in the separate client groups. Marginal effects are only calculated for the statistically significant effects. An increase of 50 pp in the financial grant has the biggest effect on the group of private individuals: It increases their likelihood of choosing RAC by 6 pp, confirming our respective hypothesis (H3.1). The lowest effect, with an increase of 4 pp, is found in the group of organizations. The incentive of being prioritized regarding one's building permit also has a larger effect on private individuals (10 pp) than organizations (6 pp). Thus, the responsiveness of the client groups differs indeed (H3.2), with private individuals showing the greatest effect, followed by organizations. At the same time, developing companies do not seem to respond to a prioritized permitting process at all. Although smaller, this same pattern is observed for the incentive of free technical assistance (9 vs. 7 pp for private individuals and organizations, respectively). This aligns with our expectation that these two groups respond more to this incentive than developers (H3.3), whose likelihood to choose RAC does not seem to be affected by it. The publicity incentive, which is only found to be effective for organizations, increases their likelihood of choosing RAC by 6 pp. This finding only partly confirms our hypothesis regarding this incentive (H3.4) since we also expected developers to respond to it. Finally, information provision has the most considerable effect in the group of developing companies (10 pp) followed by organizations (7 pp), while it seems not to be influential in the group of private individuals. Given that we expected to find the opposite pattern (private individuals responding most and developing companies responding least to information), our final hypothesis (H3.5) is not confirmed.

Table III.4: Marginal effects of changes in the incentives

	Overall	Developers	Organizations	Private individuals
Grant (+ 25 pp)	+ 10.16	+ 10.00	+ 8.21	+ 12.32
Prioritization (no/yes)	+ 7.22	–	+ 5.95	+ 9.98
Assistance (no/yes)	+ 8.32	–	+ 7.36	+ 9.38
Publicity (no/yes)	–	–	+ 5.66	–
Information (no/yes)	+ 6.32	+ 10.14	+ 6.72	–

RAC = recycled aggregate concrete, pp = percentage points

In the discrete choice experiment in our earlier work (see Part II), we find that the propensity to choose RAC over NAC is positively influenced by a high valuation of sustainability in construction, feeling responsible for considering sustainability in one's project, and familiarity with RAC. Table III.5 shows that this result only holds for the case of valuing sustainability in the factorial survey: All else being equal, respondents who rank sustainability higher as a criterion in construction are more inclined to choose RAC. Feeling responsible for considering it or being familiar with the material does not seem to influence the choice.

For the influence of socio-demographic variables in the separate client groups, the interested reader is referred to Table III.A.2, Table III.A.3, and Table III.A.4 in the appendix.

Finally, we run a series of robustness checks to validate the above results (see Table III.A.5 in the appendix). First, the model is run on subsamples that exclude extremely fast respondents based on different criteria. These are provided by the software SoSci Survey (Leiner, 2021). In models (2) and (3), respondents with a value of more than 100 and 50, respectively, on the indicator DEG Time are excluded. These values represent thresholds above which data can be classified as of lower quality, denoting two different strictness levels. 46 and 135 respondents are excluded, respectively. Another indicator offered by the software is a relative speed index (Time RSI), a more elaborate measure. Using it as an inclusion criterion, 43 respondents are excluded (see model (4)). In model (5), the subsample consists of only those respondents who finish the entire survey, resulting in 46 respondents dropping out. Finally, two more robustness checks concerning the effect of information provision are carried out. They exclude participants who stay on the information page for an unusually short time. The first criterion excludes participants who spend less time on the information page than one standard deviation below the median time spent. This removes 35 participants from the sample (see model (6)). The second criterion is based on reading speed and identifies respondents who are unlikely to have read the entire text in the time spent on the respective page based on average reading times[50]. This applies to 143 cases (see model (7)). Overall, Table III.A.5 in the appendix shows no meaningful differences between the baseline model and the robustness checks, so the results reported above can be considered robust.

[50] A threshold value of 40 seconds is calculated using the upper end of the adult average reading time (350 words per minute).

Table III.5: Regression results with individual characteristics

Grant	0.191^{***}
	(0.0179)
Prioritization	7.098^{***}
	(1.951)
Assistance	6.622^{***}
	(1.979)
Publicity	0.649
	(1.949)
Information	5.712^{**}
	(1.969)
Client groups	
Developers	9.808^{**}
	(3.246)
Organizations	4.393^{+}
	(2.250)
Sustainability	0.234^{***}
	(0.0442)
Familiarity	1.766
	(2.077)
Responsibility	3.560
	(2.354)
_cons	19.61^{***}
	(4.216)
N	770

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using the ordinary least squares estimator.
The dependent variable is the likelihood to choose RAC.

5 Discussion

Our results show that all tested instruments effectively increase the likelihood of choosing RAC in at least one of the client groups. Only one of the instruments is effective in all three groups: the financial grant. In earlier research (see Part II), we find that construction clients have a positive WTP for RA, but this WTP does not equal the price premium currently seen for RAC. Moreover, additional costs are found to be a nontrivial barrier in that study, and we see only minor differences between the groups in this respect. Thus, additional costs of RAC can generally be considered an issue among construction clients, which explains why a grant covering (a part of) these costs is effective in all three groups. This also aligns with previous research on sustainable construction finding that financial incentives are a critical driver for clients (e.g., Adams et al., 2017; Pitt et al., 2009) and the preferred policy incentive for GB among potential homebuyers (Portnov et al., 2018).

A prioritized permitting process and free technical assistance when using RAC is found to be effective only for organizations and private individuals. On the one hand, it surprises that developers are not found to be responsive to reduced processing time for their building permits. Being professional construction clients, they have the highest potential in terms of saved time. On the other hand, developers are less dependent on the permit to continue their work since they most likely have several construction projects simultaneously. Organizations and private individuals, in contrast, typically only commission a building occasionally or even just once in their lives. Thus, every day without a permit is a day that they cannot proceed. Because these two groups are not regularly involved in constructing buildings, they lack the expertise and technical knowledge developers are likely to have. Therefore, it is in line with expectations that they are responsive to free technical assistance, while developers are not. The incentive of being publicly promoted when using RAC is only found to be effective in the group of organizations. We expected this outcome for the same reason that we did not expect it for the group of private individuals: Organizations, unlike private individuals, depend on their image and reputation for economic survival. However, this also applies to developers. As Diyana et al. (2013) pose in their model of motivators for developers to engage in GB, one important factor is their image. This factor encompasses two motivational aspects: green certifications and awards and recognition. These are considered to increase developers' reputation and competitiveness. Our earlier work (see Part II) supports this view: Developers (as well as organizations) are driven to use RAC by its positive effect on their image. It is, therefore, somewhat surprising that this incentive does not seem to affect developing companies. Ariely and his colleagues (2009) find a crowding-out effect of extrinsic motivators, such as financial incentives, on people's image motivations. In other words, behaving pro-socially out of image considerations can be impeded when publicly incentivized for that behavior. If that were the case here, we would expect to find an interaction effect of the promotion incentive and the financial grant. However, after running the respective regression, we conclude that this is not the case[51]. It remains an open question to study under which conditions image incentives are effective, especially for developers.

Information provision is the final instrument we test in terms of its effectiveness. Organizations are positively influenced by the information on RAC we provide but an even larger effect of information is found in the group of developers. However, we will interpret the latter with caution since the respective result is only marginally significant. We do not find any effect of information in the group of private individuals. This group is arguably the one least informed about RAC. Only 23 % had heard of the material before participating in the survey (compared to 66 and 64 % in the groups of developers and organizations, respectively). Therefore, we expected to find the largest effect of information in this group, while the opposite is true. A potential explanation for why our study's information provision is not effective in all groups is linked to its form and timing. Firstly, it is conceivable that other forms of information provision, such as visual material, are more effective than plain text. Secondly, it could be that the time between receiving the information and potentially acting on it is too short to internalize its meaning. Finally, being exposed to the information repeatedly – instead of just once –is likely to have a more extensive and sustained effect. While these reasons would apply equally to all groups, it could be that the groups' different levels of pre-knowledge acted as moderators. Potentially, our information treatment is not strong enough to affect the clients who were unaware of RAC before the survey but serves as a reminder to those who already had some pre-knowledge. Further research should investigate under which conditions information provision is most likely to be effective, and the role pre-knowledge plays in this relationship.

This analysis shows that incentives offered to different types of clients should be chosen selectively to optimize efficiency and cost-effectiveness. The exception is a financial grant, which would stimulate all clients to choose RAC. Beyond that, one could consider offering

[51] The results are available from the authors upon request.

information to developers and a prioritized permitting process and/or technical assistance to private individuals. Although all tested incentives would increase organizations' likelihood of choosing RAC, offering them all at once may not be realistic. If one must choose, free technical assistance and provision of information are good candidates as they exhibit the strongest effect. Another perspective is to start with the selection of the client group to target. If one had to select only one group for a financial grant, choosing private individuals would yield the highest effect size among the three groups. A look at the number of building permits granted to the three groups would support this choice since private individuals account for roughly five times as many permits as organizations and developers. However, the floor space and cubic content of the buildings by organizations exceed those by private individuals and developers by far (Destatis, 2022a). This is unsurprising, considering private individuals mainly build one-family dwellings while organizations construct office buildings or warehouses. An approximation of the amount of concrete used by these groups, which is not readily available, would be necessary to conclude which group a grant would have the most considerable effect on in terms of environmental impacts.

To tackle the combination of environmental externalities and information asymmetry, a mix of a financial incentive and an information-based instrument is recommended. Interestingly, the provision of information has shown to become less effective with increasing financial grants. When a grant exceeds the additional costs of RAC compared to NAC, information does not seem to affect the probability of choosing RAC. This finding contradicts the common expectation that a combination of incentives and information is more effective than the sum of the individual instruments, especially in the case of pro-environmental behavior (e.g., Stern, 1999). Rosenow et al. (2016) categorize the interactions of single policy instruments into *complementary* (the effect of the combination is larger than the summed effects of the instruments individually), *neutral* (the effect of the combination is equal to the summed effects of the instruments individually), and *overlapping* (the effect of the combination is smaller than the summed effects of the instruments individually). They state that "information measures have a reinforcing impact on all other policy types" (p. 8), referring to a complementary interaction. One example of these other policy measures the authors name is a financial grant, as used in our study. In contrast to this expectation, we find an overlapping interaction effect. Another study proposing this instrument combination is by Bryan and Kandulu (2011), who develop an optimal policy mix using deliberative multi-criteria evaluation in a case study involving measures against water pollution. According to the authors, a mix is especially promising when multiple factors impede the adoption of the desired behavior, as is the case for the demand for RAC. In their case, the optimal mix consists of information provision, followed by incentives and then regulation. This sequence (exempt from the regulation) is also present in our study[52]. However, the time between the information and the incentive is much smaller than it is intended to be in real-life situations.

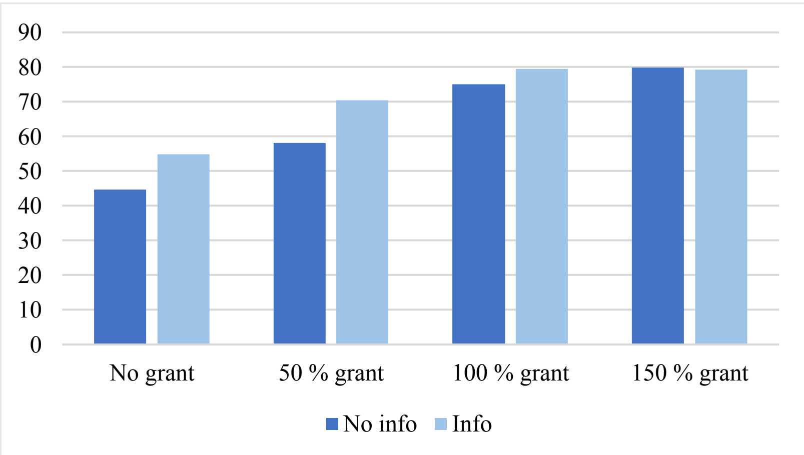
Drews et al. (2020) categorize possible interaction effects of incentives and nudges[53] into *positive synergy* (equivalent to a complimentary interaction by Rosenow et al. (2016)), *no synergy* (equivalent to a neutral interaction), *weak negative synergy* (equivalent to an overlapping interaction), and *backfire* (the effect of the combination is smaller than the effect of one of the instruments individually). The researchers stress that it is only possible to determine which effect is present when all four possible treatments (i.e., incentive only, nudge

[52] Respondents, after being assigned to the treatment or control group, do or do not receive the information text, then complete a discrete choice experiment and then the factorial survey, which presents the other policy instruments. For details, see section 3.1.

[53] Nudges are "interventions in the choice environment to induce behavioural change without reducing freedom of choice or altering economic incentives" (Drews et al., 2020, p. 1).

only, neither, both incentive and nudge) are tested. Due to the experimental nature of the factorial survey, we cover all possible combinations in our study. Figure III.1 shows the results, including all three levels of a potential grant. As can be seen, we are dealing with a weak negative synergy, as the combination of the grant and information is larger than each instrument alone but does not equal or even exceed the sum of their individual effects[54]. The authors offer an explanation for weak negative synergies that we have already introduced above: crowding out of motivation. As applied to our case, our study's information offers intrinsic motivation based on environmental consciousness. In contrast, the financial grant is a classic extrinsic motivator. Motivational crowding-out "refers to the idea that a monetary incentive weakens […] any intrinsic motivation an individual has for undertaking an action" (Drews et al., 2020, p. 3). This explanation is supported by the fact that information is found to decrease in effectiveness the higher the financial grant. Thus, our results suggest that a financial grant tends to diminish the positive effect of environmental consciousness (raised through information about RAC's environmental advantages) on clients' likelihood to choose RAC. Because these incentives, especially a financial grant, are likely only offered temporarily, it is essential to consider what happens after it is removed. If motivational crowding-out is indeed at work in this case, the intrinsic motivation may not recover but remain at a lower level (Drews et al., 2020). In line with our findings, Portnov et al. (2018) find a financial incentive to harm their respondents' WTP for green buildings. A crowding-out effect is one of the potential explanations the authors offer. In conclusion, combining a (high) financial grant and information should be carefully considered. This aligns with previous research that advocates for the deliberate coordination of instrument mixes (Bennear & Stavins, 2007a; J. Zhang et al., 2019).

Figure III.1: Effects of information provision and financial grants of different extents



The y-axis shows the likelihood of choosing RAC.

The results regarding differences between client groups suggest that developers and organizations are more likely to choose RAC than private individuals. This is the pattern we also observe in our earlier work (see Part II). This difference can partly be ascribed to the differences between the groups in the valuation of sustainability as a criterion in construction. Developers and organizations both score higher than private individuals in this regard[55], and the differences are statistically significant[56]. Controlling for sustainability renders the difference

[54] If the marginal effect of information in the case of a grant of 150 % was statistically significant, we would face backfire. However, because it is not, we are dealing with a weak negative synergy (see Table III.2).
[55] Developers: 74.95, organizations: 78.0, private individuals: 68.95
[56] Developers vs. private individuals: $t(419) = 1.9$, $p = .0029$; organizations vs. private individuals: $t(708) = 4.77$, $p = .000$

between organizations and private individuals only marginally significant (see Table III.5). However, the difference between developers and private individuals remains strong, even when additionally controlling for familiarity and responsibility. Especially regarding familiarity with the material, there are substantial differences between these two groups: Only 23 % of private individuals but 66 % of developers had heard of RAC before. Nevertheless, this does not seem to influence the likelihood of choosing RAC (see Table III.5). This aligns with the finding that information provision is effective for developers but not for private individuals. The results suggest that awareness of RAC does not influence the likelihood of choosing it. However, this contrasts our findings in previous work, where familiarity and responsibility positively influence the likelihood of choosing RAC and the WTP for it (see Part II). This suggests that the format of the question might have influenced the results in this regard. Future research should investigate this effect further.

6 Conclusion

RAC offers a way to reduce the extraction of natural resources as well as the generation of construction and demolition waste. While construction clients are willing to pay more for RA in concrete, there is still a gap between their WTP and the current price premium. Market failures in the form of environmental externalities and information asymmetries are at work here. Therefore, policy instruments are necessary to increase the demand for RAC among construction clients. This study seeks to investigate which instruments could be effective in this regard. The results show that one client group, organizations, is responsive to each of the tested instruments – a financial grant, an expedited permitting process, free technical assistance, public recognition and promotion, and information provision. Only a financial grant is effective in all three groups. The recommended combination of a financial incentive and information provision is effective but should be implemented with care. The effect of information vanishes once the financial incentive turns into a bonus such that it exceeds the additional costs of RAC compared to NAC. Developers are the most likely to choose RAC, followed by organizations and private individuals. Finally, understanding sustainability as an important criterion in construction increases this likelihood.

Through this paper's results, it has become clear that it is inefficient to offer policy instruments to all construction clients equally (except for the case of a financial grant). Instead, different client groups should be targeted using different instruments. Moreover, a policy mix, especially including a financial incentive and information provision, should be coordinated carefully to avoid inefficiencies. The design and provision of policy instruments always depend on the authorized bodies' available resources. Even so, the current results might offer guidance on where the resources are spent most efficiently. In addition, this study shows that non-financial incentives involving little to no costs can also be effective instruments to stimulate the use of recycled construction material. The results can help municipalities select the most efficient and cost-effective subset of instruments in their endeavor to support resource-efficient construction.

7 Appendix

Table III.A.1: Regression results for separate client groups including interaction term

	(1) Developers	(2) Organizations	(3) Private Individuals
Grant	0.256^{***}	0.233^{***}	0.260^{***}
	(0.0681)	(0.0374)	(0.0415)
Prioritization	2.402	6.140^{*}	9.974^{**}
	(5.388)	(2.735)	(3.156)
Assistance	7.149	6.999^{*}	9.385^{**}
	(5.329)	(2.752)	(3.164)
Publicity	2.092	5.799^{*}	– 3.283
	(5.470)	(2.744)	(3.178)
Information	18.46^{+}	16.54^{***}	6.744
	(9.852)	(4.915)	(5.464)
Information x Grant	– 0.111	-0.130^{*}	– 0.0269
	(0.0827)	(0.0522)	(0.0574)
_cons	45.36^{***}	39.80^{***}	33.33^{***}
	(9.107)	(4.349)	(4.699)
N	87	378	337

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using the ordinary least squares estimator.
The dependent variable is the likelihood to choose RAC.
RAC = recycled aggregate concrete

Table III.A.2: Regression results with socio-demographic variables (developers)

	(1)	(2)	(3)
Grant	0.200***	0.203***	0.205***
	(0.0438)	(0.0429)	(0.0466)
Prioritization	1.778	1.525	2.280
	(5.474)	(5.512)	(6.521)
Assistance	7.090	4.533	4.821
	(5.310)	(5.302)	(5.953)
Publicity	1.784	3.751	0.789
	(5.507)	(5.264)	(5.766)
Information	10.14+	10.27+	9.253
	(5.357)	(5.418)	(6.277)
Role of sustainability		0.293+	0.289
		(0.151)	(0.174)
Sustainability goals		5.476	6.765
		(6.151)	(7.336)
Founding year			0.0613
			(0.0948)
Yearly turnover			– 2.861
			(7.376)
Employees			6.605
			(7.766)
_cons	50.00***	20.47	– 103.9
	(7.720)	(20.63)	(180.1)
N	87	84	75

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using the ordinary least squares estimator.
The dependent variable is the likelihood to choose RAC.

