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Environmental sustainability of data centers. First results and recommendations

Green and Sustainable Public Procurement

Green Public Procurement when the Seller is Privately Informed about a Bidder

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Contributor/s	Marco Bettiol (UNIPD) Riccardo Camboni Marchi Adani (UNIPD) Ermina Florio (UNITORV) Marco Pagnozzi (UNINA)
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Executive summary

This policy brief includes multiple strands of research. The first focuses on the environmental sustainability of data centers, while the second encompasses both empirical and theoretical studies on green public procurement (GPP).

Data centers are critical to the digital economy but are highly energy-intensive, hence raising environmental concerns. We show using qualitative as well as quantitative methods that operators invest in energy efficiency, renewable energy, and circular economy practices, such as reusing and recycling equipment. However, progress is uneven, with challenges in adopting renewable energy due to reliability demands and limited implementation of comprehensive sustainability measures like Life Cycle Assessments (LCAs). Our findings also show that some companies effectively communicate their sustainability efforts, though most provide limited transparency: they prioritize security, energy efficiency, and connectivity in data center design, with sustainability considered secondary but increasingly important. Our research suggests that policymakers should collaborate with industry stakeholders to promote transparency, incentivize renewable energy and enforce stricter recycling measures. The effort should be directed toward balancing environmental sustainability with operational reliability.

The research on GPP empirically investigates two main strands: the dynamics of procurement scoring mechanisms and the impact of environmental laws on procurement processes and outcomes. The University of Padua (UNIPD) focuses on evaluating the balance between price and quality in public procurement tenders using a novel AI-driven methodology. Researchers analyzed an extensive dataset of Italian procurement contracts. Initial findings reveal a systemic preference for cost over quality in procurement scoring, with price accounting for 64% of the scoring weight. This bias suggests potential inefficiencies in achieving sustainability goals. By emphasizing quality more in scoring mechanisms, policymakers can incentivize greener and more sustainable procurement practices.

The introduction of Criteri Ambientali Minimi (CAM), mandatory environmental criteria for certain procurement categories, has raised reserve prices and reduced winning rebates, suggesting increased costs for public buyers. The criteria may also affect competition by slightly decreasing bidder participation, though the impact varies by

category. Our findings highlight the importance of balancing environmental goals with maintaining competition and cost efficiency in procurement.

Complementary research by UNITORV examines the role of SMEs in public procurement, particularly in leveraging the Legality Rating (LR) system to enhance transparency and competitiveness. Our results indicate that SMEs with an LR are significantly more likely to win procurement contracts, demonstrating the system's potential to support smaller firms' participation in public tenders. However, barriers such as revenue thresholds may inadvertently disadvantage smaller firms. Policy implications include the need for recalibrating procurement-scoring weights to emphasize quality, exploring mechanisms to offset CAM-related cost increases, and supporting SMEs through alternative certification mechanisms.

The study by Carannante, Pagnozzi, and Sartori (2024) analyze the design of GPP processes when the public authority has private information about one of the bidding firms. The analysis reveals how public authorities can strategically adopt procurement mechanisms to minimize costs, depending on their information about bidders. The research also shows that, among all standard auctions, first-price auctions minimize the variability of interim costs, making it the safest option for risk-averse authorities. These insights offer valuable guidance for designing public procurement policies that effectively take into account the authority’s private information, ensuring cost efficiency and reduced financial risk.

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1. Presentation and description of the research activity undertaken

1.1 Environmental sustainability of data centers

Despite being hidden from our sight, data centers play a crucial role in supporting the functioning of society and the economy. The escalating volume of data generated globally today, with anticipated growth in the coming years, underscores the increasing relevance of these systems. While the importance of data centers is unquestionable in the current landscape of digital services, it becomes crucial to understand their environmental impact. Data centers, by their very nature, are energy-intensive, consuming substantial amounts of energy for the operation of IT and electrical equipment (servers, network systems, uninterruptible power supplies), and notably, for their cooling. Moreover, the issue of environmental sustainability of data centers is a strategic issue even for the data center operators themselves, mainly the large digital companies, who are increasingly accountable to stakeholders and consumers for the impacts they generate.

Our research was born to understand how the data center industry is addressing environmental sustainability from a circular economy perspective. Our research question stems precisely from the need to gain a clear understanding of how industry players are framing this issue and the solutions they have introduced or plan to introduce in the near future. To answer this question, we adopted a qualitative-quantitative approach.

1.2 Green and Sustainable Public Procurement

The University of Padua (UNIPD) research group is investigating two research strands.

Firstly, the UNIPD studies the quantitative and qualitative elements in green procurement tenders and assesses their impact in the different phases of procurement processes (i.e., mainly in the awarding and execution phases). The research group aims to investigate the "*cost*" of green procurements at the public buyer (PB) level from two parallel perspectives: the amount of *monetary* and *non-monetary* recourses spent by PB and the outcomes of procurements in terms of *time* and *cost* of execution. We

obtained data on procurement tenders from a private company: the official documents released by every Italian public buyer on procurement contracts for cleaning services. Then, we exploited local language models (LLM) to enable artificial intelligence (AI) to read and extract specific information from such documents. After the testing phase, we extracted the relative importance of the price and quality of the services required by PBs for each tender. We linked these data to the open database of the Italian National Anti-Corruption Agency (ANAC). We are revising the activities mentioned above to move on to the empirical analysis of the research project. We expect to have the preliminary results within a few months.