Table III.A.3: Regression results with socio-demographic variables (organizations)

	(1)	(2)	(3)
Grant	0.164^{***}	0.157^{***}	0.157^{***}
	(0.0262)	(0.0266)	(0.0299)
Prioritization	5.948^{*}	5.680^{*}	6.574^{*}
	(2.754)	(2.766)	(3.161)
Assistance	7.359^{**}	6.660^{*}	6.402^{*}
	(2.776)	(2.784)	(3.224)
Publicity	5.664^{*}	5.237^{+}	5.601^{+}
	(2.767)	(2.783)	(3.255)
Information	6.720^{*}	6.023^{*}	6.836^{*}
	(2.789)	(2.812)	(3.268)
Role of sustainability		0.232^{**}	0.185^{*}
		(0.0770)	(0.0847)
Sustainability goals		1.939	3.878
		(3.092)	(3.608)
Type of business			
Non-profit			– 2.870
			(5.109)
Public			– 4.355
			(5.913)
Founding year			– 0.0103
			(0.0160)
Yearly turnover			4.758
			(5.449)
Employees			– 3.717
			(5.511)
_cons	44.74^{***}	25.85^{**}	46.32
	(3.868)	(9.924)	(35.41)
N	378	360	286

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using the ordinary least squares estimator.
The dependent variable is the likelihood to choose RAC.

Table III.A.4: Regression results with socio-demographic variables (private individuals)

	(1)	(2)
Grant	0.246^{***}	0.244^{***}
	(0.0285)	(0.0303)
Prioritization	9.982^{**}	10.91^{***}
	(3.154)	(3.277)
Assistance	9.380^{**}	9.031^{**}
	(3.160)	(3.268)
Publicity	– 3.409	– 3.888
	(3.160)	(3.220)
Information	4.706	5.521^{+}
	(3.151)	(3.244)
Male		– 4.406
		(3.281)
Age		4.819
		(3.720)
Graduate degree		7.736^{*}
		(3.558)
Household income		– 3.650
		(3.743)
Children		3.824
		(3.651)
_cons	34.42^{***}	30.41^{***}
	(4.024)	(5.373)
N	337	309

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using the ordinary least squares estimator.
The dependent variable is the likelihood to choose RAC.

Table III.A.5: Robustness checks

	(1) Baseline	(2) DEG Time 100	(3) DEG Time 50	(4) Time RSI	(5) Finished	(6) Info Time (SD)	(7) Info Time (wpm)
Grant	0.203^{***}	0.204^{***}	0.223^{***}	0.213^{***}	0.202^{***}	0.205^{***}	0.213^{***}
	(0.0180)	(0.0183)	(0.0186)	(0.0180)	(0.0185)	(0.0182)	(0.0194)
Prioritization	7.221^{***}	7.008^{***}	6.814^{***}	7.441^{***}	5.977^{**}	7.766^{***}	7.723^{***}
	(1.949)	(1.993)	(2.037)	(1.974)	(1.993)	(1.979)	(2.143)
Assistance	8.297^{***}	8.059^{***}	8.500^{***}	8.679^{***}	8.312^{***}	8.266^{***}	6.925^{**}
	(1.962)	(2.005)	(2.038)	(1.985)	(2.001)	(1.995)	(2.145)
Publicity	1.400	1.024	1.639	1.632	1.707	1.106	1.348
	(1.956)	(2.002)	(2.033)	(1.976)	(1.996)	(1.989)	(2.150)
Information	6.151^{**}	6.971^{***}	5.608^{**}	5.215^{**}	6.648^{***}	6.774^{***}	8.635^{***}
	(1.963)	(2.011)	(2.046)	(1.990)	(2.002)	(1.984)	(2.150)
Client groups							
Developers	12.28^{***}	10.47^{**}	8.602^{**}	11.68^{***}	10.85^{***}	10.88^{***}	9.709^{**}
	(3.094)	(3.178)	(3.281)	(3.102)	(3.124)	(3.190)	(3.454)
Organizations	6.614^{**}	5.105^{*}	3.756^{+}	5.977^{**}	5.574^{*}	5.644^{**}	5.342^{*}
	(2.109)	(2.174)	(2.217)	(2.142)	(2.159)	(2.148)	(2.316)
_cons	36.48^{***}	38.01^{***}	39.17^{***}	36.81^{***}	37.95^{***}	36.82^{***}	37.03^{***}
	(2.878)	(3.000)	(3.112)	(2.919)	(3.008)	(2.918)	(3.041)
N	802	756	667	759	756	767	659

Standard errors in parentheses

$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Results obtained using the ordinary least squares estimator.

The dependent variable is the likelihood to choose RAC.

RSI = relative speed index, SD = standard deviation, wpm = words per minute

Part IV

Citizens' Acceptance of Sustainable Public Construction in Their Municipality

Citizens' Acceptance of Sustainable Public Construction in Their Municipality

Ellen Sterk, Morten Endrikat & Dmytro Katerusha

Abstract

Green public procurement of construction activities has the potential to reduce a municipality's environmental footprint significantly. Moreover, it is likely to positively affect citizens' implementation of green building practices. However, the degree of citizens' acceptance of sustainable building by their municipality remains unstudied, as do the factors that influence it. Through a survey in four German municipalities, this study investigates public acceptance of sustainable public construction in its two dimensions: attitude and action. The findings consistently reveal positive attitudes driven by trust in the municipality and the perception of personal and social benefits. As anticipated, costs negatively impact citizens' attitudes. Despite these generally positive attitudes, only specific segments of the public demonstrate a willingness to support sustainable public construction actively. Citizens' willingness to participate is affected by the type of action, their age, and their level of interest and knowledge in sustainability and construction. In contrast, additional costs and the type of building in question do not appear to have an effect. The use of the default effect is shown to have the potential to enhance the behavioral dimension of public acceptance. Implications for government institutions and suggestions for further research are provided.

JEL classification: L74, L78, R50

Keywords: Green Public Procurement, Sustainable Construction, Public Acceptance, Discrete Choice Experiment, Factorial Survey

1 Introduction

Public procurement represents a significant portion of governmental expenditures. In member states of the Organization for Economic Cooperation and Development (OECD), it accounts for nearly 30 % of total government spending and almost 14 % of the gross domestic product (GDP) on average (OECD, n.d.). In Germany, the construction sector is the primary beneficiary of public tenders, being granted over a third of all contracts, second only to electricity and other energy sources in terms of economic value (Chiappinelli & Zipperer, 2017). Having invested roughly 58 billion EUR in the construction industry in 2022 (Hauptverband der Deutschen Bauindustrie e.V., 2023a), the government is considered to be the largest construction client in Germany (e.g., Hinzmann et al., 2019). Given its significant share and environmental impact, the construction industry offers significant potential to reduce the environmental footprint of public procurement activities (e.g., Fischer & Küper, 2021). So-called *green public procurement* (GPP) can be understood as "a process whereby public authorities seek to procure goods, services and works with a reduced environmental impact throughout their life cycle when compared to goods, services and works with the same primary function that would otherwise be procured" (European Commission, 2008, p. 4). The European Commission designated the construction industry as a critical sector for GPP approximately 15 years ago (European Commission, 2008). More recently, the Circular Economy Initiative in Germany recommends that public institutions lead by example through GPP to establish circular business models (Hansen et al., 2021). Several European nations, such as the Netherlands, Finland, Germany, and Slovenia, have established regulations or objectives to stimulate the procurement of environmentally sustainable products (Ferrer, 2020). However, the implementation of GPP is lacking in many cases. For example, in Germany, only 2.4 % of public tenders in 2015 included environmental criteria, and the share is even lower for operations such as construction works (Chiappinelli & Zipperer, 2017). The (perceived) necessity to invest both effort and financial resources as well as an information deficit are some of the main barriers that government institutions face (Chiappinelli & Zipperer, 2017; Fischer & Küper, 2021; Zu Castell-Rüdenhausen et al., 2021).

Due to the extent and visibility of construction activities commissioned by the government, its responsibility as a role model and pioneer in this regard is often emphasized (e.g., Dechantsreiter et al., 2015; Hinzmann et al., 2019; Ruiz Durán et al., 2019). The Federal Ministry for Housing, Urban Development and Building in Germany also avows itself to this role model function. It aims to contribute to the country's building culture through its guidelines on sustainable construction[57] (BMWSB, n.d.). Researchers appeal to government institutions to publish neutral tenders allowing for the use of recycled building material, to include environmental criteria, and to consider environmental externalities in their tenders (Chiappinelli & Zipperer, 2017; Dechantsreiter et al., 2015; Hinzmann et al., 2019). In addition to directly decreasing the environmental impact of public procurement in construction, such efforts might also induce indirect outcomes. Firstly, since public demand serves as a quality signal, it could influence public opinion by shaping awareness and reinforcing acceptance of and interest in sustainable construction. Secondly, secure demand from government institutions could create investment securities for producers and contribute to price reductions through scale and learning effects (Chiappinelli & Zipperer, 2017; Fischer & Küper, 2021; Franco et al., 2021; Wagner et al., 2022). As such, GPP is vital in promoting business model creation for the circular economy (Zu Castell-Rüdenhausen et al., 2021).

[57] Leitfaden Nachhaltiges Bauen – Zukunftsfähiges Planen, Bauen und Betreiben von Gebäuden. Bundesministerium des Innern, für Bau und Heimat (BMI), www.bundesregierung.de/breg-de/suche/nachhaltiges-bauen-2156224

Public institutions' purpose is to serve the citizens under their government. Therefore, the public interest must be considered in addition to the environmental rationale and duty as a role model for sustainable building procurement. In the context of local construction, this means that government authorities should commission construction projects that align with their citizens' preferences and needs. In this paper, we concentrate on municipalities as they account for a major share of public investments in the German construction sector, precisely 59 %[58] (Hauptverband der Deutschen Bauindustrie e.V., 2023a). Environmental considerations, amplified through government bodies' role model position, clearly point towards building sustainably as a municipality. However, it is not necessarily clear whether the citizens' interests align with this direction for public construction. As Zhao et al. (2015) highlight, public sentiment toward sustainable construction can impact its implementation, yet there is limited research on citizens' perceptions of this matter. This study aims to fill this research gap by investigating the public acceptance of sustainable public construction in the municipality and the associated influential factors. Accordingly, the research question is the following:

To what extent are citizens accepting of sustainable public construction in their municipality?

We define sustainable public construction as construction projects commissioned by government bodies (i.e., the state, federal states, and municipalities), which are executed in a way that satisfies the needs of the current generation while preserving the possibility of future generations to fulfill theirs (Brundtland, 1987). Our focus is on buildings commissioned by the municipality and accessible to all citizens. Examples of such buildings include hospitals, town halls, schools, and fire stations. We conduct a survey employing a combination of a factorial survey and a discrete choice experiment (DCE) among citizens from four German municipalities. We find acceptance, especially regarding a positive attitude, while only some segments of the public are willing to act. Their trust in the municipality, their perception of benefits and drawbacks, and associated costs influence the level of acceptance among citizens. Finally, the *default effect* (i.e., a higher rate of compliance with the option portrayed as the default) appears promising for promoting acceptance. The paper is organized as follows: Chapter 2 provides a comprehensive review of the literature on citizens' involvement, their level of acceptance, and relevant influencing factors. This review serves as a basis for deriving the hypotheses of this study. Chapter 3 presents the applied research methodology, followed by the results in Chapter 4. These are further discussed in Chapter 5, with Chapter 6 serving as the conclusion of this paper.

2 Literature Review and Hypotheses

Since the public is, by definition, affected by public construction projects, it can be seen as a stakeholder that should be involved in the respective decision-making processes. For example, Lam and his colleagues (2010) survey construction stakeholders in Hong Kong to identify success factors for implementing green specifications in construction and find that stakeholder involvement is among the most crucial. Similarly, Valdes-Vasquez and Klotz (2013) develop a framework of processes for social sustainability in construction projects and point to the relevance of stakeholder involvement in achieving this objective. In a practical guide, the authors illustrate this through actions such as engaging the final and temporary users and involving the community. A group of various experts ranks stakeholder involvement as the most critical process in the planning and design stages, closely followed by user considerations

[58] Federal states and the general government account for 19 % and 22 %, respectively.

(Valdes-Vasquez and Klotz, 2013). Although these processes are often considered within the context of private construction projects, they are also applicable in public ones, where the users are members of the public. These end users' attitudes have been shown to play a critical role in promoting green building (GB; Zuo & Zhao, 2014). For example, Franco and her colleagues (2021) compare and analyze GB policies in cities and apply their findings in a case study of the Philippines' capital, Manila. Their research highlights local stakeholders' and actors' need for active participation and engagement to complement national policies. However, for support to be achieved, acceptance is a prerequisite (Batel et al., 2013). With the growing prevalence of civic initiatives and protests, it is increasingly essential for the effective execution of political measures to gain public approval (Schubert & Klein, 2018). A report by the European Commission on the topics of recycled construction material states that "circular models require public trust and support" (p. 64) and recommends increasing public outreach and clear communication (Pacheco et al., 2023). This is also a conclusion Greiff (2012) reaches in his analysis of the social dimension of sustainable construction. His study aims to identify social indicators that complement the existing environmental and economic aspects in the first guidelines on sustainable construction by the state[59]. The first of the ten indicators established is public acceptance.

We adopt Dethloff's (2004) definition of acceptance, which posits that acceptance is the positive approval or adoption of an idea, situation, or product. Acceptance goes beyond reactive tolerance as it requires not only a positive valuation but also an active willingness to act. The concept can thus be split into two dimensions: attitude (positive to negative) and action (active to passive). Much research on public acceptance in the field of environmental sustainability has been conducted on renewable energies (e.g., Bertsch et al., 2016; Langer et al., 2018; Sonnberger & Ruddat, 2017). However, there is only limited research on public acceptance of GB, although the topic occasionally arises in studies exploring the barriers to its implementation.

For an attitude or intention to act to be directed towards an object, awareness of it needs to be present. However, awareness is low in the case of GB (e.g., Darko & Chan, 2017; Zhao et al., 2015). Eves and Kippes (2010) survey real estate offices in New Zealand and find that only buyers with a high socioeconomic status possess a strong awareness of environmental issues. Shooshtarian et al. (2020) also identify the lack of stakeholders' familiarity with recycled construction material as a primary barrier to its application. Stakeholders' unfavorable perception, that is, their lack of acceptance towards utilizing recycled products, presents another significant obstacle. Zhao and his colleagues (2015) conduct a literature review and survey citizens to assess the social issues related to GB. They find that the public is largely unaware of the concept of GB. However, upon receiving information about the environmental benefits, there is considerable acceptance and support. In addition, more than 90 % of their respondents state that they would be willing to pay more for green buildings. Several other researchers identify a positive willingness to pay (WTP) for GB – which belongs to the action dimension of acceptance – among stakeholders owning or living in the building (e.g., Khan et al., 2020; Mandell & Wilhelmsson, 2011; Portnov et al., 2018; Wiencke, 2013). However, the level of citizens' acceptance of sustainable public construction in their municipality remains unexplored. Considering that the relationship with public buildings is likely to differ significantly from that with private residences, attitudes and the inclination to act (e.g., contribute financially) may also vary substantially. Notwithstanding, another strand of literature reveals that citizens are willing to pay for the avoidance or reduction of CO_2 emissions through

[59] Leitfaden Nachhaltiges Bauen – Zukunftsfähiges Planen, Bauen und Betreiben von Gebäuden. Bundesministerium des Innern, für Bau und Heimat (BMI), www.bundesregierung.de/breg-de/suche/nachhaltiges-bauen-2156224

policies (e.g., Alberini et al., 2018; Brännlund & Persson, 2010; Longo et al., 2008). Based on the combination of these findings, we hypothesize that citizens accept public GB in both the attitude and the action dimensions. To verify this notion, we study citizens' attitudes toward and willingness to act in favor of sustainable construction in their municipality directly. The following hypotheses guide this part of the research:

H1. Citizens have a positive attitude toward sustainable public construction in their municipality.

H2. Citizens are willing to act in favor of sustainable public construction in their municipality.

While the initial two hypotheses describe the general state of the two components that constitute public acceptance (attitude and willingness to act) of sustainable public construction, the following sections examine potential factors influencing these components, beginning with people's attitudes. It has been argued that trust in responsible organizations affects attitudes toward GB. Rajaee et al. (2019) show that trust in responsible organizations for GB technologies enhances attitudes and intentions toward using these technologies. Franco et al. (2021) argue that transparency and accountability in planning and implementing sustainable construction projects are essential for building citizens' trust, which is critical for acceptance. According to Greiff (2012), involving local citizens in construction projects by informing them about the project and related decisions fosters acceptance and social integration. Perceived benefits and risks are further aspects that influence attitudes. For the case of carbon capture and storage (CCS), Schumann (2015) distinguishes between perceived social and personal risks and benefits. As anticipated, the perceived risks have an adverse impact, whereas the perceived benefits positively affect respondents' initial attitudes towards CCS. Since GB is not typically associated with risks that could harm one's health, we consider drawbacks rather than risks to be the opposite of benefits. Finally, higher costs for sustainable building processes and materials have repeatedly been found to hinder their adoption (e.g., Gan et al., 2015; Lam et al., 2009; Pitt et al., 2009; Shooshtarian et al., 2020). However, these studies concentrate on the direct expenses incurred by construction clients. In the case of public buildings, citizens are only indirectly impacted by additional costs through increased taxes or potentially forgoing other spending on public goods in the municipality. The influence of additional costs on citizens' perception of public buildings remains unclear. This study examines whether these factors influence citizens' attitudes toward sustainable construction in their municipality. The following hypotheses are formulated for this purpose:

H3.1 Trust in their local government positively influences citizens' attitudes toward sustainable public construction in their municipality.

H3.2 Perceiving personal and social benefits/drawbacks positively/negatively influences citizens' attitudes toward sustainable public construction in their municipality.

H3.3 Higher costs of GB negatively influence citizens' attitudes toward sustainable public construction in their municipality.

While the aspects above are thought to primarily impact the attitude dimension of acceptance, others are likely to affect the action dimension. One example is the default effect. Notably, Araña and León's (2013) survey respondents demonstrate a significantly greater WTP for a carbon offsetting scheme when the default option is to contribute compared to when they have to actively opt in. Similarly, a different study finds that when the default option is a green energy contract, and respondents have to opt out actively, purchases of such contracts are nearly tenfold compared to when the default option is a conventional energy contract (Ebeling & Lotz, 2015). Another potential determinant of support for sustainability in public construction is the type of building in question. As the concept of sustainability is intertwined with future generations, the willingness of individuals to behave in an environmentally friendly manner may be influenced by the association of the building with children. Specifically, we hypothesize that citizens are more likely to engage when the building is a school instead of a town hall or a train station. The school represents buildings directly connected to children, whereas the town hall and train station exemplify administrative buildings and other institutional buildings, respectively. In contrast, sustainable construction processes exhibit environmental benefits over conventional ones independent of the building's usage profile. Therefore, if citizens were to act rationally, the type of building ought to have no bearing on their support for sustainable public construction. Finally, it is hypothesized that costs also influence people's willingness to act in favor of sustainable public construction. Some of these factors have not yet been put into the context of GB, and those that have remain untested empirically. The objective of this study is to bridge this gap by examining the following hypotheses:

> **H4.1** Citizens' acceptance of sustainable public construction is higher when the default is sustainable building standards.
>
> **H4.2** Citizens' willingness to act in favor of sustainable public construction in their municipality depends on the type of building to be constructed. It is higher for a school than for a train station or a town hall.
>
> **H4.3** Higher costs of GB negatively influence citizens' willingness to act in favor of sustainable public construction in their municipality.

3 Methods

3.1 Research Strategy and Data Collection

Citizens of four German municipalities (three cities and one district) were surveyed between the end of May and the end of August 2022. The three cities are situated in the south (A), north (B), and west (C) of Germany. Cities A and B are part of a metropolitan region, while city C is near Germany's most extensive urban agglomeration. City B has slightly over 75,000 inhabitants, and City A has close to 95,000 inhabitants, with City C being the most populous at just over 250,000 inhabitants. The district, municipality D, is in the western part of Germany and has a total population of slightly over 300,000 inhabitants.

After giving their consent, respondents are asked some basic socio-demographic questions, followed by a section focusing on sustainability (in construction). They then answer questions regarding their perceptions of trust, perceived benefits and drawbacks associated with sustainable construction within their municipality, and willingness to participate in various formats on the subject. All questions up until this point are item-based. Then, the central and experimental parts of the survey follow: a factorial survey and a DCE. Both will be described in detail in the following. The complete survey transcript can be found in Table IV.A.1 in the appendix.

Factorial surveys depict hypothetical situations and ask participants to indicate the likelihood of exhibiting specific behaviors. Aspects of these situation descriptions (*vignettes*) are varied to determine their influence on the likelihood of the behavior (Rossi, 1951). This study's hypothetical situation is the new construction of a public building in the respondents' municipality. The varied attributes encompass the type of building (school, town hall, or train station[60]), whether sustainable standards[61] are to be applied or not (default effect), and the additional costs associated with these standards (5 %, 10 %, 15 %, 20 %, or 25 %). The respondent is asked to assume that a petition with sufficient signatures can enforce or prohibit the application of sustainable standards (depending on the default option stated). The question then is how likely the respondent is to sign the petition on a scale from 0 ("very unlikely") to 100 ("very likely"). The following is an exemplary vignette (the attributes that are variable are highlighted in bold):

> Imagine the city/district of x is planning to construct a new **train station**. It was decided that the city would **abstain from** using sustainable building standards. For the construction project to **still be executed along** these standards, enough signatures must be collected in a petition. Compared to the conventional way of building, construction following sustainable standards would incur additional costs of **15 %**.

Through the combination of the variable attributes, there are 30 unique vignettes. Each participant was randomly presented with one vignette, drawn from an urn without replacement, to ensure an equal number of presentations and responses for each vignette.

DCEs, based on McFadden (1986), enable the researcher to assess the impact of attributes of different choice options on the probability of being chosen by a respondent. Including the price of the options as an attribute permits the computation of a WTP for the other attributes. The options presented in this DCE correspond to policies that promote the enhancement of sustainability in new public construction projects within the municipality. The policies are characterized by four attributes, one of which is the additional monthly costs imposed on the respondent. These costs can take the values of 3 EUR, 9 EUR, and 15 EUR, collected through duties from all citizens. Firstly, these values align with values from other researchers estimating the WTP for policies targeting environmental improvements (e.g., Alberini et al., 2018; Dietz & Atkinson, 2010; Longo et al., 2008). Secondly, they are deemed appropriate as affordable monthly contributions citizens would be willing to make toward enacting the proposed policies. Finally, selecting values easily divided by 30 enables the respondents to calculate the respective daily contribution. The remaining three attributes correspond to environmental aspects throughout the life cycle of a building. The first attribute pertains to the construction phase and represents the proportion of recycled material used in public construction projects. It can take the values of 20 %, 35 %, and 50 %. These figures are based on an estimated current value of 5 %[62] and a (current) realistic maximum of 20 to 30 % (based on personal communication with industry experts). The values exceeding this realistic maximum demonstrate an advantage of DCEs, namely the hypothetical nature of the choice situation. The second attribute is the reduction of greenhouse gas (GHG) emissions during the use phase compared to a situation in which no policy is implemented. The possible values are 33 %, 67 %, and 100 %. A 100 % reduction in GHG emissions would imply carbon neutrality in buildings, which has already

[60] While the Deutsche Bahn (the main German railway operator) is one of the main stakeholders and actors when it comes to building train stations, it does so in cooperation with the state, federal states, and municipalities (Deutsche Bahn, n.d.).

[61] In this context, sustainable standards are understood as a set of guidelines for construction that ensure that the environmental impact of a building is kept as small as possible.

[62] In 2020, 13.2 % of aggregates used in the construction industry were RA. However, only approximately 20 % of these RA are used in building construction as opposed to civil and underground engineering (Kreislaufwirtschaft Bau, 2023). Thus, 5 % is an optimistic estimation when considering mineral aggregates only. However, steal and synthetic materials are also candidates to be recycled and used.

been accomplished in selective buildings and for which guidelines exist (e.g., Braune et al., 2020). The other values represent equal increments between the current status quo of 0 % and the maximum. Finally, the recycling rate, referring to the end of life of the building, can take values of 40 %, 60 %, and 80 %. Here, we assume a current value of around 20 %[63] and a feasible maximum of 80 %, such that 40 % and 60 % are intermediate increments of equal magnitude. Three policy options, labeled A, B, and C, are characterized by these attributes. In addition, a status-quo alternative exists as a no-policy option, which remains consistent across choice sets. This option entails no additional costs and no changes in the environmental attributes to the current status quo. A status-quo alternative allows the interpretation of respondents' choices in the light of standard welfare economic terms (Hanley et al., 2002) and is typically included when the alternatives consist of policies (e.g., Alberini et al., 2018; Longo et al., 2008). To avoid imposing a decision on participants, which could diminish data quality, we include the opt-out option "I cannot answer this question". An exemplary choice set is shown in Table IV.1.

Table IV.1: Exemplary choice set

	Policy A	Policy B	Policy C	No policy
Share of recycled construction material	50 %	35 %	20 %	no change
Reduction of greenhouse gas emissions	67 %	100 %	67 %	no change
Recycling rate	60 %	40 %	40 %	no change
Additional monthly costs for you	9 €	15 €	3 €	0 €
Which policy do you choose?	◯	◯	◯	◯
◯ I cannot answer this question.				

Respondents are instructed to imagine that their municipality is planning to introduce a policy to increase sustainability in the construction of public buildings. They are then asked to choose the policy that aligns best with their interests from a selection of three. Next, the attributes describing the policies are explained. It is pointed out that these policies may generate future financial savings, which could be redistributed among the citizens, but that this is omitted for simplification. Information is provided on the construction industry's environmental impact for orientation, specifically addressing yearly amounts of natural resource extraction, CO_2 emissions, and construction and demolition waste. Finally, respondents are asked to assume that the share of recycled construction material and the recycling rate, in the absence of any policy, is around 5 % and 20 %, respectively. Each participant is presented with six distinct choice sets.

Since a full factorial design – comprising all possible choice sets – is not feasible[64], a fractional factorial design is generated using the Balanced Overlap design option from the Lighthouse Studio software. This method balances statistical efficiency with some overlap to allow for interaction effects (Sawtooth Software, 2021). The survey is programmed within the online platform SoSci Survey and made available for respondents via www.soscisurvey.de (Leiner,

[63] While the official recycling rate in Germany is almost at 90 % (Destatis, n.d.), this figure includes road- and backfilling. Actual recycling of mineral waste, which entails retaining the original material's value, is much lower (in the single-digit scope). Recycling rates for other materials, such as metal, are significantly higher (EuRIC, 2022). Therefore, a recycling rate of 20 % is an approximation across all construction materials.
[64] The set of all possible alternatives is formed by the Cartesian product of all attributes and levels (3 x 3 x 3 x 3 = 81). With three alternatives, there are 531,441 (81 x 81 x 81) possible choice sets.

2021). The respective municipal administration primarily approached participants through social media posts, press releases, and word-of-mouth promotion.

3.2 Empirical Model

The data gathered through the factorial survey are analyzed using linear regression models of the following form:

$$\text{likelihood to sign the petition} = \beta_0 + \beta_1 \text{ train station} + \beta_2 \text{ city hall} + \beta_3 \text{ additional costs} + \beta' Z_i + \epsilon$$

where β_0 denotes the constant, β_{1-3} are the coefficients describing the effects of the variable aspects[65], and Z_i is a vector of respondents' individual characteristics. ϵ describes the error term. Two of these models are calculated, distinguished by the default effect (conventional building standards as the default with a petition in favor of using sustainable building standards instead and sustainable building standards as the default with a petition against their use).

The choices respondents make in the DCE are analyzed based on *random utility theory* (McFadden, 1986). Louviere et al. (2010) formalize a consumer's utility of different choices with the following equation:

$$U_{ia} = V_{ia} + \varepsilon_{ia}$$

U_{ia} describes individual i's utility of alternative a and consists of a systematic component V_{ia} that can be observed and an unobservable random component ε_{ia}. The consumer (individual i) will choose an option (alternative a) when the utility derived from that option is larger than the utility derived from any other option:

$$U_{ia} > U_{ib} \qquad all\ b \neq a \in A$$

Combining the two previous equations, the following probability of choice can be derived:

$$P(a|C_i) = P[(V_{ia} + \varepsilon_{ia}) > Max(V_{ib} + \varepsilon_{ib})], \text{ for all } b \text{ alternatives in choice set } C_i$$

where C describes a choice set with several options, among which alternative a. The choice model one applies depends on the assumptions made about the probability distribution of the random components ε_{ia}. The most basic one is the multinomial logit model (McFadden, 1974), which assumes ε_{ia} to be independently and identically distributed among the alternatives. It also relies on the Independence of Irrelevant Alternatives (IIA) assumption (Louviere et al., 2010). Including a status-quo option often violates this assumption (Dhar & Simonson, 2003), which states that adding a further option may not alter the relative probabilities of choice of the other options. The assumption is relaxed in McFadden and Train's (2000) mixed logit (ML) model, which allows some of the attribute coefficients to be random, accounting for preference heterogeneity.

Our dataset has a panel form since respondents make six choices each, adding a time dimension to the utility function:

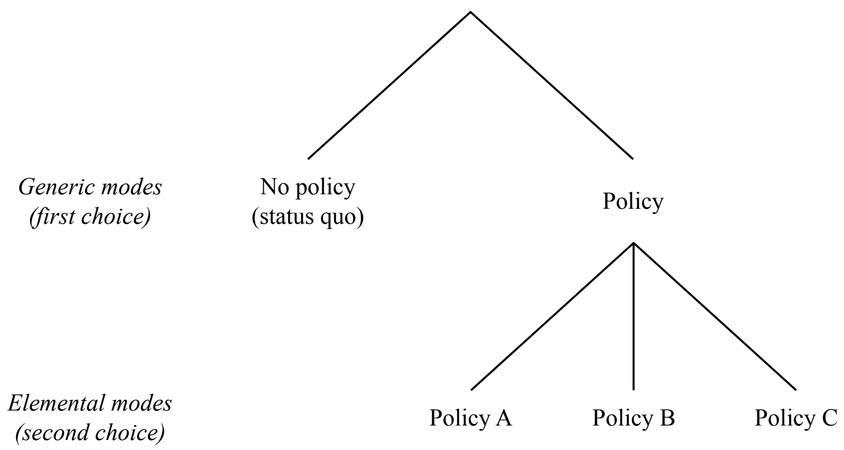
[65] The building type is included using dummy variables (*train station* and *city hall*), where the base category is *school*. Additional costs are coded as a continuous variable. The default of building standard is not included as a variable, since it is used to distinguish two different models.

$$U_{iat} = \beta'_i \, x_{iat} + \alpha' \, w_{iat} + \delta'_a \, z_{it} + \varepsilon_{iat}$$

x_{iat} and w_{iat} represent vectors of the attributes that define the alternatives, where β' is the vector of random coefficients and α' are fixed coefficients. z_{it} describes a vector of the decision-makers' individual characteristics, where δ'_a are also fixed coefficients.

To ensure the robustness of the results, we apply a nested logit model (Hensher & Greene, 2002). This model creates a hierarchical choice by grouping similar alternatives into nests. In our case, respondents' choice can be formalized as a first choice between a policy and the status quo and (if applicable) a second choice between the three policies (see Figure IV.1). This approach also relaxes the assumptions made by the multinomial logit model.

Figure IV.1: Hierarchical choice of policies



The utility a decision-maker derives from a policy (a so-called *elemental mode* m, which is contained within a *generic mode* g) can be formalized as follows:

$$U_{gm} = U_g + U_{m|g}, m \in M_g, g \in G$$

or in terms of the systematic and unobserved components of utility:

$$U_{gm} = V_g + V_{m|g} + \mu_g + \varepsilon_{m|g}, m = 1, \ldots, M_g, g = 1, \ldots, G$$ (Louviere et al., 2010).

All models are calculated using the statistical software *Stata* (StataCorp, 2021).

4 Results

A total of 514 citizens took part in the study. Respectively, 214, 142, 87, and 71 are from the same city or district. Approximately two-thirds of all participants (337) completed the entire survey. The descriptive characteristics of the sample (i.e., socio-demographic information) can be found in Table IV.B.1 in the appendix. Respondents give an average rating of 72.2 (n = 383, SD = 24.48[66]) regarding their perception of personal benefits versus drawbacks of sustainable

[66] The abbreviations "n" and "SD" represent the sample size and standard deviation, respectively.

public construction. The scale ranges from only personal drawbacks (coded as 0) to only personal benefits (coded as 100). With a score of 80.60 (n = 394, SD = 23.95), the rating is even higher regarding perceived social benefits and drawbacks (refer to Table IV.B.2 in the appendix). This implies a positive attitude among citizens toward sustainable construction, supporting our first hypothesis (H1). The respondents' associations with sustainable construction are also predominantly positive. The negative and positive values for each pair of potential associations are coded 0 and 100, respectively. Only the aspects of effort and space score below 50. The comparison between higher and lower costs obtains a score of 51.2. All other aspects (design, comfort, environmental impact, health, and quality) are rated well above 50 (see Table IV.B.3 in the appendix). Thus, citizens' positive associations with sustainable construction dominate, in line with our first hypothesis (H1).

Table IV.2 displays the results of the DCE. The signs of the alternative-specific coefficients are consistent with expectations: Higher costs lower the choice probability of a policy, while a higher share of recycled material, a higher share of reductions in GHG emissions, and an increased recycling rate each have a positive effect. The negative impact of the cost attribute supports our hypothesis that higher costs negatively influence citizens' attitudes toward sustainable construction in their municipality (H3.3). Since the coefficients in a ML model are difficult to interpret, we calculate marginal effects. An increase of 9 EUR in monthly costs for the respondents' household[67] reduces the likelihood of choosing that policy by 12.5 percentage points (pp). The other three attributes are all measured in pp, so a direct comparison of their impact is possible. An increase of 20 pp in the share of recycled material, the share of reduction in GHG emissions, and recycling rate results in an increase in the choice probabilities of 8.8, 9.4, and 6.3 pp, respectively. Thus, reducing GHG emissions has the most considerable impact on policy choice. The coefficient of the alternative-specific constant (ASC), which is coded 0 for the status-quo alternative and 1 for all policy alternatives, indicates that respondents are more inclined to choose a policy than to choose the status quo (see Table IV.2). This finding again confirms our hypothesis regarding the positive attitude of citizens toward sustainable construction (H1). The table's lower half displays the attributes' standard deviations (SD), whose significance confirms the suitability of a ML model.

The WTP for the three environmental attributes can be calculated by dividing the respective coefficient by the cost variable coefficient (Hole, 2007). Although preference heterogeneity concerning costs is likely to exist, it is statistically problematic to model the cost coefficient as random (Carson & Czajkowski, 2019). Therefore, we model it as fixed and report the confidence intervals of the estimates obtained using the delta method (Hole, 2007; StataCorp, 2021). Table IV.3 provides the WTP estimates for the share of recycled material, the reduction of GHG emissions, and the recycling rate. The estimates refer to a one pp change. Thus, citizens are most willing to pay for a pp increase in GHG reductions (0.34 EUR), followed by a pp increase in the share of recycled material (0.28 EUR). The WTP for a pp increase in the recycling rate is the lowest (0.19 EUR). The difference between the recycling rate and the other two attributes is significant since this WTP estimate is outside the other confidence intervals. The positive WTP estimates align with our hypothesis that citizens are willing to act in favor of sustainable construction in their municipality (H2). A nested logit model is additionally implemented to ensure the robustness of the results. This alternative specification confirms the findings, as shown in Table IV.C.1 and Table IV.C.2 in the appendix.

[67] 9 EUR is selected as it represents the median value among the possible cost attribute values in the DCE. 9 EUR corresponds to roughly 0.3 % of the median monthly household income in our sample.

Table IV.2: Main regression results (DCE)

Costs	– 0.157*** (0.0142)
Recycled Material	0.0436*** (0.00491)
GHG Reduction	0.0529*** (0.00377)
Recycling Rate	0.0301*** (0.00375)
ASC	8.896*** (2.370)
/Normal	
SD(Recycled Material)	0.0419*** (0.00594)
SD(GHG Reduction)	0.0345*** (0.00361)
SD(Recycling Rate)	0.0331*** (0.00506)
SD(ASC)	9.612*** (2.705)
N	7536

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using a mixed logit model.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
DCE = discrete choice experiment, GHG = greenhouse gas, ASC = alternative-specific constant, SD = standard deviation

Table IV.3: WTP estimates for environmental attributes

	Recycled Material	GHG Reduction	Recycling Rate
WTP (1 pp)	0.28	0.34	0.19
Lower limit	0.22	0.28	0.14
Upper limit	0.34	0.39	0.24

Values are given in EUR and refer to a pp increase.
WTP = willingness to pay, GHG = greenhouse gas, pp = percentage point

A further result that sheds light on the second hypothesis is the degree of citizens' willingness to participate in different hypothetical offers by the city. These offers include a discussion round, an online platform, and two newsletters: one with additional information on subsidies for private construction clients and the other without. All of these are described to be on the topic of sustainability in public construction. Respondents are assigned randomly to one of four groups, being presented with only one offer. They are then asked to rate their likelihood of engagement on a scale from 0 ("very unlikely") to 100 ("very likely"). The results show an average response of 50.42 (n = 390, SD = 35.10) and no significant difference between the formats (see Table IV.B.4 in the appendix). A score of 50 can be interpreted as "neither likely nor unlikely" or "ambivalent", which does not provide substantial support for our hypothesis of a positive willingness to act (H2).