Secondly, UNIPD and the University of Rome (UNITORV) are investigating the introduction of *Criteri Ambientali Minimi* (CAM): the minimum environmental criteria that green procurements must have and are specific to various stages of the procurement process. The related law was modified over time for the same type of goods, services, and work. We rely on the policy discontinuities that these laws created over procurement contracts: we study how introducing these laws has influenced both awarding mechanisms of procurement contracts and contract outcomes. We distinguish procurement contracts belonging to the following categories: *i*) procurement categories never modified by the law (our control group), procurement categories modified at least once by the law (first treatment group), and *ii*) procurement categories modified more than once by different laws (second treatment group). This categorization allowed us to have an overview of the regulative changes and identify the groups of interest for the empirical analyses. We have started implementing a staggered Diff-in-Diff (DID) analysis using the treatment and control groups described above since the policy discontinuities affect procurements at different points in time and for different procurement categories.

The UNITORV research group studies how the entry of small and medium-sized enterprises (SMEs) in public procurement is affected by the rules of green and sustainable procurement. Moreover, researchers also aim to investigate if public procurement promotes sustainable practices among SMEs. To this end, they examine the performance of SMEs in the Legality Rating. The Legality Rating (LR) is an institutional tool developed by the Italian Antitrust Authority to assess the legality of Italian companies in terms of fiscal transparency, adoption of anti-corruption practices, attention to corporate social responsibility, etc.[1] Using a Regression Discontinuity Design, the research group has exploited the possibility for Italian

[1] LR is a discrete measure, from 1 to 3, where the minimum score is assigned to firms that only comply with the basic requirements on fiscal discipline, transparency of the records, and safety regulations.

companies to apply for the LR if their previous year revenues are above two million euros and compared firms that were marginally above the two million euros threshold with firms that were just below the threshold to predict the attainment of the LR. We looked at the effect of the predicted value of the LR attainment on the dummy for winning tenders.

1.3 Green Public Procurement when the Seller is Privately Informed about a Bidder

In many GPP processes for the execution of public works, the public agency in charge of the process has some information about at least one of the firms participating in the process. For example, the agency may have information about the actual cost of production of a firm that is currently executing similar work for it, or that has re-negotiated an existing procurement contract. What is the procurement format preferred by an authority that is informed about one of the bidders? How does the preferred format depend on the precise information that the authority has about the bidder?

The research project "Interim Information and Seller's Revenue in Standard Auctions" by Marco Pagnozzi (joint with Federica Carannante and Elia Sartori) addresses these questions in the context of standard auctions, which are sealed-bid auctions where the winner is the highest bidder that are ex-ante equivalent by the Revenue Equivalence Theorem. In particular, Carannante et al. (2024) analyzes the *interim revenue* — i.e., the expected seller's revenue conditional on the valuation of one of the bidders — in the efficient equilibrium of different types of standard auctions. The authors show that the first-price auction yields higher (lower) interim revenue than the second-price auction if the valuation is below (above) a threshold. When a bidder has a sufficiently low valuation, the first-price auction also has the highest interim revenue among all standard auctions. By contrast, when a bidder has a sufficiently high valuation, the first-price auction yields the lowest interim revenue, while the last-pay auction — an atypical mechanism where only the lowest bidder pays — allows the seller to extract arbitrarily large revenues.

The results of the research project are relevant for settings where the seller has private information about a particular bidder, while other competitors are unaware of that. In the context of GPP, the results imply that the public authority should prefer to adopt a

different procurement process, depending on its information about one of the possible suppliers. In particular, if the authority expects that one of the bidding firms has a higher-than-average cost of production, then it should prefer a procurement process where the bid of that firm does not affect the payments of other bidding firms. In this case, the best mechanism would be a first-price auction. By contrast, if the authority expects that one of the bidding firms has a lower-than-average cost of production, then it should prefer a procurement process where the bid of that firm does affect the payments of other bidding firms, like in a second-price auction.

2. Relationship with the existing literature on the topic

2.1 Environmental sustainability of data centers

While scientifically validated estimates are currently lacking, a recent report by IDC[2] attempts to calculate the worldwide growth of data production. According to this estimate, the amount of data will grow from 33 zettabytes in 2018 to as much as 175 in 2025. The prediction is that about 50 percent of this data will be hosted in data centers. This growth is also accompanied by the increase in investment in the sector, which according to a recent McKinsey[3] report will rise from $31 billion in 2022 to $49 billion in 2030 with a growth of 5.4 percent per year. According to Data Center Map, the number of data centers has reached the figure of 4984 units. Although data centers are located in 130 countries around the world, their geographical distribution is not homogeneous. In the United States alone, 37 percent (1851) of the world's data centers are located.