We hypothesized that certain individual traits could impact citizens' attitudes, specifically their level of trust in the local government and their perception of benefits and drawbacks. We test these hypotheses using a nested logit model, the results of which are presented in Table IV.4. As expected, a higher level of trust in their municipality increases respondents' likelihood of opting for a policy over the status quo (i.e., no policy; H3.1). The trust variable comprises general trust, trust in the intention and in the competence of the municipality to act in the best interest of the citizens and the environment, and feeling adequately informed regarding new construction projects and their sustainability efforts (see Table IV.B.5 in the appendix for descriptive results of these aspects). Likewise, perceiving more benefits than drawbacks to sustainable construction in the municipality, personally and socially, raises the likelihood of choosing a policy. These results align with our hypothesis (H3.2). Including these factors renders the coefficients of the alternative-specific attributes insignificant. Thus, the attributes' effects on the choice probability of a GB policy are driven by respondents' trust in the municipality and the benefits they associate with GB[68].

Table IV.4: Regression results (DCE) with individual characteristics

Alternative	
Costs	– 0.0215
	(0.0228)
Recycled Material	0.00651
	(0.00687)
GHG Reduction	0.00681
	(0.00722)
Recycling Rate	0.00408
	(0.00434)
ASC	– 1.014
	(1.054)
Policy (nest)	
Trust	0.688^{***}
	(0.168)
Personal drawbacks vs. benefits	1.278^{***}
	(0.355)
Social drawbacks vs. benefits	1.762^{***}
	(0.316)
N	6160

Standard errors in parentheses
$^{+}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$
Results obtained using a nested logit model.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
GHG = greenhouse gas, ASC = alternative-specific constant

The factorial survey results reveal that the default effect significantly impacts respondents' (hypothetical) willingness to act. When the default is a conventional construction process, the

[68] Both specifications with only trust and only perceived drawbacks and benefits as individual characteristics yield the same result with respect to the insignificance of the alternative-specific attributes.

average likelihood of signing the petition (in favor of using sustainability standards instead) is 65.52 %. This value differs significantly from a value of 50 %, which we denote as ambivalence (t(187) = 5.58, p = 0.00). This finding also supports our hypothesis that citizens are willing to support sustainable construction in their municipality (H2). If sustainable standards are meant to be implemented, the average likelihood of signing a petition against their use is only 19.55 %. This value significantly differs from 50 % (indicating ambivalence; t(186) = – 12.32, p = 0.00). Thus, as hypothesized (H4.1), the default effect significantly influences citizens' acceptance of sustainability in public construction. The willingness to act also differs depending on the default, but acceptance materializes either in acting or in not acting according to the goal of the action. If sustainability measures are not planned to be implemented, there is a 65.52 % likelihood of acting against this decision (thus favoring sustainability). However, if sustainability measures are presented as the default option, the average probability to (silently) agree increases to 81.45 % (100 % – 19.55 %). These values differ significantly from each other (t(373) = – 4.01, p = 0.00).

The willingness to sign a petition supporting sustainability standards is highest when the building is a school (see model (1) in Table Table
IV.5). However, the differences in likelihood compared to a train station and a town hall are insignificant and only marginally significant, respectively. If the default is the adherence to sustainability standards, there are no significant differences between building types (see model (2) in Table Table
IV.5). Consequently, the results are not conclusive regarding our corresponding hypothesis (H4.2).

Table IV.5: Main regression results (factorial survey)

Default	(1) Conventional	(2) Sustainable
Building types[69]		
Train station	– 5.368	– 2.475
	(6.567)	(5.688)
City hall	– 12.22^{+}	8.879
	(6.813)	(6.161)
Costs	– 1.751	– 0.907
	(1.995)	(1.517)
_cons	76.82***	20.17***
	(7.823)	(5.908)
N	188	187

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using the ordinary least squares estimator.
The dependent variable is the likelihood to sign a petition in favor of applying sustainability standards.

The additional costs imposed by building according to sustainability standards do not seem to affect respondents' willingness to sign a petition for or against using these standards (see Table IV.5). Analyzing the additional costs as a categorical variable, however, reveals some effects. Table IV.6 displays these results. They suggest that if sustainable standards are planned to be implemented, additional costs of 25 % for a train station decrease, whereas additional costs of 15 % for a town hall increase respondents' likelihood to sign a petition against these standards. Both effects are challenging to explain and are likely to be artifacts. If the plan is to build conventionally, additional costs of 25 % for building a town hall according to sustainability

[69] The building type *school* is the base category.

standards significantly decrease respondents' likelihood to sign a petition in favor of such standards. Overall, the results are inconclusive such that we cannot confirm nor reject our hypothesis regarding the effect of costs on the public's willingness to act in favor of sustainable construction in their municipality (H4.3).

Table IV.6: Regression results of the effect of building type and additional costs (factorial survey)

Default	(1) Conventional	(1) Sustainable
School x 10 %	1.230	9.225
	(16.22)	(14.38)
School x 15 %	– 3.182	11.48
	(16.52)	(12.24)
School x 20 %	1.929	2.010
	(17.67)	(8.851)
School x 25 %	3.364	9.548
	(15.60)	(11.16)
Train station x 5 %	– 7.610	8.292
	(16.85)	(12.12)
Train station x 10 %	– 4.825	11.24
	(16.54)	(11.01)
Train station x 15 %	5.000	11.53
	(16.27)	(14.09)
Train station x 20 %	– 14.43	– 7.675
	(16.78)	(6.336)
Train station x 25 %	– 0.932	-11.37^{+}
	(16.75)	(5.928)
City hall x 5 %	1.118	0.989
	(17.69)	(9.193)
City hall x 10 %	– 14.98	22.62
	(17.71)	(14.22)
City hall x 15 %	– 7.610	30.72^{*}
	(16.90)	(14.53)
City hall x 20 %	0.218	9.625
	(16.40)	(11.35)
City hall x 25 %	-34.81^{*}	13.49
	(16.85)	(10.88)
_cons	71.18^{***}	11.37^{+}
	(13.02)	(5.928)
N	188	187

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using the ordinary least squares estimator.
The dependent variable is the likelihood to sign a petition in favor of/against applying sustainability standards.

We also examine the impact of socio-demographic information on the likelihood of choosing a policy over the status quo. Respondents' importance of sustainability in their personal lives significantly increases the probability of choosing a policy. Moreover, younger and higher-income respondents display a marginally significantly higher likelihood of doing so than their counterparts. Significant differences exist between the municipalities regarding citizens' likelihood of choosing a policy. Refer to Table IV.C.3 and Table IV.C.4 in the appendix for the corresponding regression results.

5 Discussion

Government bodies should serve the citizens for whom they are responsible. Part of that service is to involve and act in the interest of these citizens, and construction projects and the associated sustainability efforts are no exception. Our findings indicate that citizens generally accept sustainable public construction, mainly in terms of positive attitudes and, to some extent, a willingness to act. Participants' positive attitudes are identified in several ways. One of these is their perception of significantly more benefits than drawbacks to sustainable construction in their municipality, both on a personal and a societal level. Furthermore, most of their associations with building sustainably are positive. The only exceptions are effort, space, and costs, with participants associating more effort and less space with sustainable construction, while being undecided about costs. These negative associations largely reflect reality, at least for now. As sustainable construction practices are not (yet) the norm, applying them requires extra effort. This may be one of the reasons for increased costs, as is the lower availability of GB materials and consultants. However, both factors will likely become negligible as sustainable building practices become more common, at least in cases where sustainable products or processes replace conventional ones rather than requiring additional materials or steps. In addition, some products or processes that are considered sustainable can be seen as a form of investment. For example, renewable energy systems require direct costs now but may generate profits in the future (Dietrich, 2023). Moreover, the differences in costs between conventional and sustainable alternatives could significantly decrease – if not disappear altogether – in numerous cases, by internalizing externalities, such as through taxation (Söderholm, 2011b). While government institutions would be equally affected by such a consumption tax as private individuals, they are additionally driven to choose the sustainable option because of their duty to act in the interest of the general welfare. The idea that less space generates less environmental impact than more space is likely to remain valid since building space inevitably consumes resources and energy (e.g., Goldstein et al., 2020; Lavagna et al., 2018). Despite these factors, respondents' attitudes are dominated by positive associations, which is also reflected in their choice of policies in the DCE. They choose policies meant to decrease public buildings' environmental footprint throughout their life cycle over the status quo despite it costing them personally. These choices are hypothetical and should be interpreted as such. However, research indicates that the *hypothetical bias* in stated preference studies is not as pronounced as previously believed, especially when choice-based elicitation methods are employed, as in this case (Murphy et al., 2005).

The factors that we hypothesized to influence citizens' attitudes do indeed show the expected effect (see Table IV.4: Regression results (DCE) with individual characteristics). Trust in the municipality and perceiving more benefits than drawbacks to sustainable public construction have a positive impact on participants' likelihood of choosing a policy that reduces the environmental footprint of buildings. Similar results are found in other areas. For instance, Siegrist (2000) analyzes trust's role in accepting gene technology. Through a questionnaire survey, he discovers that trust in responsible institutions is the most critical influence on gene technology perception. Additionally, Suh and Han's (2002) research on attitudes toward Internet banking in the early 2000s shows that trust in the banking website has a significant positive effect on both attitudes toward and intention to use Internet banking. This pivotal role of trust extends the so-called *Technology Acceptance Model* (Davis, 1985) beyond perceived usefulness and ease of use. Perceived usefulness is one path through which the impact of trust in the municipality on citizens' attitudes can be explained. Researchers find that trust influences the perceived usefulness of green buildings and their respective technologies, positively affecting attitudes (Liu et al., 2018; Rajaee et al., 2019). However, it should be noted that the findings from these studies only apply to private buildings and cannot be directly transferred to public construction. Future research could identify whether perceived usefulness also functions as a mediator in this case. Another common finding in the studies by Liu et al. (2018) and Rajaee et al. (2019) is that trust influences the behavioral intention to use or apply the technology under consideration. As this effect refers to the behavioral dimension of acceptance, it goes beyond our hypothesized influence of trust. We check whether our data support this result and find that trust also positively influences the willingness to act[70] (refer to Table IV.D.1 in the appendix). This influence can be utilized by municipalities seeking to enhance their citizens' acceptance of sustainable public construction. Through transparency and participatory offers (in public building projects), trust in the municipality can be increased, fostering citizens' acceptance.

Another reason why trust is important is that it affects the perceived risks (drawbacks) and benefits of the object or process, which in turn directly determine its acceptance (Siegrist, 2000). Since trust reduces uncertainty and thus perceived risk, it is essential in cases of high complexity or unfamiliar areas (Rajaee et al., 2019). GB will likely fulfill this criterion for most of our participants being lay people. Thus, trust and the perception of benefits and risks (drawbacks) are closely linked. In the context of sustainability, both personal and social benefits and risks (drawbacks) play a role. Schumann's (2015) study on attitudes toward carbon capture and storage reveals that perceived social benefits have the most considerable impact compared to social risks, personal risks, and personal benefits. Since we model risks (drawbacks) and benefits on the same scale, identifying the distinct effects of these two opposites is infeasible. However, our results support Schumann's (2015) finding that social effects have a greater influence on the likelihood of choosing environmentally friendly policies over the status quo than personal effects. Municipalities should consider this in their communication of construction projects. Focusing on the benefits, especially those to society, could further foster the public's positive attitudes. Of course, it is critical also to communicate any potential drawbacks transparently.

Our results support our hypothesis regarding the negative influence of costs on attitudes toward sustainable public construction. Costs are consistently identified as a barrier to adopting GB practices. For instance, Pitt et al. (2009) study factors that prevent sustainable construction and identify affordability as the most critical barrier. Similarly, Lam et al. (2009), in their survey of clients, consultants, and contractors, find that additional costs are considered the primary barrier by all stakeholder groups. In their study, Huijts et al. (2012) examine the relationship between costs and public acceptance of sustainable energy technology. The researchers set up a framework of energy technology acceptance based on psychological theories and empirical studies in the field. They posit that the perceived costs of a technology directly influence people's attitudes toward it, consequently affecting its acceptance level. Our results verify this premise in relation to public construction.

The identified WTP for an increase in the environmental aspects of sustainable public construction indicates a positive willingness to act, which constitutes the second dimension of public acceptance. Participants are found to be willing to pay the most for a reduction in GHG emissions, followed by an increase in the share of recycled material. In contrast, their WTP for increasing the recycling rate is the lowest. The estimated values translate to a monthly WTP of 6.80 EUR, 5.60 EUR, and 3.80 EUR for a reduction in GHG emissions, an increase in the share of recycled material, and an increase in recycling rate by 20 pp in public buildings, respectively. Robbins and Perez-Garcia's (2005) survey of the general population and real estate agents regarding their valuation of environmental improvements produce results consistent with this

[70] We use the likelihood of signing a petition in favor of applying sustainability standards in a public construction project as the dependent variable.

implied ranking: The researchers find that the public is significantly more willing to pay for reducing GHG emissions than for reducing air pollution or solid waste emissions. In contrast, real estate agents exhibit the highest WTP for reducing solid waste emissions. At least two reasons may explain why our respondents' WTP for GHG emissions is highest. Firstly, GHG emissions and climate change are arguably the most prominent topics in the public debate surrounding sustainability. Respondents may not be as aware of resource scarcity[71] and, as a result, may not be as willing to pay for improvements in this area. Secondly, the reduction of GHG emissions is explicitly stated to apply to the use phase of the building, while the share of recycled material and the recycling rate are linked to the construction and demolition phases, respectively. As the respondents represent the general public rather than construction stakeholders or experts, they are presumably most familiar with the use phase of a building. Some may never have been involved in construction or demolition processes. Therefore, reducing GHG emissions is likely to be the most relatable aspect for them. The disparities between the general public and real estate agents concerning their WTP to reduce GHG emissions versus solid waste emissions, as revealed by Robbins and Perez-Garcia's (2005) study, corroborate this explanation. Our WTP estimates for reducing GHG emissions align with prior research (Dietz & Atkinson, 2010; Ščasný et al., 2017). One potential reason for the WTP for increasing the recycling rate being lowest could be the tendency to neglect buildings' end of life. Adams and her colleagues (2017) find that a significant challenge for implementing a circular economy in the construction sector is the lack of consideration of end-of-life issues among stakeholders. It is conceivable that this issue extends to our respondents as well. Moreover, the demolition process and, where applicable, recycling lie the furthest in the future, resulting in the utility of a higher recycling rate being most strongly discounted (Fishburn & Rubinstein, 1982).

Another finding that supports citizens' positive willingness to act in support of sustainable public construction is their expressed intent to sign a petition advocating for the use of sustainability criteria in public construction projects (and not against it). In contrast, the results regarding their willingness to engage in various formats offered by the municipality on the subject remain inconclusive. Overall, participants report being neither very likely nor unlikely to engage, independent of the format. The reported likelihood to engage differs substantially between participants (refer to Table IV.B.4 in the appendix), suggesting that individual factors may play a role in the decision to engage. In an attempt to identify these factors, we find that age plays a role, with older respondents (56 and above) being significantly more likely to participate in these formats. Additionally, those who value sustainability more in their personal lives and possess knowledge of sustainable construction are more likely to engage. See Table IV.D.2 in the appendix for these results. However, it remains unclear why the overall willingness to participate in these formats is substantially lower than it is to pay or sign a petition. Further research is necessary to identify the factors influencing whether citizens will act in favor of sustainable public construction.

Our results regarding the determinants of the willingness to act in favor of sustainable public construction are inconclusive. However, one aspect that clearly shows an effect is default framing. A significantly higher proportion of citizens approve of implementing sustainability standards in public construction when it is presented as the default option. Researchers propose three explanations for this effect. One reason people favor the default option is the lower effort and cost involved compared to choosing an alternative (Araña & León, 2013; Dinner et al., 2011). The case of signing a petition, although not much effort is required, does take up some

[71] Naturally, recycling building material is also directly linked to GHG emissions (the extent depends on the material and the processing necessary). However, we assume that the aspect of resource use is more salient in this setting.

time and potentially involves travel. A second explanation is implied endorsement, meaning that setting an option as the default signals that this option is the desired or beneficial one (Dinner et al., 2011). Participants may assume the standards are desirable because the municipality allegedly endorses them. This relates to the importance of trust in the responsible institution as previously discussed. The anchoring effect or reference dependence constitutes the third and final explanation for the default effect. The concept suggests that the default option is interpreted as the status quo, against which other options are compared and perceived as either gains or losses (Araña & León, 2013; Dinner et al., 2011). If implementing sustainability standards is the default option, building conventionally may be perceived as a loss, typically disliked by individuals (which is known as *loss aversion*; Tversky & Kahneman, 1991). Our research has demonstrated that default framing represents an effective nudge for promoting sustainable construction. Especially given that it steers behavior in a desired direction while preserving freedom of choice, default framing is an attractive policy instrument to encourage the adoption of GB practices (Thaler & Sunstein, 2008). Note that the results regarding the default effect restrict the apparent extent of the public's willingness to act in favor of sustainable construction. When conventional building is the default, it requires active behavior to demonstrate one's support for sustainable construction. Conversely, when sustainable standards are to be implemented by default, doing nothing implies agreement or acceptance. The difference in the likelihood of accepting sustainable construction in the two settings (66 % versus 81 %) shows that not all citizens with a positive attitude are willing to act on it.

Although our results indicate that costs negatively affect the attitudinal dimension of acceptance of sustainable public construction, no concrete evidence is found to support this effect on the behavioral dimension. The setting in the study is a newly constructed public building that would incur additional costs if built along sustainability standards. The situation description does not specify who would bear these expenses. Thus, one potential reason why we do not find an effect is that participants do not perceive these costs as disadvantageous to themselves. Despite citizens contributing a significant proportion of municipal funds, this relation might be too indirect or unknown. Rajaee et al. (2019) find that costs hurt decision-makers' intention to adopt GB technologies when they perceive these costs to be their burden, for example, because the building in question is their home. Further research is required to determine if citizens are genuinely indifferent toward additional costs for sustainable public construction or if they would behave differently when made aware that they are eventually responsible for bearing (at least some of) these costs.