In the report prepared by the Environmental Protection Agency (EPA) and presented to the U.S. Congress in 2007, it was estimated that data center energy consumption in the United States was equivalent to about 1.5 percent of the country's total energy consumption of 61 terawatt-hours (TWh) in 2006 for a total electricity cost of about $4.5

[2] https://www.seagate.com/files/www-content/our-story/trends/files/idc-seagate-dataage-whitepaper.pdf

[3]https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/investing-in-the-rising-data-center-economy

billion. More recently, research conducted by the European Union's Joint Research Center (JRC) estimated the consumption of European data centers at 74 TWh per year or 2.25 percent of total energy consumption.

Several scientific studies have tried to calculate the energy consumption of data centers. Estimates again vary widely. On the one hand, there are studies that calculate that consumption will increase from 200 TWh in 2010 to a range of 2000 to 3000 TWh in 2030 (A. Andrae & Edler, 2015; A. S. G. Andrae, 2020; Belkhir & Elmeligi, 2018b; The Shift Project, 2019). In contrast, other studies seem to have used a different approach and calculated that data center consumption has remained essentially stable over the past few years (IEA, 2017; Masanet et al., 2020; Shehabi et al., 2018). In this case the values are significantly smaller: between 196 TWh (Masanet et al., 2020) and 400 TWh (Hintemann, 2020).

The substantial difference in estimates can be attributed to the absence of shared methodologies for calculating energy consumption at the aggregate level. Calculations pose a challenge because individual data centers do not disclose data on their annual consumption. Therefore, reliance on estimates is necessary. However, these estimates may not always account for the rapid technological changes and engineering solutions developed by companies to enhance the efficiency of individual appliances and data centers as a whole.

2.2 Green and Sustainable Public Procurement

The literature on GPP remains limited and has seen little change from the previous year's policy briefs.[4] A notable addition is a new working paper by Chiappinelli et al. (2024), who rely on US data to investigate the effect of sustainable procurement on awarded firms and find that it positively impacts economic performance and green corporate practices. Krieger and Zipperer (2022) show that small and medium-sized firms introduce more environmentally friendly products after introducing green clauses in public purchasing. In accounting and finance, Zheng and Wen (2024) find that GPP enhances corporate environmental performance, social responsibility, and ESG metrics, promoting sustainable development. Similar findings have been reported by Huang, Han, and Li (2023), though using a different methodological approach.

[4] See Chiappinelli (2022) for a review of the literature.

Regarding public buyers and the design of awarding mechanisms for GPP, Chiappinelli, and Seres (2024) find that GPP can be an optimal mechanism for environmentally conscious procurers. These findings challenge existing literature (Lundberg and Marklund, 2011, 2013; Lundberg et al., 2016), which often views GPP as a suboptimal and non-cost-effective policy tool. In summary, recent studies highlight the positive impacts of GPP on firm productivity and corporate sustainability while suggesting that well-designed GPP mechanisms can be cost-effective for public buyers.

Parallelly, the limited impact of green criteria on the final decisions in supplier selection (Igarashi et al., 2015) might be attributed to the authorities' deficiency in competence to integrate environmental criteria into the selection procedures (Cheng et al., 2018)[5], low administrative capacity in the execution of complex technical requirements (Chiappinelli et al. 2019), and the rigidity of GPP regulations (Shadrina et al., 2022). However, Alvarez and Rubio (2015) and Cerutti et al. (2016) suggest that GPP may have positive effects in enhancing sustainable practices adopted by the companies. Then, even if green criteria requirements are still not commonly present in public procurement, they appear to affect firms, buyers, and the environment positively.

2.3 Green Public Procurement when the Seller is Privately Informed about a Bidder

In an environment with risk-neutral bidders who have independent private valuations, the celebrated Revenue Equivalence Theorem (Vickrey, 1961; Myerson, 1981; Riley and Samuelson, 1981) shows that any efficient equilibrium of any auction mechanism where the lowest bidder's type obtains 0 surplus yields the same ex-ante expected revenue for the seller, and also results in the same expected payment by every type of bidder. This second result (which actually implies the first one) is sometimes called the bidders' Payoff Equivalence Theorem (see, e.g., Milgrom, 2004). Hence, the choice of the auction format is irrelevant both for the seller and for all types of bidders.

Carannante et al. (2024) builds on these results and analyzes the *interim* seller's revenue — i.e., the expected seller's revenue conditional on the valuation of one of the

[5] Closely related to this issue is the lack of organizational resources, which affects small PAs and serves as a barrier to the adoption of GPP practices (Michelsen and de Boer, 2009; Testa et al., 2012). Small-sized authorities, characterized by a structural resource deficiency, are unlikely to establish a dedicated department to develop internal expertise. Furthermore, they face financial limitations that prevent them from relying on external assistance to include environmental criteria in public tenders.

bidders. The authors show that, in this case, the interim seller's revenue, as well as the expected payment by all other bidders, do depend on the particular auction mechanism chosen by the seller.