Finally, the building type in question (i.e., school, train station, or town hall) is found to have no impact on the decision to support sustainability standards in public construction. Our hypothesis predicts that support would be highest for schools, and while we do find the expected signs, the results are not significant or only marginally so. The hypothesis is based on the connection between sustainability and future generations. Therefore, we test whether this effect is present for participants with children, given that this connection is likely more salient for parents. However, the results indicate that this is not the case[72]. Accordingly, we conclude that the type of building does not influence citizens' willingness to act in favor of constructing it along sustainability standards. Instead, citizens appear to behave rationally and advocate for implementing such standards (or not) regardless of the type of building.

The results above are averaged across the four municipalities in our sample. Naturally, variations in size, geographical location, industrial focus, and the extent to which they already employ practices of GPP and sustainable construction exist. The sample of municipalities is too

[72] The results are available from the authors upon request.

small to control for these differences. As a result of these varying characteristics, the respective levels of the municipalities' citizens' acceptance may differ. For example, in Table IV.D.3, we analyze whether trust and perceived benefits versus drawbacks have varying effects in different municipalities. Indeed, in one municipality (A), only the perception of social but not personal benefits versus drawbacks increases the likelihood of choosing a policy promoting sustainable construction over the status quo. Moreover, trust does not seem to have an effect in this municipality. Thus, municipalities should check these factors within their specific context before potentially designing measures based on them.

6 Conclusion

Sustainable public construction provides a solution for the significant environmental impact caused by government bodies in procuring new buildings. As with any decision or action that affects citizens, following the public's interest is desired, and attaining acceptance is critical. Therefore, this study identifies citizens' stance on sustainable construction in their city or district by surveying four German municipalities. The survey primarily consists of a factorial survey and a DCE. The main findings are as follows: Overall, citizens accept sustainable public construction, particularly regarding the attitudinal dimension. They consider the concept beneficial for themselves and for society, associate it primarily with positive factors, and would opt for policies that encourage sustainable construction in their municipality over the status quo of conventional construction. Trust in the municipality and perceived benefits compared to drawbacks have a positive impact, while associated costs negatively affect attitudes. Results are more mixed regarding the behavioral dimension of acceptance. On the one hand, we find evidence of a willingness to act in terms of financial contributions and signing a petition to implement sustainability standards in buildings. The default framing appears to be an effective tool to increase the acceptance of sustainable public construction. On the other hand, only specific segments of the public seem to be willing to engage in formats offered by the municipality to discuss and inform on topics of sustainable construction. Elderly citizens and individuals interested in and knowledgeable about sustainability and construction are likelier to engage. However, overall, the likelihood of engagement is only moderate. Furthermore, our results indicate that not all citizens who passively accept sustainable construction would be willing to show their support actively.

To summarize, public acceptance of sustainable construction in the municipality exists but is stronger in the attitudinal compared to the behavioral dimension. Further research is needed to determine more precisely the factors that may influence and foster citizens' willingness to act in favor of sustainable construction. Our results suggest that one promising avenue is using the default effect. Municipalities seeking to limit their environmental impact and to utilize the potential offered by construction in this regard could establish the implementation of sustainability standards as the default for new buildings. Based on our findings, the local government would likely be met with a favorable response from the public while still having the option to diverge from imposed regulations if deemed necessary. Theoretically, very courageous municipalities could set a financial contribution by citizens as the default. In practice, fiscal responsibilities would need to be transferred from the central government to local authorities for them to be able to set tax rates autonomously. Such a (partly) decentralized tax system may further contribute to a higher level of acceptance and WTP since it implies that tax money is spent locally. Accompanied by clear and transparent communication, a financial contribution as the default may be an effective strategy given our findings, which indicate that the public is willing to pay for an increase in environmental sustainability in the construction of public buildings.

7 Appendix

Appendix A

Survey Transcript

Table IV.A.1: Full survey transcript

Question	Wording	Response options
Start		
Consent (filter question)	*Information on the survey and data protection.*	→ I give my consent and wish to participate in this survey. (Survey continues.) → I do not want to participate in this survey. (Survey is terminated.)
Socio-demographic information		
Gender	Which gender are you?	→ female → male → other → not specified
Age	How old are you?	→ younger than 16 → 16 – 25 → 26 – 35 → 36 – 45 → 46 – 55 → 56 – 65 → older than 65
Education	Which educational status do you have?	→ no degree → Certificate of Secondary Education → General Certificate of Secondary Education → completed apprenticeship → vocational diploma → general qualification for university entrance → graduate degree → other: *Text*
Income	How high is your monthly net household income?	→ less than 500 EUR → 500 EUR to less than 1000 EUR → 1000 EUR to less than 2000 EUR → 2000 EUR to less than 3000 EUR → 3000 EUR to less than 4000 EUR → 4000 EUR to less than 5000 EUR → 5000 EUR to less than 6000EUR → 6000 EUR to less than 7000 EUR → 7000 EUR to less than 8000 EUR → more than 8000 EUR → not specified
Children	How many children do you have?	→ 0 → 1 → 2 → 3 → more than 3
Residency	Please indicate your postal code.	*Text*

The municipality		
Information channels	Which of the following channels do you use to inform yourself about news from [*the respective city or district*]?	→ local newspaper → local radio → local TV → website of [the respective city or district] → newsletter from [the respective city or district] → notice, for example in the city hall → (digital) placards → Facebook → Instagram → LinkedIn → Twitter → other: *Text* *Options are partly adapted to the municipality*
Sustainability		
Importance of sustainability	How important is sustainability (sustainable behavior) in your private life to you?	*Slider from 0 (not at all important) to 100 % (very important)*
Knowledge of sustainable construction	How do you evaluate your knowledge on sustainable construction?	*Slider from 0 (no knowledge at all) to 100 % (very good knowledge)*
Associations with sustainable construction	Which of the opposed characteristics do you rather associate with sustainable construction? *All pairs listed.*	*Slider from – 50 (negative characteristic) to + 50 (positive characteristic) for each pair*
Sustainability in construction in [*the respective city or district*]		
Identification	How strongly do you identify with [*the respective city or district*]?	*Slider from 0 (not at all) to 100 % (very strongly)*
Trust and feeling of being informed	To what extent do you agree with the following statements? – I have great trust in the political and administrative entities of [*the respective city or district*]. – I trust that the political and administrative entities of [*the respective city or district*] have the <u>intention</u> to consider the interests of citizens as well as the environment. – I trust that the political and administrative entities of [*the respective city or district*] have the <u>competency</u> to consider the interests of the citizens as well as the environment. – I feel sufficiently informed about new construction projects and their sustainability in [*the respective city or district*].	*5-point Likert scale from 1 (I do not agree at all) to 5 (I totally agree).* *Opt-out option: I cannot assess this.*
Source of information	Where would you like to see this type of information?	*Text*
Personal and social benefits and drawbacks	Which of the opposed statements fits you better? – I personally experience disadvantages if there would be more sustainable construction in [the respective city or district]. – I personally benefit if there would be more sustainable construction in [*the respective city or district*].	*Slider from – 50 (disadvantages) to + 50 (benefit) for each pair*

	– The society experiences disadvantages if there would be more sustainable construction in [the respective city or district]. – The society benefit if there would be more sustainable construction in [*the respective city or district*].	
Engagement		
Likelihood to engage in different formats	*Situation description (newsletter, newsletter with information on subsidies, online platform, or discussion round)* How likely do you think it is that you would *[register for the newsletter/engage on the platform/participate in the event]?*	*Slider from 0 ("very unlikely") to 100 % ("very likely")*
Factorial survey		
Factorial survey	*Explanation.* *Situation description (vignette).* How likely is it that you would sign this petition?	*Slider from 0 ("very unlikely") to 100 % ("very likely")*
Discrete choice experiment		
Discrete choice experiment	*Explanation.* *Facts for orientation.* Which policy would you choose? *6 choice sets with differing attribute levels (see text).*	→ Policy A → Policy B → Policy C → no policy → I cannot answer this question.

Appendix B

Descriptive Results

Table IV.B.1: Descriptive results (sample)

Gender		
Female	238	50.96 %
Male	209	44.75 %
No statement	12	2.57 %
Not answered	8	1.71 %
Total	467	100.00 %
Age		
< 16	1	0.21 %
16 – 25	48	10.28 %
26 – 35	116	24.84 %
36 – 45	102	21.84 %
46 – 55	89	19.06 %
56 – 65	63	13.49 %
> 65	29	6.21 %
Not answered	19	4.07 %
Total	467	100.00 %
Education		
Certificate of Secondary Education	6	1.28 %
General Certificate of Secondary Education	33	7.07 %
Completed apprenticeship	43	9.21 %
Vocational diploma	40	8.57 %
General qualification for university entrance	82	17.56 %
Graduate degree	246	52.68 %
Other	10	2.14 %
Not answered	7	1.50 %
Total	467	100.00 %
Monthly Net Household Income		
< 500 EUR	7	1.50 %
500 <= x < 1000 EUR	23	4.93 %
1000 <= x < 2000 EUR	51	10.92 %
2000 <= x < 3000 EUR	89	19.06 %
3000 <= x < 4000 EUR	80	17.13 %
4000 <= x < 5000 EUR	64	13.70 %
5000 <= x < 6000 EUR	66	14.13 %
6000 <= x < 7000 EUR	22	4.71 %
7000 <= x < 8000 EUR	9	1.93 %
> 8000 EUR	15	3.21 %
No statement	22	4.71 %
Not answered		
Total	467	100.00 %
Number of Children		
0	340	41.92 %
1	67	14.35 %
2	111	23.77 %
3	23	4.93 %
> 3	11	2.36 %
Not answered	22	4.71 %
Total	467	100.00 %

Table IV.B.2: Descriptive results of sustainability (in construction)

Variable	Nr. of Observations	Mean	SD	Min.	Max.
Importance of sustainability	420	79.00	20.80	0	100
Knowledge of sustainable construction	419	52.03	25.91	0	100
Personal consequences	383	72.20	24.28	0	100
Social consequence	394	80.60	23.95	0	100

SD = standard deviation

Table IV.B.3: Descriptive results of associations with sustainable construction

Variable	Nr. of Observations	Mean	SD	Min.	Max.
Financial costs vs. win	403	51.20	27.76	0	100
More vs. less effort	409	34.22	22.15	0	100
Attractive vs. unattractive design	389	68.96	21.88	0	100
Less vs. more comfort	394	64.92	21.69	0	100
Less vs. more space	386	46.77	20.43	0	100
Negative vs. positive consequences environment	416	91.05	15.22	0	100
Negative vs. positive consequences health	408	86.35	17.61	0	100
Lower vs. higher quality	406	79.53	20.80	0	100

SD = standard deviation

Table IV.B.4: Descriptive results of likelihood to participate in different formats

Variable	Nr. of Observations	Mean	SD	Min.	Max.
Discussion round	102	50.75	31.71	0	100
Online platform	93	52.55	31.79	0	100
Newsletter	99	49.25	38.00	0	100
Newsletter with information on subsidies	96	49.21	38.71	0	100

SD = standard deviation

Table IV.B.5: Descriptive results of trust in the municipality (different dimensions)

Variable	Nr. of Observations	Mean	SD	Min.	Max.
General trust	374	3.01	1.08	1	5
Trust in municipality’s intention	380	3.37	1.17	1	5
Trust in municipality’s competency	372	2.99	1.12	1	5
Being sufficiently informed	357	2.55	1.14	1	5

SD = standard deviation

Appendix C

Robustness Checks

Table IV.C.1: Robustness check: main regression results using a nested logit model

Costs	– 0.0645***
	(0.00493)
Recycled Material	0.0188***
	(0.00147)
GHG Reduction	0.0206***
	(0.000950)
Recycling Rate	0.0125***
	(0.00116)
N	7536

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using a nested logit model.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
DCE = discrete choice experiment, GHG = greenhouse gas

Table IV.C.2: WTP estimates for environmental attributes based on the nested logit model

	Recycled Material	GHG Reduction	Recycling Rate
WTP (1 pp)	0.29	0.32	0.19
Lower limit	0.24	0.28	0.15
Upper limit	0.34	0.36	0.24

Based on results obtained using a nested logit model.
Values are given in EUR and refer to a pp increase.
WTP = willingness to pay, GHG = greenhouse gas, pp = percentage point

Table IV.C.3: Robustness check: regression results with individual characteristics using a nested logit model

Costs	– 0.0300**
	(0.0114)
Recycled Material	0.00886**
	(0.00335)
GHG Reduction	0.00959**
	(0.00359)
Recycling Rate	0.00557*
	(0.00217)
Policy (nest)	
Gender	0.0999
	(0.225)
Age	– 0.492+
	(0.292)
Education	0.411
	(0.283)
Income	0.557+
	(0.288)
Children	0.335
	(0.311)
Importance of sustainability	1.830***
	(0.315)
Knowledge of sustainable construction	0.00734
	(0.00535)
N	6652

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using a nested logit model.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
GHG = greenhouse gas

Table IV.C.4: Robustness check: effect of municipalities

Costs	-0.0841^{***}
	(0.00774)
Recycled Material	0.0246^{***}
	(0.00233)
GHG Reduction	0.0270^{***}
	(0.00191)
Recycling Rate	0.0165^{***}
	(0.00176)
Policy (nest)	
Municipality	
B	-1.247^{***}
	(0.295)
C	-0.940^{*}
	(0.374)
D	-1.019^{***}
	(0.261)
N	7536

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using a nested logit model.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
GHG = greenhouse gas

Appendix D

Continuative Analyses

Table IV.D.1: Regression results: effect of trust and perceived benefits/drawbacks on the willingness to act

	(1)	(2)
Trust	12.77***	5.347^{+}
	(2.631)	(2.906)
Personal drawbacks vs. benefits		0.190
		(0.131)
Social drawbacks vs. benefits		0.436**
		(0.164)
_cons	26.58**	1.941
	(9.151)	(9.889)
N	166	156

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using the ordinary least squares estimator.
The dependent variable is the likelihood to sign a petition in favor of applying sustainability standards.

Table IV.D.2: Regression results: effect of individual characteristics on the willingness to engage

Format	
Online platform	6.522
	(5.210)
Newsletter	1.704
	(4.941)
Newsletter +	– 2.074
	(5.050)
Gender	– 1.353
	(3.782)
Age	
26 to 35 years	13.56^{+}
	(6.897)
36 to 45 years	6.589
	(7.708)
46 to 55 years	15.41^{+}
	(8.148)
56 to 65 years	23.04^{**}
	(8.369)
older than 65 years	29.18^{**}
	(9.871)
Education	– 4.489
	(4.835)
Income	– 1.597
	(3.921)
Children	2.093
	(4.346)
Importance of sustainability	0.453^{***} (0.0898)
Knowledge of sustainable construction	0.277^{***} (0.0750)
_cons	– 8.258
	(12.84)
N	335

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using the ordinary least squares estimator.
The dependent variable is the likelihood to participate in different formats on sustainability in (public) construction.

Table IV.D.3: Regression results with individual characteristics for separate municipalities

Municipality	(1) A	(2) B	(3) C	(4) D
Alternative				
Costs	– 0.115	– 0.0160	– 0.0278	– 0.0151
	(0.0952)	(0.0318)	(0.0699)	(0.0308)
Recycled Material	0.0322	0.00720	0.00704	0.00428
	(0.0261)	(0.0144)	(0.0163)	(0.00871)
GHG Reduction	0.0256	0.00723	0.0124	0.00481
	(0.0207)	(0.0143)	(0.0311)	(0.00982)
Recycling Rate	0.0166	0.00363	0.00748	0.00304
	(0.0146)	(0.00726)	(0.0186)	(0.00622)
ASC	3.497	– 2.954	– 2.077	– 1.118
	(3.697)	(2.206)	(4.161)	(1.378)
Policy (nest)				
Personal drawbacks vs. benefits	– 0.641	18.80^{***}	16.48^{***}	1.970^{*}
	(0.628)	(0.271)	(0.669)	(0.797)
Social drawbacks vs. benefits	1.664^{**}	1.148^{*}	18.35^{***}	3.808^{***}
	(0.618)	(0.459)	(0.395)	(1.084)
Trust	– 1.149	1.368^{***}	0.797^{+}	0.611^{***}
	(0.866)	(0.345)	(0.432)	(0.183)
N	1788	1164	632	2576

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using nested logit models.
The dependent variable is a choice: y = 1 if the alternative a has been chosen, y = 0 otherwise.
GHG = greenhouse gas, ASC = alternative-specific constant

Part V

Resource Taxes as an Instrument to Foster Circularity? Analysis of the Effects of Resource Taxation on Circular Economy Progress in Europe

Resource Taxes as an Instrument to Foster Circularity? Analysis of the Effects of Resource Taxation on Circular Economy Progress in Europe

Linda Reinhart & Ellen Sterk

Abstract

The concept of Circular Economy (CE) keeps gaining momentum in political and societal debates as it is considered to contribute to a more sustainable use of natural resources. Policymakers seeking to foster CE progress require adequate regulatory instruments. One instrument often recommended is a tax on the use of natural resources. The present paper analyzes the effects of resource taxation on different CE indicators, especially resource productivity, based on panel data for 30 European countries from 1995 to 2021. The Augmented Mean Group (AMG) estimator is applied, and the results are checked for robustness using the Pooled Mean Group (PMG) estimator. Despite current low levels of resource taxation, the results indicate that resource taxes positively affect resource productivity at least in the short run. The effect differs substantially in different countries. Hence, resource taxation seems to foster circularity, but the results indicate that additional factors are of influence and should be considered when designing policies.

JEL classification: F55, H23, L78, Q58

Keywords: Environmental Tax; Resource Taxation; Circular Economy; CE Indicators; Panel Data Regression Analysis

1 Introduction

Economic growth is strongly linked to investment, infrastructure, and construction activity, which increases global material use (OECD, 2019). Global material use is expected to rise from 89 Gigatons[73] in 2017 to 167 Gigatons by 2060 (OECD, 2019). The sharply increasing resource demand not only leads to the question of planetary limits to economic growth (Meadows & Club of Rome, 1972) but also – if further economic growth and prosperity are aimed at – requires society to significantly improve material management and its environmental impact. The impact of material use is not limited to resource depletion: Currently, the extraction, processing, use, and disposal of materials are estimated to account for approximately 60 % of global greenhouse gas (GHG) emissions (OECD, 2019). Furthermore, material extraction directly contributes to 90 % of total biodiversity loss and water stress impacts as well as up to 33 % of health effects of air pollution (The World Bank, 2022a). The circular economy (CE) concept, which promotes the extension of resource use, is considered a solution component (European Commission, 2020a). However, despite decreases in recycling costs due to technological progress, shares of secondary materials remain stable in current projections due to high labor costs and their high labor intensity compared to primary products and materials (OECD, 2019). Consequently, policy instruments are needed to foster economic transformation towards sustainability and circularity (European Commission, 2019).

Mitigating environmental impacts while ensuring resource supply and creating jobs through the enhancement of resource efficiency and promotion of CE principles – for example, through the creation of new job profiles along the value chain, especially concerning recycling and maintenance – have been acknowledged as critical societal goals by institutions at the national and international level (OECD, 2019). In this vein, the United Nations' Agenda 2030 with its 17 Sustainable Development Goals (SDGs) explicitly includes efficient use and sustainable management of natural resources in SDG 12, "Responsible consumption and production" (United Nations, 2015a). Implementing these goals at the European level, the European Commission has launched the Green Deal, which aims to increase the economy's resource efficiency and competitiveness (European Commission, 2019). The latter objective is intended to be realized by transitioning from linear economic structures to circular ones, promoting the successive use of materials (European Commission, 2019). In this context, the CE Action Plan defines targets and strategies for a transformation toward a CE and sets up a monitoring framework with indicators to measure progress (European Commission, 2020a, 2023). The present paper uses these indicators in the context of the analysis.

For regulating natural resource management and resource efficiency, many potential policy instruments exist (Bahn-Walkowiak & Wilts, 2017; Coria & Sterner, 2011). In Europe, (financial) market-based policy instruments reinforcing the polluter-pays principle, such as environmental taxes, constitute an increasingly favored policy instrument for pollution control and natural resource management (Eurostat, 2013; Söderholm, 2011b). Their effect is established through a price differential, making secondary resources more competitive in the market (Ludewig & Meyer, 2012).

During the last decade, resource taxation has been intensively discussed as different stakeholders request and recommend its implementation. At the European Union (EU) level, the Commission outlines the importance of revising taxes and subsidies distorting real resource usage costs (European Commission, 2011). Resource taxation is also frequently discussed, for example, at the national and sectorial level in Germany (Bahn-Walkowiak et al., 2010b;

[73] Throughout this article, "ton" refers to a metric ton (1000 kg).

Baronick et al., 2019a; Ludewig & Meyer, 2012; Meyer, 2012; Ostertag et al., 2021b). At the same time, some European countries have already introduced resource taxes for specific resources, such as the taxes on natural aggregates in place in Sweden, Denmark, and the United Kingdom (European Environment Agency, 2008b; Söderholm, 2011b). Nevertheless, robust empirical evidence on the effectiveness and steering effects of such taxes available at the public scientific level is still lacking (Postpischil & Jacob, 2018). Therefore, the present article contributes to closing the research gap on the effectiveness of resource taxation for CE purposes by answering the following research question:

How do resource taxes impact the implementation of circular economy principles in European countries?

The remainder of this article will be structured as follows: Chapter 2 briefly summarizes current scientific literature on environmental taxation and its effects and, based on that, further explains the research gap the present paper aims to fill. Afterward, Chapter 3 presents the data as well as the methods used. The results will be presented in Chapter 4 and further discussed in Chapter 5.

2 Background

In the definition by Eurostat[74] (2013), environmental taxes, that is, "tax[es] whose tax base is a physical unit (or a proxy of a physical unit) of something that has proven, specific negative impact on the environment" (p. 9) can be divided into energy, transport, pollution, and resource taxes. Due to its direct relationship to material management, a core component of CE, the present paper focuses on resource taxation, even though resource and pollution tax together only account for 4 % of total environmental taxes in Europe (Eurostat, 2019).

Many European countries have installed a resource tax, but their specific implementation differs strongly. One example is Sweden, which introduced a tax on gravel extraction in 1996 with a tax rate of around 0.57 EUR/t. Denmark introduced a more encompassing tax of around 0.67 EUR/t in 1990, which applies to stone, sand, gravel, peat, clay, and limestone, taxing both the extraction and import of these materials. The United Kingdom applies a much higher tax rate through their *aggregates levy*. The extraction of sand, gravel, and crushed stone is taxed at around 2.30 EUR/t (Bahn-Walkowiak et al., 2012b). More current information on tax rates is not readily available, but the low values of change in relation to the countries' gross domestic product (GDP) between 2010 and 2022 indicate that these rates have not changed significantly (European Commission, 2022). The experience with the taxation of natural resources in Europe is mixed. Researchers argue that the impact of such a tax by itself is modest but that the combination with other instruments is promising (Postpischil & Jacob, 2018; Söderholm, 2011b).

For researchers and policymakers, environmental taxes' implementation level, design, and effectiveness in promoting sustainability goals are of great importance. In the scientific context, the role of environmental taxes in transitioning towards CE is discussed rather sporadically. To obtain a comprehensive picture of the status quo of the scientific debate before diving deep into

[74] Eurostat is the statistical office of the European Union; https://ec.europa.eu/eurostat

the analysis of the research question, a literature review[75] is conducted. The review is not limited to resource taxation but considers environmental taxation in general. The key results from the literature research are presented below.

Milios (2021) proposes a tax framework for fostering CE, including resource and waste hierarchy taxation and tax reliefs for reuse and repair. In this framework, raw material resource taxation constitutes the most mature component (Milios, 2021) due to its implementation in several European countries[76] (European Commission, 2022). Virgin resource taxation may counter market failure, internalize environmental externalities of resource depletion, and prevent the transformation of materials into waste (Ludewig & Meyer, 2012; Söderholm, 2011b). A study by the European Environment Agency (2008) on the effects of aggregates taxation assumes positive effects of taxation on material use. However, it declares data to be insufficient to provide robust statistical results.

At the empirical level, numerous studies analyze the impact of CE indicators or environmental taxes on economic growth (Busu & Trica, 2019; Georgescu et al., 2022; Hysa et al., 2020; Sabău-Popa et al., 2022), sectoral production (Freire-González et al., 2022), and life satisfaction (Ortega-gil et al., 2021) or the impact of macroeconomic variables on environmental performance (Apalkova et al., 2022). However, literature on the impact of environmental taxes on CE progress remains scarce and does not draw a uniform picture of tax effects.

A case study for Spain shows that incineration and landfill taxation would have positive environmental impacts while not causing significant adverse effects at the national economy level (Freire-González et al., 2022). At the European level, the effects of environmental taxation on CE are found to depend on the indicator used, but energy, pollution, and transport taxes are found to positively contribute to overall CE progress (Ha, 2022). In another study, environmental tax revenues show moderate correlations with the Circular Material Use Rate (CMUR; 0.289), recycling rates for municipal waste (0.258), and resource productivity (RP; 0.174), whereas correlations with other variables studied are low (Busu & Trica, 2019). In the same vein, the relative importance of environmental tax revenues compared to total tax revenues is shown to have a significantly positive impact on CMUR and recycling rates (Kostakis & Tsagarakis, 2022). In contrast, no significant effects of environmental taxes are found on the recycling rate of municipal waste (Tantau et al., 2018) or RP at the European level (Taušová et al., 2022; Vuţă et al., 2018), while environmental taxes are even found to have a significant negative impact on RP in another study (Robaina et al., 2020). However, in a study focusing on Poland, the Czech Republic, Slovakia, and Hungary, a significantly positive effect of environmental taxes on RP is found (Taušová et al., 2022). Table V.A.1 in the appendix provides an overview of recent studies on the effects of environmental tax on CE in Europe.

Existing studies consider a multitude of different variables in their panel data models using a large variety of analysis methods. Due to the limited panel size in both years and individual countries due to data availability issues, this multitude of explanatory variables includes the risk of model overfitting (Hawkins, 2004), making it difficult to draw robust conclusions from these models. Moreover, except for Ha (2022), the existing studies analyze the effects of environmental taxes without distinguishing between tax categories. The study by Ha (2022) combines pollution and resource tax revenues into one variable and only covers nine years. In

[75] Literature is assembled via the Scopus database searching for full papers using the following keyword combinations: “Circular Economy” AND “Environmental Tax” as well as “Circular Economy” AND “Resource Tax”.

[76] For a detailed overview of countries having introduced a resource tax in the scope of our study, see Table V.A.3 in the appendix.

addition, a study by the European Environment Agency (2008), while indicating a positive effect of resource taxation on resource use, is qualitative. Thus, the current scientific literature cannot provide robust results on the effects of resource taxation on CE. The present study aims to contribute to this research gap.

The literature review and preliminary research reveal significant drawbacks that should be considered during the analysis. First, the concept of CE itself can be measured through numerous indicators (European Commission, 2023) due to its large scope, leading to difficulties in deriving unambiguous results, which is also reflected in the studies outlined above. Second, researchers suggest that resource taxation, as well as environmental taxation in general, cannot be the sole solution toward CE progress, which should instead be addressed by a multitude of different simultaneous measures (Bahn-Walkowiak & Wilts, 2017; Coria & Sterner, 2011; Ludewig & Meyer, 2012). These may include taxes on backfilling (Ostertag et al., 2021b), subsidies incentivizing eco-innovation (Bimonte et al., 2022), as well as a change in labor taxation (Groothuis, Femke, 2014; Kimla-Walenda, 2021; Vence & López Pérez, 2021). Therefore, Vence and López Pérez (2021) outline that current environmental taxation differs from circular taxation (i.e., taxation models explicitly and comprehensively supporting CE progress). These potential limitations identified during the literature review are considered in our data analysis.

3 Methods

3.1 Data Collection

We use regression analysis on data that we collect to answer the research question stated in Chapter 1. Our units of observation are member countries of the EU as well as of the Schengen Zone to increase our dataset. We collect data from Eurostat[77] and the World Bank[78]. Due to data availability and reliability issues, we exclude Liechtenstein, Romania, and Switzerland from the sample. Apart from these three countries, all members of the EU and the Schengen Zone are included (see Table V.A.3 in the appendix for an overview).

We choose our dependent variable from the CE monitoring framework published by the European Commission (European Commission, 2023) to measure the implementation of CE principles in different countries. The framework contains 27 indicators in total from which we select a set of five indicators that all refer to entire economies instead of specific sectors and for which sufficient data is available to conduct a robust panel data analysis. This set resembles the indicators chosen in previous studies as referred to in Table V.A.1 in the appendix. A table showing the specific reasons for the exclusion of each rejected indicator from the framework can be found in Table V.A.2 in the appendix. RP, the relationship between a country's GDP and its use of natural resources (domestic material consumption (DMC); European Commission 2023), shows the decoupling of economic growth from natural resource extraction, which reflects the state of the economy's circularity (European Commission, 2023). In particular, RP expresses the resource efficiency of an economy, which is likely to be affected by resource taxation. Hence, it is chosen as the main dependent variable. Data on RP is readily available in Eurostat, but only from 2000 onwards. To exploit a longer time range, we calculate this variable ourselves according to the formula used by Eurostat (Eurostat, 2016). Since data on the limiting factor, DMC, are available from 1995, we extend our time range by five years, now covering

[77] https://ec.europa.eu/eurostat/web/main/data/database
[78] https://data.worldbank.org

the period from 1995 to 2021. Because we compare countries over time, we use real GDP corrected for inflation using chain-linked volumes. To allow for comparisons between countries, we control for purchasing power by adding a conversion factor as a control variable. This method, in contrast to transforming the values into purchasing power parities, retains RP in its commonly used entity (i.e., EUR/kg).

To increase the reliability of our study and to make it less vulnerable to potential drawbacks of RP as a CE indicator (see Chapter 5), we furthermore test the effects of resource taxation on the following alternative dependent variables taken from the EU CE monitoring framework (European Commission, 2023):

- Material footprint,
- CMUR,
- Gross value added (GVA) related to CE sectors,
- Patents related to waste management and recycling.

The material footprint measures raw material consumption, that is raw material equivalents needed for the products consumed within a country, regardless of whether it is domestic or foreign extraction or direct or indirect use of these raw materials, and is measured in tons per capita (European Commission, 2023). In contrast, CMUR, also referred to as *circularity rate*, does not focus on total resource use but measures the percentage of circular material use expressed through waste recycled, corrected for imports and exports, compared to total DMC (European Commission, 2023). Hence, the indicator outlines how much of the primary resources in an economy can be substituted by secondary materials (European Commission, 2023). Our fourth indicator, GVA related to CE sectors, measures the contribution of CE to economic growth (European Commission, 2023) and is measured as a percentage of GDP to allow for cross-country comparison. Unlike the aforementioned indicators, which refer to the outputs of a CE transition, we understand patents related to waste management and recycling as an indicator for an ongoing or even upcoming CE transition based on innovation (European Commission, 2023). The indicator outlines the number of patents per million inhabitants which can be classified as related to recycling and secondary raw materials according to the Cooperative Patent Classification (European Commission, 2023). All alternative indicators are directly taken from Eurostat.

Our independent variable, the resource tax rate (RTR), requires calculations depicted in the formula below. The revenue from resource taxes in absolute terms is available but is problematic for comparing countries over time. Firstly, it is neither adjusted for purchasing power nor inflation. Secondly, it blends the number of resources extracted and the height of the resource tax. Hence, to obtain a tax rate, we correct the revenue for inflation using chain linking and divide it by the amount of natural resources extracted (domestic extraction (DE)). Since the total value for domestic extraction includes fossil energy materials and carriers (Eurostat, 2018b), but the resource tax revenues do not apply to these materials[79] (European Commission, 2022; Eurostat, 2020), we subtract this part from the total value to obtain our denominator. Note that this calculated tax rate represents the effective tax rate rather than the formal one. Not all resources are subject to resource taxation, and tax bases may differ according to tax regimes. The tax rate is expressed in monetary units (EUR) per ton, like is done, for example, for carbon taxes in Europe.

[79] Taxes on the extraction of oil and gas are not classified as resource but as energy taxes.

$$\text{Resource Tax Rate [EUR/t]} = \frac{\frac{Resource\ Tax\ Revenues}{Chain\ Linked\ Volumes\ Index}}{Total\ DE - DE\ fossil\ energy\ carriers}$$

We control for GDP since, being one of its components, it influences RP directly. Furthermore, productivity variables are shown to increase with increasing GDP and vice versa (so-called *procyclical behavior*; Basu & Fernald, 2001). To correct for skewed distributions and highly variable scales, we use the natural logarithm of RP, all alternative dependent variables, and GDP. Furthermore, we control for the share of non-renewable energy sources (the sum of solid fossil fuels, natural gas, and oil and petroleum products excluding biofuels) in total energy use. This is expected to strongly influence resource use and hence RP (European Environment Agency, 2012) as well as the material footprint and the CMUR, since energy production and consumption significantly contribute to total resource consumption but are not accounted for in resource taxes (European Commission, 2022, 2023). We choose to control for this effect by including the share of non-renewable energy as a control variable since this share cannot accurately be extracted from RP[80]. We further control for purchasing power to enable the comparison between countries. See Table V.1 for a detailed description of the variables in our model. Our regression model has the following form:

$$\ln(\text{RP}) = \beta_0 + \beta_1\ \text{RTR} + \beta_2\ \ln(\text{GDP}) + \beta_3\ \text{share of fossil energy} + \delta\ \text{power purchasing conversion factor} + \epsilon$$

Table V.1: Description of the variables in the model

Variable	Definition	Unit	Source[81]
RP (log)	GDP in relation to the total amount of materials directly used by an economy (measured as DMC; RP = GDP/DMC; Eurostat, 2016)	EUR/kg	Own calculations based on data from Eurostat and The World Bank
RTR	Resource tax revenue per ton of DE (excl. fossil energy materials/carriers)	EUR/ton	Own calculations based on data from Eurostat
GDP per capita (log)	Real GDP per capita corrected for purchasing power	EUR/capita	Own calculations based on data from Eurostat and The World Bank
Fossil Energy	Share of fossil fuels in final energy consumption (solid fossil fuels, natural gas, and oil and petroleum products excluding biofuels)	%	Own calculations based on data from Eurostat
Purchasing Power Conversion Factor	Spatial price deflator and currency converter that controls for price level differences between countries, designed for comparisons of GDP.	Factor	The World Bank

RP = resource productivity, GDP = gross domestic product, DMC = domestic material consumption, RTR = resource tax rate, DE = domestic extraction

3.2 Model Selection

While panel data offer a large potential for (economic) research, they come with the risk of cross-sectional dependence (CD). Ignoring the interdependence between observational units leads to biased estimation results (e.g., Sarafidis and Robertson, 2009). Therefore, we test for

[80] While the data allow for the subtraction of non-renewable energy materials or carriers from DMC, data is missing on the output generated with these materials, which can therefore not be extracted from GDP.
[81] Details on the calculations applied are available from the authors upon request.

the presence of CD in our data using Pesaran's (2004) CD test. The null hypothesis for this test is cross-sectional independence. The result indicates that we should reject the null hypothesis and thus that we are dealing with CD in our data (see Table V.2). To verify this result, we also apply the Lagrange Multiplier (LM) test by Breusch and Pagan (1980) and the bias-adjusted LM test by Pesaran, Ullah, and Yamagata (2008) on a balanced subset of our data[82], which confirm the presence of CD.

Table V.2: Results of Pesaran's (2004) CD test

Test	Statistic	p-value
Pesaran (2004) CD Test (postestimation after fixed effects panel regression)	7.641	0.000

CD = cross-sectional dependence

As a next step, we apply the so-called CIPS test by Pesaran (2007) instead of first-generation unit root tests to test for stationarity, as it allows for CD. As seen in Table V.3, we accept the null hypothesis of non-stationarity for the RTR but not RP and energy consumption from fossil sources. These variables appear to be stationary in their level form. The results further suggest that GDP per capita and the purchasing power conversion factor are stationary in their first difference but only in the specifications without and with a time trend, respectively.

Table V.3: Results of Pesaran's (2007) CIPS test for unit-root

	Intercept	Intercept + Trend
Log RP	– 4.255***	– 5.199***
RTR	3.394	2.692
Log GDP p.c.	0.792	2.839
Fossil Energy Consump.	– 1.550^{+}	– 2.906**
Purchasing Power Conv. Factor	1.915	– 0.427
Δ Log RP	– 2.232*	– 3.371***
Δ RTR	4.619	3.823
Δ Log GDP p.c.	– 1.464^{+}	0.879
Δ Fossil Energy Consump.	0.499	– 1.631^{+}
Δ Purchasing Power Conv. Factor	0.512	– 2.172*

$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

RP = resource productivity, RTR = resource tax rate, GDP p.c. = gross domestic product per capita

To test the cointegration relationship between the variables, we again apply a second-generation test that takes CD into account. Table V.4 shows the results of the Westerlund (2005) test of cointegration. The test rejects the null hypothesis of no cointegration, and both alternative hypotheses – cointegration in some and all panels – are accepted.

Table V.4: Results of Westerlund's (2005) test for cointegration

	Statistic	p-value
Variance ratio (some panels)	– 3.7013	0.0001
Variance ratio (all panels)	– 2.1094	0.0175

[82] These tests are only applicable to balanced datasets.

A final test of our data checks for slope homogeneity. The assumption of slope homogeneity is often invalid in panels with relatively large cross-sectional and time dimensions, and consequently, estimation procedures that assume slope homogeneity are biased (Pesaran & Smith, 1995). We apply the test by Pesaran and Yamagata (2008), which is robust to CD. As expected, we find slope heterogeneity in our data (see Table V.5).