3. Research output

3.1 Environmental sustainability of data centers

We initiated qualitative research through the organization of a focus group with five technical managers of major Italian companies that manage data centers and offer co-location and cloud services. It emerged that there is a strong focus on the issue of sustainability and strong pressure from management/entrepreneurs to adopt all the necessary solutions to reduce energy consumption. However, some practitioners also pointed out technical limitations to adopting some sustainable practices, such as the use of renewable sources, to the extent that data centers need to be reliable under all circumstances and must ensure constant operation day and night.

Based on these results, we decided to develop a quantitative survey by making a questionnaire to address data center operators at the European level. To achieve our research objective, we had to build the universe of all data center operators in Europe: we cross-referenced information from specialized industry sites and the most important companies in the industry; we were able to build a database consisting of 522 European data center organizations.

We developed an online questionnaire consisting of 33 questions to analyze many features of the environmental sustainability of data centers. In addition, we decided to conduct exploratory research on how data centers communicate on their websites the issue of environmental sustainability.

Turning now to the priorities managers have when designing a data center, there are three factors that stand out prominently. Security of the infrastructure (and thus continuity of operation over time), energy efficiency and connectivity were mentioned as extremely important elements when setting up a data center. Environmental sustainability is also considered important but at a lower level than the other three factors. Cost, which is a decisive factor for a company, can also be put slightly on the back burner in relation to the technical operation of the data center (refer to Table 1).

Design principles for data center building	Not at all important	Not important	Somewhat important	Neutral	Moderately important	Very important	Extremely important
Security	3,92%	1,96%	0%	1,96%	7,84%	27,45%	56,86%
Energy Efficiency	5,88%	1,96%	0%	0%	5,88%	31,37%	54,90%
Connectivity	5,88%	1,96%	0%	0%	3,92%	35,29%	52,94%
Environmental Sustainability	3,92%	1,96%	5,88%	1,96%	21,57%	23,53%	41,18%
Costs	3,92%	1,96%	1,96%	5,88%	7,84%	37,25%	41,18%
Technological innovation	3,92%	3,92%	0%	5,88%	31,37%	23,53%	31,37%
Level of automation	3,92%	1,96%	3,92%	5,88%	27,45%	35,29%	21,57%

Table 1 – Design Principles for data center building

An important aspect we discovered with our survey is the renewal rate of equipment (servers, hard drives, uninterruptible power supply, etc.) in the data center. Nearly 50% of enterprises report that they change their equipment fleet within 4-5 years. Only 24% of enterprises have replacement times longer than 5 years. There are two reasons why enterprises have such a high renewal rate: energy savings and service continuity. New equipment consumes less energy and tolerates increasingly higher operating temperatures. In addition, changing them often reduces the risks of possible malfunctions and maintenance costs.

In terms of adopting best practices related to the circular economy, companies basically try to adopt multiple solutions over time. For example, they aim to reuse servers where possible within the company itself or resell them on the market to other companies. Only 38 percent have signed partnerships with companies certified in e-waste recycling. As many as 10% of companies even send equipment to landfills with no possibility of recycling (Table 2)

.

Actions in circular economy	%
Reuse of hardware in the company	48
Resale of hardware	48
Partnering with certified companies to recycle electronics	38
In-house recycling following international standards	29
Disposal without recycling	10
Partnership with companies not certified to recycle electronic products	7
Internal recycling not following international standards	7

Table 2 - Actions related to the circular economy

The application of LCA to a data center can be seen as the first step toward a circular approach. The results obtained from our survey are encouraging. Only one-third of

data centers (31 percent) said they had not yet adopted this methodology compared to an almost equal percentage (33 percent) who, on the other hand, have already used LCA.

3.1.1 Communicating sustainability online

In addition to the survey, we conducted an exploratory study on how data center operators communicate sustainability issues through their websites. The research had two main objectives: first, to understand how data centers address sustainability issues, and second, to examine the commitments they have made to improve their impact. Using the data center database developed for the survey, we created an original dataset containing website texts retrieved through Web Scraping techniques. We then analyzed the results using text analysis tools and machine learning techniques.