Table V.5: Results of Pesaran and Yamagata's (2008) test for slope homogeneity

	Delta	p-value
Non-adjusted	17.412	0.000
adjusted	20.497	0.000

Note: The table shows the values for the overall model with all three explanatory variables. Separate tests show that all individual explanatory variables also have heterogeneous slopes.

To sum up, our data are cross-sectionally dependent in the errors, (at least partly) non-stationary, cointegrated, and have heterogeneous slopes. An estimation procedure that can deal with this type of data is the Augmented Mean Group (AMG) estimator by Eberhardt and Teal (2010). This estimator is also suitable for our data dimensions since it is designed for macro panels (moderate cross-section and time dimensions; Eberhardt, 2012). The AMG estimator is applied to a model of the following form:

$$y_{it} = \beta_i x_{it} + u_{it}$$

where y_{it} is an observable variable that is regressed on an observable variable x_{it} with a country-specific slope β_i. The unobservable variables as well as the error term are included in u_{it}:

$$u_{it} = \alpha_{1i} + \lambda_i f_t + \varepsilon_{it}$$

with α_{1i} being country-fixed effects that capture time-invariant heterogeneity across countries, f_t being an unobserved common factor, and λ_i the respective country-specific heterogenous coefficients. The latter captures CD and heterogeneity that varies over time (Eberhardt, 2012). Just like the related Mean Group (MG) estimator by Pesaran and Smith (1995) and the Common Correlated Effects Mean Group (CCEMG) estimator by Pesaran (2006), the AMG estimator first estimates an Ordinary Least Squares (OLS) regression for each country and then averages the resulting coefficients. The AMG estimator augments these OLS regressions with the so-called *common dynamic process* (cdp), derived from a pooled first-difference OLS with time dummies (Eberhardt, 2012).

To test for a causal relationship between the RTR and RP, we apply a Granger-causality test (Granger, 1969) in two steps. Firstly, we fit a panel vector autoregression (VAR) model with three lags of the RTR and RP. Then, we estimate the Granger causality Wald test for each equation in the panel VAR model. This tests the hypothesis that the RTR and its lags are jointly zero in the equation for RP (and vice versa; Abrigo & Love, 2016).

3.3 Robustness Checks

As a robustness check, we apply the Pooled Mean Group (PMG) estimator by Pesaran et al. (1999). The PMG and Mean Group (MG; Pesaran & Smith, 1995) estimators have been developed to deal with slope heterogeneity, which often occurs in macro panels. Both estimators allow short-run coefficients, intercepts, and variances to vary between groups. In

PMG, long-run coefficients are constrained to equality across countries assuming a long-term equilibrium, while the MG estimator also allows for heterogeneity in the long run (Blackburne & Frank, 2007). Both estimators are apt to deal with non-stationarity in the variables (Blackburne & Frank, 2007) and potential endogeneity issues. Since one could argue that resource taxes might be raised or installed to improve the country's RP or further unobserved variables are of influence, endogeneity could play a role in our case. While the AMG estimator does not take endogeneity into account, Eberhardt and Teal (2010) argue that "adopting a nonstationary panel econometric approach that accounts for cross-section dependence [...] is a sound empirical alternative to address both [endogeneity and instrument validity in macro panel data]" (p. 20). Nevertheless, we apply an estimator that can deal with potential endogeneity (i.e., PMG) to check whether our results are potentially influenced in this way. One drawback of the PMG estimator is that it does not control for CD, which should be kept in mind when interpreting the results. With the approach described, we follow the methodology of Sencer Atasoy (2017) with the following deviations: Firstly, we choose only the PMG instead of both the PMG and the MG estimator as a robustness check because it is more efficient if the assumption of long-run homogeneity is valid (Sencer Atasoy, 2017). In samples where the observational units are arguably similar, as for EU countries, assuming a common equilibrium relationship in the long run is reasonable. Secondly, we refrain from using the Common Correlated Effects Mean Group (CCEMG) estimator because it requires too many degrees of freedom for our sample size.

4 Results

4.1 Descriptive Results

RP has a mean of 1.69 EUR/kg. Its minimum value is found in Bulgaria in 2001 at 0.26 EUR/kg, and its maximum value of 5.88 EUR/kg belongs to the Netherlands in 2021. These values are based on our calculation of RP but are in line with those by Eurostat (Eurostat, 2022d). The mean RTR is 0.50 EUR/t. In a little less than one-third of our observations (excluding missing values), there is no RTR at all. Only four countries have introduced a resource tax during our time range from 1995 to 2021: Norway (2007), Luxembourg (2010), Iceland (2014), and Lithuania (2015). The highest RTR is found in Luxembourg in 2015 at 7.63 EUR/t. Note that these values depict the effective tax rates (see Section 3.1) and do not necessarily reflect the actual rates applied. The descriptive statistics of the variables in our model are listed in Table V.6[83]. See Figure V.1 for an overview of RP and the RTR per country in 2019[84].

Table V.A.3 in the appendix shows a list of the included countries (N = 29). The table also shows which years are included in the regression per country. In most cases, early observations are excluded because data on DMC, domestic extraction, and/or resource tax revenues in these years are not available. The earliest and latest data in our sample are from 1995 and 2021, respectively (T_{max} = 27). The dataset is unbalanced.

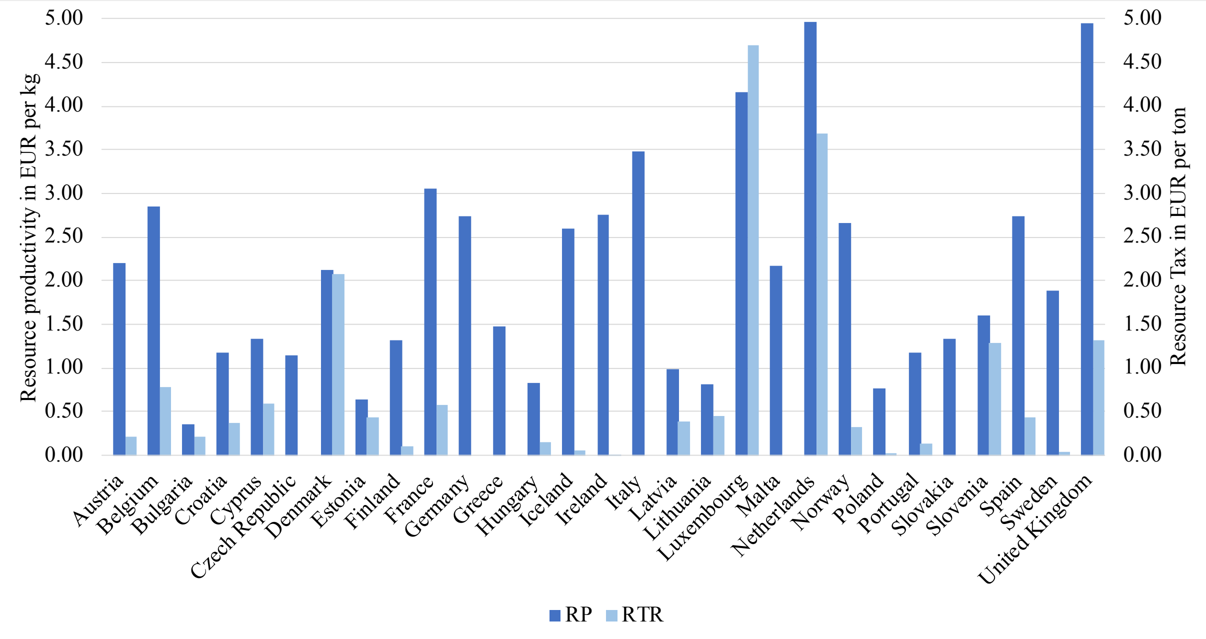
[83] The descriptive values refer to the variables in their base form. We partly use logarithmic transformation in the regressions.
[84] 2019 is chosen as the most recent year that is not influenced by the Covid-19 pandemic.

Table V.6: Descriptive results

Variable	Nr. of obs.	Unit	Mean	SD	Min.	Max.
RP	691	EUR/kg	1.69	1.02	0.26	5.88
RTR	641	EUR/t	0.50	1.00	0	7.63
GDP p.c.	776	EUR	28356.35	19161.26	3191.15	101321.90
Fossil energy consumption	781	%	59.30	14.13	16.55	83.66

Note: The purchasing power conversion factor is included in the model as a control variable, but omitted from this table as its parameters are not of interest.
SD = standard deviation, RP = resource productivity, RTR = resource tax rate, GDP p.c. = gross domestic product per capita

Figure V.1: Resource productivity and effective resource tax rate in 2019



RP = resource productivity, RTR = resource tax rate

4.2 Regression Results

Table V.7 shows the regression results of the AMG estimator with and without a time trend. We find a statistically significant positive effect of the RTR on RP. The results suggest that an increase in resource taxation of one EUR per ton of extracted material leads to an 8 to 10 % increase in RP on average.

Since the AMG estimator calculates country-specific regressions in the first step, we can get these country-specific results. Table V.8 shows large differences in the effect of the resource tax on the country's RP. We find strong evidence for a positive effect in Denmark, Portugal, Slovenia, Spain, and the United Kingdom and weak evidence for a positive effect in Sweden. In Latvia and Luxembourg, we find a negative effect of resource taxes on RP. We find no significant effect in the other countries in which a resource tax is implemented.

Applying the model to alternative dependent variables that measure the progress of CE, we find an effect of the resource tax on some of them (see Table V.9). While the RTR does not seem to influence the CMUR or the number of patents related to recycling and secondary raw materials, we find effects for the material footprint and GVA from CE-related activities. The statistically significant effects in columns 3 and 4 of Table V.9 imply that increasing the RTR (by one EUR/t) negatively influences a country's material footprint (by 11 to 16 % on average). The effect of resource taxes on GVA is positive in both and statistically significant in the specification without a time trend (column 7), suggesting that an increase of tax rates by one EUR/t leads to an increase in GVA from CE-related activities as a share of GDP by around 9 %. Note that the number of observations is decreased substantially when indicators other than RP are used because data is only available from later years on and/or not yet available until 2021.

Table V.7: Main regression results

	(1) AMG	(2) AMG with trend
RTR	0.0841^{**}	0.104^{*}
	(0.0323)	(0.0447)
Log GDP p.c.	0.0437	– 0.175
	(0.129)	(0.171)
Fossil Energy Consumption	– 0.00581	– 0.00247
	(0.00418)	(0.00399)
Purchasing Power Conversion Factor	0.0899	0.142
	(0.168)	(0.114)
cdp	0.716^{***}	0.606^{**}
	(0.142)	(0.201)
trend		0.00404
		(0.00499)
_cons	0.189	2.133
	(1.249)	(1.344)
N	625	625

Standard errors in parentheses
$^{+}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$
Results obtained using the AMG estimator
The dependent variable is log(RP).
AMG = augmented mean group, RTR = resource tax rate, GDP p.c. = gross domestic product per capita, cdp = common dynamic process, RP = resource productivity

Based on the test for Granger causality, we accept the null hypothesis that the RTR does not Granger-cause RP and RP does not Granger-cause the RTR (see Table V.10). This means that previous values of the RTR cannot be used to predict current values of RP or vice versa.

4.3 Robustness of Results

The regression results using the PMG estimator show an insignificant long-run but marginally significant and positive short-run effect (see Table V.11), suggesting that the positive effect of the RTR on RP is limited to a short-run effect. The error correction term (ec) coefficient is negative and statistically significant, confirming that the variables converge to a long-run equilibrium (Blackburne & Frank, 2007). Since the PMG estimator is not apt to deal with CD, the result should be interpreted carefully.

The results are also checked for robustness against outliers. We apply the criteria of being more than 1.5 times the interquartile range (IQR) above the third quartile of the RTR to identify outliers. Excluding these observations, the regression results remain qualitatively the same with respect to the positive and statistically significant effect of the RTR on RP[85].

Table V.8: Regression results for separate countries

Country	(1) AMG	(2) AMG with trend
Austria	0.212	0.368
Belgium	– 0.041	– 0.068
Bulgaria	0.016	– 0.042
Croatia	0.158	0.163
Cyprus	0.230	0.207
Denmark	0.082^{*}	0.081^{+}
Estonia	– 0.148	– 0.121
Finland	1.184	1.205
France	0.258	0.233
Hungary	0.342	0.322
Iceland	0.032	0.632
Ireland	9.710	4.452
Latvia	-3.487^{**}	-4.519^{**}
Lithuania	0.049	0.056
Luxembourg	-0.029^{**}	-0.030^{**}
Netherlands	0.023	0.001
Norway	0.448	0.447
Poland	0.310	0.737
Portugal	3.113^{***}	2.565^{***}
Slovenia	0.158^{**}	0.132^{*}
Spain	0.705^{**}	0.767^{***}
Sweden	1.626	2.720^{+}
United Kingdom	0.058^{**}	0.053^{**}

$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
The table only displays the coefficient of the RTR.
Results obtained using the AMG estimator
The dependent variable is log(RP).
Countries in which no resource tax is implemented are omitted from the table.
RP = resource productivity

[85] The results are available from the authors upon request.

Table V.9: Regression results with alternative dependent variables

	(1) RP	(2) RP with trend	(3) Material Footprint	(4) Material Footprint with trend	(5) CMUR	(6) CMUR with trend	(7) GVA	(8) GVA with trend	(9) Patents	(10) Patents with trend
RTR	0.0841^{**} (0.0323)	0.104^{*} (0.0447)	-0.163^{**} (0.0593)	-0.108^{*} (0.0516)	0.00395 (0.137)	0.0183 (0.0821)	0.0891^{*} (0.0446)	0.0466 (0.0369)	0.343 (0.309)	0.177 (0.312)
Log GDP p.c.	0.0437 (0.129)	– 0.175 (0.171)	0.966^{***} (0.154)	0.844^{***} (0.243)	0.112 (0.369)	0.232 (0.706)	-0.482^{**} (0.162)	-0.591^{**} (0.183)	– 2.164 (1.653)	– 0.671 (1.818)
Fossil Energy Consumption	– 0.00581 (0.00418)	– 0.00247 (0.00399)	0.00528 (0.00547)	0.00280 (0.00732)	– 0.00728 (0.0138)	– 0.0170 (0.0117)	0.00173 (0.00430)	0.00262 (0.00378)	– 0.0282 (0.0238)	-0.0749^{**} (0.0233)
Purchasing Power Conv. Factor	0.0899 (0.168)	0.142 (0.114)	0.168 (0.370)	– 0.755 (0.578)	– 1.166 (1.360)	– 1.231 (1.318)	– 0.387 (0.355)	– 0.485 (0.413)	– 1.378 (1.830)	– 0.701 (1.389)
cdp	0.716^{***} (0.142)	0.606^{**} (0.201)	0.883^{***} (0.170)	0.984^{***} (0.176)	0.527 (0.544)	0.472 (0.805)	0.896^{***} (0.172)	1.004^{***} (0.197)	0.496 (0.454)	0.392 (0.596)
trend		0.00404 (0.00499)		– 0.00594 (0.0128)		0.00375 (0.0280)		– 0.00390 (0.00722)		– 0.0320 (0.0540)
_cons	0.189 (1.249)	2.133 (1.344)	-7.553^{***} (1.218)	-7.199^{***} (1.886)	7.602 (5.654)	8.763 (7.913)	6.060^{***} (1.826)	7.073^{***} (1.961)	21.37 (15.84)	16.77 (14.38)
N	625	625	346	346	299	299	422	422	386	379

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
All dependent variables are logarithmized.
RP = resource productivity, CMUR = circular material use rate, GVA = gross value added, RTR = resource tax rate, GDP p.c. = gross domestic product per capita, cdp = common dynamic process

Table V.10: Results of the Granger-Causality test

	chi2	p-value
RTR → RP	0.260	0.967
RP → RTR	1.296	0.730

RTR = resource tax rate, RP = resource productivity

Table V.11: Robustness check: main regression results using the PMG estimator

Long Run	
RTR	– 0.0100
	(0.0210)
Log GDP p.c.	0.304***
	(0.0393)
Fossil Energy Consumption	– 0.0195***
	(0.00226)
Purchasing Power Conversion Factor	– 0.00265
	(0.00193)
Short Run	
ec	– 0.320***
	(0.0595)
D.RTR	0.718+
	(0.422)
D. Log GDP p.c.	– 0.337*
	(0.161)
D. Fossil Energy Consumption	– 0.00307
	(0.00390)
D. Purchasing Power Conversion Factor	– 0.704**
	(0.266)
_cons	– 0.570***
	(0.141)
N	596

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Results obtained using the PMG estimator
The dependent variable is log(RP).
RTR = resource tax rate, GDP p.c. = gross domestic product per capita, ec = error correction, PMG = pooled mean group

5 Discussion and Outlook

5.1 Discussion of Results

As outlined in the previous chapter, our analysis indicates that resource taxation contributes to CE progress when considering RP, material footprint, or the share of GVA related to CE activities as CE indicators. However, for two other CE indicators – CMUR and patents related to recycling and secondary materials – no significant impact of resource taxation is found. This ambiguity in results depending on the indicator used aligns with findings from previous studies on environmental tax effectiveness for CE progress purposes shown in the introduction. The concept of CE has multiple definitions and can be understood differently depending on the focus set (Moraga et al., 2019; Vranjanac et al., 2023). After analyzing and categorizing various CE indicators at different levels, Moraga et al. (2019) conclude that CE requires a set of indicators to be holistically assessed. However, such a set of indicators is not currently available and would cause substantial difficulties for regression analysis due to the multitude of dependent variables. Thus, with the knowledge of the possible shortcomings of a single indicator and the absence of a combined indicator encompassing all dimensions of CE, it is decided to target multiple indicators for the analysis. Nevertheless, the different CE indicators and their advantages and potential drawbacks, as well as further limitations to the results, will be discussed in more detail in this section.

The effect of an increase of 8 to 10 % in RP if resource taxes are increased by one EUR per ton might seem extremely high at first sight. However, it must be considered that the dataset is based on aggregate country data even though resource taxation is most probably only applied to a relatively small number of resources and the total calculated RTR only has a mean of 0.50 EUR per ton. Hence, an increase of one EUR would, in relative terms, correspond to an increase of 200 % in resource taxation. To contextualize these values, it is helpful to indicate that tax rates of 2 to 3 EUR per ton[86] are recommended for the implementation of a resource tax on construction minerals in Germany (Bahn-Walkowiak et al., 2012b; Ludewig & Meyer, 2012; Ostertag et al., 2021b).

Despite the positive results in the main analysis, the results using the PMG estimator do not show a significant long-run effect, and the Granger causality test does not show a causal relationship between resource taxation and RP, the latter meaning we cannot predict future RP based on previous or current resource taxation values with reasonable certainty. The lack of a significant long-run effect and statistical causality may be explained by factors such as the limited time span in data availability, the isolation of resource taxation as one measure of a potential policy mix, and potential distortions in the resource tax variable. These will each be explained in detail in the following.