Etichette di riga	Rank	2 Metrics	3 Green Factors	4 Footprint	5 Circular Economy	6 Certifications	Totale
Nlyte Software	1	13,88	2,08	5,30	4,51	12,81	38,58
DigiPlex	2	6,71	10,43	9,39	5,31	3,38	35,23
CONAPTO	3	2,17	10,59	7,28	4,35	6,38	30,77
Lamda Hellix	4	11,87	3,56	6,22	1,36	5,06	28,07
Echelon Data Centres	5	3,62	5,68	10,58	6,32		26,20
Lefdal Mine Data Center	6	5,49	5,67	8,33	2,54	1,67	23,70
Green Mountain Data Center	7	4,27	5,98	5,81	5,63	1,30	22,99
Dassault Systemes (DELMIAworks)	8	1,30	3,60	8,80	8,38	0,61	22,69
Atos	9	1,06	4,26	7,65	6,21	0,88	20,06
Submer	10	11,20	0,29	5,81	2,15	0,22	19,67
Tele2 AB	11	1,96	2,18	8,19	6,14	0,14	18,61
Telia Company AB	12	0,49	2,91	9,15	5,81	0,10	18,44
Google	13	1,77	3,74	6,66	4,33	1,70	18,20
IBM	14		6,50	5,99	4,80	0,60	17,89
Turk Telecom	15	2,86	4,43	5,80	2,20	2,51	17,81
EnerKey	16	3,28	1,27	5,32	5,53	2,35	17,75
Vodafone Group Plc	17	1,30	1,92	5,66	7,38	1,28	17,55
Ark Data Centres	18	3,97	2,06	6,44	1,40	3,22	17,10
Kao Data	19	2,25	3,93	6,81		3,89	16,87
Capacity Media	20	2,37	1,48	8,07	1,97	2,26	16,15
Verne Global	21		11,15	3,99		0,51	15,65
HPE	22	1,59	2,37	3,74	6,93	0,50	15,12
Workspace Technology	23	4,31	1,37	6,62	1,57	1,21	15,07
Telenor Group	24	1,03	4,80	7,52	1,56		14,90
Orange	25	1,31	2,01	5,13	6,15	0,12	14,71
EcoDataCenter	26	3,91	3,39	4,63	1,02	1,18	14,12
NDC-GARBE	27	5,34	3,30	3,75	1,71		14,09
Cisco Systems	28	0,87	2,28	5,29	4,39	0,67	13,50

Table 3 – Results

We used TF-IDF metrics to rank websites according to the intensity of their sustainability communication. The assumption is that the greater the frequency of a certain term, the greater its importance to the company. The TF-IDF score of a term is higher when it appears both frequently and only in a small number of websites. The results collected

are interesting. As can be seen from Table 3, in the top positions of the index constructed from the analysis of the texts, not only large companies in the industry such as Google (13th) and IBM (14th) appear, but also smaller realities such as Nlyte Software and DigiPlex: lesser known and smaller realities that have bet strongly on environmental sustainability as a differentiator in the market.

However, broadening our gaze and analyzing the distribution, we can find that the vast majority of websites are in the first quartile of the TF-IDF index. This means that compared to a few companies that are particularly attentive to these issues, most data centers devote little attention to environmental issues on their websites.

3.2 Green and Sustainable Public Procurement

Regarding the first research strand, our team has been working on an original dataset purchased from Telemat that is an Italian company specialized in procurement contracts providing consulting services. The obtained dataset comprises tender documents from 2006 to 2023 (primarily in Italian), containing crucial information about procurement processes. We have parsed these documents into plain text. Each file contains a unique identifier, the Italian *Codice Identificativo di Gara* (CIG), a 10-character alphanumeric code essential for tracking public procurement processes. Using this CIG code, we linked approximately 5,000 procurement contracts from the Telemat dataset with corresponding records in the main ANAC procurement database.

Our analysis involved searching for specific keywords related to quality components within these documents and extracting text segments around those trigger words. Focusing on these neighborhoods of relevant information reduced computational load by a factor of 5x to 10x compared to processing entire documents.

We successfully extracted the scoring weights assigned to price and quality in each procurement process as a preliminary result. Among the 5,041 auctions for cleaning services identified through this method, the average weight given to quality was 36%, while that of price was 64%. This suggests that public buyers generally prioritize cost over quality.

Interestingly, the predominant scoring mechanism awards up to 70 points for price and no more than 30 for quality. This indicates a greater emphasis on financial considerations rather than environmental or other qualitative aspects.

Regarding the second research strand, we discuss some preliminary results here. The dataset we constructed contains all the procurement contracts related to goods, services, and works where at least a CAM was enacted before the end of 2023. Through preliminary descriptive statistics, we compare four different variables before and after the introduction of the CAM: the *reserve price* (the value assigned to the procured good/service/work), the *winning rebate* (reserve price minus the price offered by the winning bidder, divided by the reserve price), the *number of auction participants*, whether an *open auction* is used instead of a less competitive mechanism. Although specific categories may vary, on average, we find how the introduction of a minimum quality requirement (the CAM) pushed up the reserve price, down the winning rebate (thus increasing the price paid by the public buyer), slightly down the competition (however, with a lot of category-specific variation), and we found no specific effect on the probability of using an open procedure.

	(1)	(2)
VARIABLES	Rating Dummy	Rating Dummy
Revenues ≥2M		0.007***
		(0.000)
SME	-0.007***	-0.002***
	(0.000)	(0.000)
Revenues ≥2M × SME		-0.004***
		(0.000)
Innovative SME	0.006***	0.005***
	(0.000)	(0.000)
Observations	14,099,943	14,099,943
Year F.E.	Yes	Yes
Municipality F.E.	Yes	Yes
Sector F.E.	Yes	Yes
R-squared	0.005	0.007
Mean Dep. Var.	.0007	.0011

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 4: Legality Rating predictors

	(1)
VARIABLES	Winning firm
SME	-0.071***
	(0.010)
Observations	45,088
R-squared	0.157
Region F.E.	Yes
Publication year F.E.	Yes
Sector F.E.	Yes
Mean Dep. Var.	0.502

Robust standard errors clustered at sector level in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 5: SMEs and Public Procurement

To investigate how SMEs perform in the Legality Rating, researchers at UNITORV employ three different sources of data. The first one is the outcome of the Legality Rating at the firm level. The second refers to firm-level data retrieved from Aida-BVD. The third dataset covers data on participating and winning firms in public procurement tenders above 40,000EUR. In the final dataset, each firm participating and/or winning a procurement tender is associated with a legality score, the date on which that score is assigned, the number of employees, the revenues, the share of female individuals in the board, the average age of individuals in the board, the municipality in which the firm is based and the sector in which the firm operates. Also, information on whether the firm is an innovative SME or less according to the Italian legal system is included.

The results reported in Table 4 suggest that SMEs are less likely to obtaing LR and that having revenues above 2 million Euros is a predictor of having obtained the LR.

In addition, SMEs are 7 p.p. less likely to be awarded procurement contracts (see Table 5), but LR is positively associated with being awarded a tender for all firms (including SMEs – see Table 6).

	(1)	(2)	(3)
VARIABLES	Winning firm	Winning firm - SMEs	Winning firm - Non-SMEs
Rating Dummy	0.028**	0.013	0.017
	(0.011)	(0.012)	(0.017)
Observations	45,088	22,156	22,842
R-squared	0.155	0.192	0.142
Region F.E.	Yes	Yes	Yes
Publication year F.E.	Yes	Yes	Yes
Sector F.E.	Yes	Yes	Yes
Mean Dep. Var.	0.502	0.424	0.578

Robust standard errors clustered at sector level in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 6: Rating, SMEs, and Public Procurement

The researchers adopt a Regression Discontinuity Design to deal with endogeneity issues in Legality Rating's attribution to firms exploiting firms which had revenues just above and just below 2 millions. Thus, they estimate the following in the RDD-refined sample (window: optimal bandwidth estimated using Calonico et al. 2016):

$$y_{pirts} = \beta_0 + \beta_1 Rating\ Dummy_{irts} + \delta_r + \gamma_t + \theta_s + \beta_2 X_i + \beta_3 Z_p + \epsilon_{pirts}$$

Table 7 shows the results from the estimation. While the Rating Dummy does not have an effect on winning procurement contracts in general, it increases the probability of

SMEs to win by 12.9 p.p. (31% of the mean value). Therefore, LR is an essential tool for SMEs' performance in public procurement.

	(1)	(2)
VARIABLES	Winning firm	Winning firm – SMEs
Rating Dummy	-0.015	0.129***
	(0.082)	(0.034)
Observations	34,344	18,829
R-squared	0.171	0.202
Region F.E.	Yes	Yes
Publication year F.E.	Yes	Yes
Sector F.E.	Yes	Yes
Mean Dep. Var.	0.484	0.412

Robust standard errors clustered at sector level in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 7: Legality Rating and Public Procurement – RDD

3.3 Green Public Procurement when the Seller is Privately Informed about a Bidder

Carannante et al. (2024) considers an auction with risk-neutral bidders who have independent private valuations and assume that the seller privately learns the valuation of one of the bidders, referred to as the *special bidder*. For example, this information about a bidder's valuation may emerge exogenously if a potential buyer in the auction has a score derived from his past purchases. Alternatively, the seller may obtain information endogenously, for example in multiple auctions where a bidder is the winner of a past auction who has revealed his valuation through his bid. In other environments, the seller may simply know whether the valuation of a bidder is higher or lower than a threshold, for example because she observed whether or not the bidder previously agreed to pay a fixed price for an object similar to the one on sale.

In this environment, the celebrated Revenue Equivalence Theorem (Vickrey, 1961; Myerson, 1981; Riley and Samuelson, 1981) characterizes the ex-ante expected seller's revenue. In particular, the theorem shows that, in any efficient equilibrium where the lowest bidder type achieves zero surplus, the seller's expected revenue remains identical across different auction formats, as does the expected payment by every type of bidder. This second result, which implies the first, is often called the bidders' Payoff Equivalence Theorem (see, e.g., Milgrom, 2004). Hence, the theorem implies that the choice of the auction format is irrelevant both for the seller and — ex interim — for all

types of bidders, because in all auction formats they win with the same probability and expect to pay the same.

Does this indifference also hold conditional on the valuation of one of the bidders? Or does knowing the valuation of the special bidder induce the seller to prefer a specific auction format, thereby breaking this indifference? To address these questions, Carannante et al. (2024) focus on the two most common auction formats: the first-price auction (FPA) — where the winner pays his bid — and the second-price auction (SPA) — where the winner pays the second-highest bid. The authors show that there is a unique threshold such that the interim seller's revenue is higher in the FPA than in the SPA if the bidder's valuation is lower than the threshold, while it is higher in the SPA than in the FPA if the bidder's valuation is higher than the threshold.

Carannante et al. (2024) also generalizes this analysis by considering standard auctions, a broad class of sealed-bid auctions that assign the object to the highest bidder and are characterized by the set of bidders who make a transfer to the seller and by a function that determines the transfer made by each of these bidders. This class includes, in addition to the FPA and SPA, other winner-pay auctions where only the highest bidder pays one of the submitted bids, and pay-as-bid auctions (like the all-pay auction) where one or more bidders pay their own bids.