According to the Organization for Economic Cooperation and Development (OECD, 2019), transformations of industrial sectors and their value chains are assumed to take 25 years. Even though our dataset comprises 25 years, the effects of changes in resource taxation that occurred within this time might only become visible in the future and cannot be displayed in the dataset at the current time. In addition, for many countries in our sample, 25 consecutive years (after resource tax implementation or increase) are not available. Especially with the ongoing CE debate, our study can only be understood as a first step, and it would be worth analyzing the effects of resource taxation again with a more extensive database.

As touched upon earlier, it should be kept in mind that significant resource problems are often addressed by a multitude of different simultaneous measures since the use of multiple policy instruments is seen as more efficient than a single instrument in many cases (Bahn-Walkowiak & Wilts, 2017; Bennear & Stavins, 2007b; Coria & Sterner, 2011). Such instruments could, for example, include criteria for public tenders, restricted mining licenses, or regulations for selective demolition (Postpischil & Jacob, 2018). Thus, it might seem expected that resource taxation as a single instrument cannot be proven to have a significant causal impact on RP. In

[86] Note that such a tax rate would be reflected in our data as much lower, since construction materials only make up a part, although significant, of all materials consumed within an economy.

this context, it is important to bear in mind that the effect of RTR found only reflects a part of the overall resource taxation in Europe. This is because the authority for taxation, particularly in environmental tax reform aimed at promoting resource efficiency, is not confined solely to the national level. Instead, regions also play a supplementary role (Bahn-Walkowiak & Wilts, 2017). The environmental tax data considered includes central, state, and local government taxes as well as social security funds (Eurostat, 2013). On the one hand, this enables capturing all environmental taxes in a country but, on the other hand, makes it more challenging to analyze single effects as the area or sector they apply to cannot precisely be delimited, limiting the accuracy of results.

The resource tax variable may also be subject to distortions: As resource tax revenues depend on the amount of primary resources used, tax revenues would not be suitable for comparing regulatory measures across countries. Tax revenue changes could result from changes in tax rates or bases and from changes in economic agents' behavior (European Commission, 2022). Hence, it is decided to calculate the effective RTR manually. However, the actual resource taxes may only tax specific raw materials. Thus, as no comprehensive information on the respective tax bases is available, the tax rates calculated are an approximation. Hence, the results can only be interpreted as an indication of the effectiveness of resource taxation. However, an in-depth sector- or resource-level analysis is strongly recommended once sufficient data is available. In such an analysis, the motivation for tax introduction should also be considered since even an environmental tax may be only fiscally motivated (European Commission, 2022), and motivation could be crucial for tax design and hence effectiveness regarding environmental effects.

The variety in country-specific results gives another potential reason why RP progress cannot reliably be predicted from resource taxation only and will be discussed later. Furthermore, the metrics used in this analysis treat imports and exports of materials differently. In addition, imports fall under the resource tax in some but not all countries. Therefore, it is impossible to neatly calculate RP or a tax rate taking material trade into account. The results are checked for robustness to this impurity in data by adding imports and exports of materials as control variables and calculating RP with domestic extraction as a denominator only. The results are qualitatively unchanged in both cases[87].

Despite the limitations explained above, the fact that not only RP but also material footprint and the share of CE-related GVA seem to be significantly affected by resource taxation strengthens our conclusion of a positive effect of resource taxation on CE progress. Even though RP seems to perfectly illustrate if a country has achieved decoupling economic growth from resource use at first sight, it needs to be considered that RP increases may also result from outsourcing of material-intensive production steps (Eurostat, 2023d). However, the material footprint is explicitly outlined as robust to production outsourcing and includes raw material consumption from products produced abroad (European Commission, 2023). At the same time, it should be noted that material footprint does not account for the countries' level of economic prosperity, which is included in RP. Despite these limitations, since resource taxation seems to decrease the material footprint per capita while increasing RP, we conclude that the positive impact on CE indicators is not distorted by potential drawbacks of the indicators caused by the globalization of value chains or different levels of economic prosperity. However, it still needs to be considered that the economic crisis between 2007 and 2014 led to an increase in RP due to declined construction activity, resulting in a stronger decrease in DMC compared to GDP (European Environment Agency & ETC/WMGE, 2016). As the material footprint is a mass-

[87] The results are available from the authors upon request.

based indicator heavily influenced by construction activity, the crisis will most likely have had the same effect on the material footprint. Based on these considerations, we check CE-related GVA, which also seems to be positively affected by resource taxation, for any decline or other evident impact from the financial crisis. However, we could not depict anomalies in the dataset during this period. Therefore, we conclude that the economic crisis does not drive the effects of resource taxation on our indicators.

It seems astonishing that no significant effect of resource taxation on CMUR is found. Thus, it appears necessary to analyze the indicator in more detail. Recent research on the CMUR shows that changes in the denominator, DMC, mainly drove variation in the indicator during the last almost 20 years, while recycling amounts remained more or less stable (Christis et al., 2023). This might explain why we find an effect when applying indicators more directly related to total material consumption than CMUR. Furthermore, the maturity of the indicator needs to be questioned since it only considers recycling (Christis et al., 2023) but cannot correctly display other circular material uses. These would currently only be reflected through a decrease in the denominator (i.e., DMC) but not an increase in the numerator of the indicator, even though they would – at least theoretically – be part of it. Furthermore, Eurostat data induces that definitions used to collect data should be further clarified (Eurostat, 2018a). If there were different understandings of definitions amongst European countries, this might distort and hence weaken the indicator in its current state. Finally, a large share of the CMUR data is marked as a "Eurostat estimate", while for some countries, there is no data at all. The finding that resource taxation does not seem to influence the relative number of patents related to waste management and recycling in a country could result from not distinguishing between different material flows. For example, one significant stream of resource consumption is minerals, for which the recycling process is already advanced enough to produce secondary materials of high quality. Thus, patents would not necessarily reflect progress in this area.

As mentioned above, the country-specific results show that resource taxes are not uniformly effective. We find evidence – whether strong or weak – of a positive effect of the tax on RP in six countries. Further, two countries show a negative effect, and six countries do not have any resource tax installed. This leaves 16 countries where the tax does not seem to influence RP. In addition, the effect sizes also vary strongly between the countries with a significantly positive effect. This suggests that there are further unobserved factors that influence this relationship. One candidate for such a factor is the specific implementation of the tax. As stated earlier, tax systems fall under the jurisdiction of the national governments or even federal states, leading to a wide range of specifications of the same tax in different countries. These differences are not reflected in our data and could thus explain the differences in the effects. The countries with a negative effect are especially interesting. For Latvia, data on resource tax revenues are only available from 2008. The effective tax rates we calculate range from 0.20 to 0.42 EUR per ton. Luxembourg draws a very different picture: The country installed a resource tax in 2010, which shows very high variation (the effective tax rate ranges from 2.37 to 7.63 EUR per ton). It is conceivable that the effects are artifacts or reflect a potential issue of reverse causality: The countries might have implemented or raised resource taxes to foster the CE based on low performances thus far. However, an in-depth analysis of other potential influencing factors would be necessary to unequivocally explain the effects of resource taxation for Latvia and Luxembourg. This could identify why the effects of resource taxation appear to deviate strongly from tendencies observed in other countries or in the cross-country analysis.

5.2 Outlook

As mentioned earlier, regulatory environmental incentivization most likely includes a set of different measures. As tax incentives are rarely installed in isolation, it is conceivable that at least some countries implemented the resource tax in combination with other measures. The potential variety of these accompanying measures and their interplay with the resource tax is another conceivable factor determining whether and to what extent the resource tax affects RP. One endeavor for future research could be to identify these distinguishing factors to inform policymakers regarding the most efficient way to design policy instruments and their combinations. The introduction already outlines that regulatory incentivization of circular practices might also include changes in labor taxation (Groothuis, Femke, 2014; Kimla-Walenda, 2021; Vence & López Pérez, 2021). An example is the environmental tax reform, which implies shifting taxation from labor and capital to pollution and resource depletion (Ekins, 2009). Labor taxation is not included in the present model for reasons of simplicity and data availability.

Similarly, our model could be extended by including waste taxation, which the CE taxation framework by Milios (2021) suggests. However, lack of data availability is the reason why this variable is not included in the model: Environmental taxation data at the European level only reports pollution taxes (Eurostat, 2013), which, besides waste taxes, also include taxes on emissions to air and water, as well as noise taxes (Eurostat, 2013). In addition, these taxes are only reported as revenues (Eurostat, 2013), which would – analogously to resource taxation – lead to additional uncertainties as different tax bases might be confounded when calculating tax rates.

A profound understanding of policy intervention effects on resource efficiency would also require a detailed analysis at the sectoral level (OECD, 2019). Throughout the elaboration of the present paper, attempts have been made to conduct a corresponding regression analysis for the construction sector since it is specifically known to have significant impacts on resource consumption and waste generation (European Commission, 2020a). However, due to the unavailability of sector-split DMC data in the Eurostat database, alternative databases were taken into consideration. Significant differences in the total economy's DMC data manifested during the analysis between Eurostat and its considered alternatives. To ensure data reliability and coherence between different datasets considered for the analysis, only total economy data are analyzed in the present analysis.

In summary, resource taxation – though it might still play a smaller role in Europe than other environmental taxes – seems to contribute to CE progress even in its current stadium. Nevertheless, further research should be conducted to investigate the effects of regulatory measures and moderating factors on CE progress in more detail.

6 Appendix

Table V.A.1: Overview of selected empirical studies

Authors	Period observed	Empirical Methods	Dependent Variables (CE indicators)	Independent Variables
Ha, 2022	2011 – 2019	– Panel-corrected Standard Errors Model – Feasible Generalized Least Squares Estimates – Autoregressive Distributed Lag Method	– Patents associated with recycling & secondary raw materials – Generation of municipal waste – CMUR – Waste recycling share (total & for specific waste fractions)	– *Environmental tax revenues (total/energy/resource & pollution/transportation)* – Gross Domestic Product (GDP) per capita – Trade share – Net inflow of foreign direct investment – Industrialization level – Environmental Performance Index – Natural rents – Democratization
Kostakis & Tsagarakis, 2022	2010 – 2017	– Fixed effect panel data analysis – Instrumental variable fixed effect panel analysis	– CMUR – Recycling rate of municipal waste	– Real GDP per capita – Tertiary education level – Fertility rate – Urbanization – *Environmental taxes (% of total tax revenues)* – Research & Development (R&D) expenditure
Robaina et al., 2020	2000 – 2016	– Cluster analysis – Panel unit root test – Panel cointegration test – Vector autoregression model	– RP	– *Environmental tax revenues (% of GDP)* – Renewable energy consumption – R&D expenditure – Recycling rate – Population density – Gross value added (GVA) per sector
Tantau et al., 2018	2010 – 2014	– Random and fixed effects panel data analysis	– Recycling rate of municipal waste	– CMUR – R&D expenditure – RP – Trade in recyclable raw materials – *Environmental tax revenues*

Taušová et al., 2022	1990 – 2020	– Multiple linear regression analysis	– RP	– DMC per capita – Energy productivity – Recycling rate – Water productivity – Landfill rate – GHG emissions per capita – Energy dependence – Eco-Innovation – Energy taxation – *Environmental taxes (% of GDP)* – Share of renewable energy – Waste generation – CMUR
Vuţă et al., 2018	2005 – 2016	– Panel data regression analysis	– RP – Real GDP growth rate	– Recycling rates (packaging, biowaste, municipal waste) – *Environmental tax revenues (% of GDP)* – CE research activity (patents, R&D expenditure) – Real GDP growth rate

Studies analyzing the effects of environmental taxation in the CE context in Europe at country-level. Environmental tax variable highlighted in italics
CE = circular economy, CMUR = circular material use rate, GDP = gross domestic product, R&D = research and development, GVA = gross value added, RP = resource productivity, DMC = domestic material consumption

Table V.A.2: CE Indicators: Reasons for in- or exclusion in the model

No.	Indicator	Inclusion in the model	Indicator description and rationale for in-/exclusion
1a	Material footprint	Yes	The material footprint measures an economy's raw material consumption, i.e., domestic and foreign extractions required directly or indirectly for the consumption of an economy (European Commission, 2023). As it is robust to production outsourcing (European Commission, 2023), it is particularly interesting to consider this indicator in addition to RP. A drawback to this indicator is that the data are only fully available from 2008 on.
1b	RP	Yes	RP is deemed suitable for the analysis because it sets resource consumption into relation to economic activity. Hence it expresses if an economy becomes more resource-efficient which might potentially also be fostered by resource taxation.
2	Green public procurement	No	Indicator is still being developed (European Commission, 2023).
3a	Total waste generation per capita	No	Sustainable resource use which could be fostered by resource taxation should also result in decreasing amounts of waste. While we would have liked to include the indicator in our analysis, data is only available from 2004 on and recorded biannually. This leaves us with an insufficient database to run any meaningful regressions.
3b	Total waste generation (excl. major mineral waste) per GDP	No	The indicator explicitly excludes major mineral waste which accounts for a large share of resource use and hence of resources potentially taxed (Eurostat, 2023g). We assume that mining and quarrying as well as construction sector could be a main focus area of resource taxation.
3c	Generation of municipal waste per capita	No	Resource taxation has a broad scope and may include all kinds of natural resource use or depletion (Eurostat, 2013). In the absence of reliable EU-wide data on which types of resource taxes account for the largest share in resource taxation, we refrained from applying sector-specific CE indicators because we cannot reliably assume sector-specific causal effects.
3d	Food waste	No	
3e	Generation of packaging waste per capita	No	

3f	Generation of plastic packaging waste per capita	No	
4a	Recycling rate for municipal waste	No	
4b	Recycling rate for all waste excl. major mineral waste	No	Major mineral waste includes mainly construction/demolition and mining wastes (Eurostat, 2022b). However, we assume that mining and quarrying as well as construction sector could be a main focus area of resource taxation. Hence, the indicator does not seem to be suitable for our analysis.
5a	Recycling rate for overall packaging waste	No	Resource taxation has a broad scope and may include all kinds of natural resource use or depletion (Eurostat, 2013). In the absence of reliable EU-wide data on which types of resource taxes account for the largest share in resource taxation, we refrained from applying sector-specific CE indicators because we cannot reliably assume sector-specific causal effects.
5b	Recycling rate for plastic packaging waste	No	
5c	Recycling rate for electrical and electronic equipment waste that is separately collected	No	
6a	CMUR	Yes	Primary resource taxation is assumed to increase resource prices. The latter might also increase the demand for and use of secondary materials which would then be reflected in the circular material use rate expressing the ratio of recycled waste material to overall material demand (European Commission, 2023). A drawback of this indicator is that the data are only fully available from 2010 on and declared as “estimates” by Eurostat. Data for some countries are lacking entirely (Eurostat, 2023f).
6b	End-of-life recycling input rate	No	Limited data availability, data is only collected every three years from 2013 onwards (European Commission, 2023).
7a	Recyclable raw material imports from outside the EU	No	The indicator focuses on specific material categories. In the 2023 update of the EC CE Monitoring framework, the following categories were added to the indicator: ‘glass’, ‘wood’, ‘textiles’, ‘minerals’, and ‘animal and vegetal’ products (European Commission, 2023). The latter categories do not yet seem to be integrated in the dataset (Eurostat, 2022a), but constitute important shares of total material use (Eurostat, 2023g). Since we assume them to be potentially relevant targets for resource taxation, we consider the indicator as not suitable for our purposes in the status quo of data available.
7b	Recyclable raw material exports to outside the EU	No	
7c	Intra-EU trade in recyclable raw materials	No	

8a 8b 8c	Private investments related to CE sectors Employment related to CE sectors Gross value added related to CE sectors	No No Yes	To keep analysis of resource taxation effects clear and concise, we decided to limit the total number of indicators analyzed. Hence, it was decided to include only one of the competitiveness indicators. Out of these three indicators, the share of CE-related GVA seemed to be most directly influenced by resource taxation. Moreover, we assume private investments to potentially have a delayed effect that we cannot control for. Finally, employment figures might not necessarily reflect all improvements in CE activities (i.e., CE progress can also occur to a certain extent with constant employment levels).
9	Patents related to waste management and recycling	Yes	The indicator reflects innovation activity related to recycling and secondary raw materials (European Commission, 2023). As transformation of industrial sectors and its value chains are assumed to take 25 years (OECD, 2019) which exceeds the time span for which data is available. Indicators such as RP illustrate the results of a transition process towards CE whilst patents could also show the transition in progress.
10a	Consumption footprint	No	Data availability: data only available from 2010 onwards.
10b	GHG emissions from production activities	No	To our understanding, there is no direct link between resource taxation and GHG emission, except for the emissions caused by recycling activities. We would expect other environmental taxes to have significant effects on GHG emissions (e.g., energy or pollution taxes).
11a 11b	Material import dependency EU self-sufficiency of raw materials	No No	The indicator reflects the ratio between (net) material imports and material inputs or material consumption (European Commission, 2023). If total material input decreases due to CE transition, the ratio may not reflect this progress properly if, for example, the imports decrease at the same rate as input or if they even remain stable since the material group imported cannot yet be replaced by secondary materials. Hence, we decided not to include the indicator in our analysis.

Indicators from the CE Monitoring Framework (European Commission, 2023)
CE = circular economy, RP = resource productivity, GDP = gross domestic product, EU = European Union, CMUR = circular material use rate

Table V.A.3: Overview of the countries in the model

Country	Resource Tax (1995 – 2021)	Years included in regression
Austria	Yes	1995 – 2020
Belgium	Yes	1995 – 2020
Bulgaria	Yes	2000 – 2020
Croatia	Yes	2000 – 2020
Cyprus	Yes	2008 – 2020
Czechia	No	1995 – 2020
Denmark	Yes	1995 – 2020
Estonia	Yes	2000 – 2020
Finland	Yes	2000 – 2020
France	Yes	2008 – 2020
Germany	No	2000 – 2020
Greece	No	2000 – 2020
Hungary	Yes	1995 – 2020
Iceland	Since 2014	1995 – 2019
Ireland	Yes	1995 – 2021
Italy	No	1995 – 2021
Latvia	Yes	2008 – 2020
Lithuania	Since 2015	2000 – 2020
Luxembourg	Since 2010	2000 – 2020
Malta	No	2000 – 2020
Netherlands	Yes	1996 – 2020
Norway	Since 2007	2006 – 2020
Poland	Yes	2003 – 2020
Portugal	Yes	1995 – 2020
Slovakia	No	1998 – 2021
Slovenia	Yes	1995 – 2020
Spain	Yes	2000 – 2020
Sweden	Yes	2008 – 2020
United Kingdom	Yes	2000 – 2019

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