The main insight of the analysis is that, because the special bidder's transfer conditional on *his own* valuation is independent of the auction format (by the Revenue Equivalence Theorem), differences across formats depend only on the expected payment of the other (interim symmetric) bidders, which are determined jointly on the special bidder's valuation and the auction format. Hence, comparing two alternative auction formats given the special bidder's valuation v, the auction with the higher interim revenue is the one in which a generic other bidder expects to pay the highest price, prior to drawing his type but conditioning on the information that one of his competitors has valuation v.

Leveraging on this observation, the authors show that, when the special bidder's valuation is the lowest possible one, or close to it, the FPA yields the highest interim revenue among all standard auctions. By contrast, when the special bidder's valuation is close to the highest possible one, the FPA yields the lowest interim seller's revenue among all standard auctions. In fact, the special bidder's payment represents a lower bound for the interim revenue, and the FPA achieves this bound when the special bidder has the highest possible value.

Other formats with a different set of payers, however, yield a higher interim seller's revenue when the special bidder has the highest possible value. For example, the interim revenue is strictly higher in the all-pay auction, where all bidders pay their bids, than in any winner-pay auction. The reason is that, in the all-pay auction, the seller obtains payments from all other bidders, in addition to the special bidder. Finally, the interim revenue is even higher when only losing bidders pay: when the special bidder's valuation is close to the highest possible one, the interim revenue tends to infinity in the Last-Pay Auction (LPA) — an atypical mechanism where only the lowest bidder pays his bid. Conversely, the LPA yields the lowest interim seller's revenue when the special bidder's valuation is the lowest possible one.

Since the FPA maximizes the interim revenue when the special bidder's value is the lowest possible one, and minimizes it when the special bidder's value is the highest possible one (and since the interim revenue is increasing in the special bidder's value), the FPA yields the smallest range of possible interim revenues for the seller among standard auctions, and it maximizes the minimum interim revenue. This provides a new interpretation for why the FPA may be considered the less risky standard auction format for the seller. The common interpretation is that a risk-averse seller ex-ante prefers the FPA because, although the expected seller's revenue is the same, the realized seller's revenue in other standard auctions is a mean-preserving spread of the one in the FPA (Waehrer et al., 1998).

4. Policy implications

4.1 Environmental sustainability of data centers

Our research allows us to take an initial stock of how data centers are addressing environmental sustainability and the circular economy, revealing four main themes.

The first theme revolves around the awareness of the impact data center facilities have on the environment. Operators today are particularly sensitive to this issue, recognizing the challenges of balancing environmental sustainability with the technical and functional needs of a data center. Service continuity is paramount, and initiatives on sustainability must acknowledge this requirement. A compromise between functionality and sustainability is challenging for the market, as end consumers

consider data center service continuity as a given. Therefore, policymakers designing new rules and laws should carefully consider the necessity to balance sustainability and business continuity in this industry.

The second aspect focuses on the direction of investment. The research indicates that operators are investing in energy efficiency (data center design) and obtaining energy from renewable sources. New design techniques (e.g., hot and cold aisles) and investment in the latest generation of equipment (e.g., servers) with lower power consumption result in substantial energy savings. Economic sustainability and environmental sustainability overlap in this case. Concentrating on data center efficiency reduces consumption and, consequently, environmental impact. Simultaneously, data center operators are making significant investments in renewable energy, categorized as direct and indirect. Direct investments involve the construction or acquisition of power generation facilities from renewable sources (hydro, solar, and wind), while indirect investments entail purchasing energy from qualified suppliers ensuring it comes from renewable sources. Policymakers could incentivize these investments, with a focus on local green energy procurement without the possibility of compensation to reduce potential distortions.

The third theme addresses how data center operators are tackling the challenges of the circular economy. Results suggest less positive outcomes than expected. Operators primarily focus their actions on the use phase of the data center and struggle to envision impacts beyond company boundaries. However, there is growing awareness regarding end-of-life management and e-waste. Given the high replacement rate of equipment (between 3 and 5 years), managing and reusing discarded equipment will become increasingly important. The application of the Life Cycle Assessment (LCA) methodology is not yet standard, hindering managers from precisely understanding all possible impacts of the data center and embracing a circular approach. The expectation is that, given the importance of data centers and their increasing electricity consumption, the focus on a circular approach will grow in the near future. Policymakers could impose increasing levels of reuse or recycling requirements on data center companies over time.

Finally, the fourth theme pertains to communication. At the European level, data centers do not, on average, give particular attention to environmental aspects on their websites. However, operators that do focus on communicating their initiatives related to environmental sustainability do so in depth, allocating significant space to the topic. According to our research, the operators most active in sustainability communication

are also those that seem to have genuinely invested in this direction. However, it is challenging to ascertain if data center companies practice what they preach. Policymakers could advocate for more transparency in communication and incentivize data centers to conduct LCAs with the help of an independent agency.

4.2 Green and Sustainable Public Procurement

Public procurement represents a non-negligible share of GDP in most countries, and, specifically, public procurement spending has been 15% of the GDP in OECD countries in 2020 (OECD, 2021). Modern, well-managed, and efficient procurement is essential to ensure high-quality public services.

Our preliminary analysis of the scoring weights assigned to price and quality in each procurement process for cleaning services contracts shows a pronounced bias towards price over quality, with price accounting for 64% of the overall weights, compared to just 36% for quality. This imbalance underscores an opportunity to rethink procurement policies by increasing the relevance assigned to quality in the scoring function. This is particularly important in light of growing environmental impact and sustainability concerns. Striking a better balance between these factors could lead to service provision that is not only cost-effective but also aligned with sustainability goals. Specifically, adjusting this ratio could incentivize a higher level of qualitative and environmental aspects.

The introduction of CAM appears to have influenced procurement outcomes, with reserve prices increasing and winning rebates declining. These shifts suggest that CAM requirements may introduce higher costs for public sector buyers. In response, future policies might explore mechanisms to alleviate these additional expenses while upholding crucial environmental standards. Interestingly, a slight reduction in bidders since CAM's introduction indicates a potential impact on competition. The complexity and added costs of meeting environmental criteria may discourage some suppliers from participating. Further analysis on this is warranted. Finally, the need for continuous monitoring of CAM's impact is evident, as it allows for real-time adjustments in response to empirical data.

The use of AI in procurement analysis represents an innovative step forward, allowing for the extraction of qualitative data that can deepen our understanding of bid quality and supplier practices. Policies that support the integration of AI and other advanced technologies in public administration could enhance efficiency, transparency, and the

overall quality of service provision.
In addition, significant variability in documents and procedures across different public buyers highlights the importance of standardization.

Finally, our research could help Governments design effective laws on green procurement that prevent strategic tendering procedures by purchasing bodies (e.g., anticipating the publication of tenders or splitting tenders to avoid public purchasing requirements).

4.3 Green Public Procurement when the Seller is Privately Informed about a Bidder

The theoretical analysis of Carannante et al. (2024) has relevant policy implications, since it highlights conducts that may be adopted by the seller in an auction to increase his revenue, when he has information about one of the bidders who participate in the auction. In particular, the analysis has a direct application to environments where the seller is privately informed about the valuation of a particular bidder, and other competitors are unaware of that.

For example, the seller may obtain this private information through an exogenous rating based on the bidder's purchasing history, or when a bidder participates repeatedly in sequential auctions for similar objects. In this environment, the results of Carannante et al. (2024) suggest that the seller may obtain a higher revenue by choosing a particular auction format conditional on this information, if other bidders do not draw any inference from the seller's choice and always bid as in an auction with symmetric competitors. This may be a natural assumption in environments with inexperienced or unsophisticated bidders.

The results also emphasize the importance of obtaining information about a bidder's valuation and identify the type of information that is most useful for the seller. Because of single crossing, the seller can determine if her expected revenue is higher in either the FPA or SPA simply by knowing whether the valuation of one of the bidders is lower than any threshold. For example, in a sequence of auctions for similar objects, a seller learns that a bidder has a low valuation if he observes that he lost a previous auction, even if she does not observe any of the bids in the previous auction. Similarly, the seller learns that a bidder has a higher-than-average valuation, if he observes the bidder winning a previous auction. Or the seller may only observe whether the bidder has

previously completed a purchase of a similar object at a fixed price, even without observing the actual price.

In the context of public procurement, the results of Carannante et al. (2024) highlight how a public authority can design a procurement process when it is privately informed about some relevant characteristics of a potential provider that participates in the process. In particular, if the public authority wants to minimize the interim price — i.e., the price that the authority expects to pay for the good or service that it acquires, conditional on its information — it should adopt a different procurement process, depending on its private information about the efficiency or the cost of production of a provider.

If the authority expects that one of the bidding firms has a higher-than-average cost of production, then it should prefer a procurement process where the bid of that firm does not affect the payments of other bidding firms. In this case, the best mechanism would be a first-price auction, because the first-price auction minimizes the price that the authority expects to pay for the good or service that it acquires, conditional on the information about the relatively high cost of a firm. In a different procurement process like a second-price auction, the presence of an inefficient firm would negatively affect the price paid by the authority, in case a different firm is awarded the contract.

By contrast, if the authority expects that one of the bidding firms has a lower-than-average cost of production, then it should prefer a procurement process where the bid of that firm does affect the payments of other bidding firms. This happens, for example, in a second-price auction — i.e., a procurement process where the firm who submits the lowest bid is awarded the contract, but it is paid a price equal to the bid of the second-lowest firm. In such a format, the presence of an efficient firm reduces the expected cost of the goods or services acquired, because it reduces the expected price that the authority has to pay to a different firm, when such a firm is awarded the contract.

Moreover, a public authority that wants to minimize risk — in the sense of (i) minimizing the range of possible interim prices that it could pay for acquiring a good or service, or (ii) minimizing the highest interim price that it could pay for the good or service — should adopt a procurement mechanism based on the first-price auction — i.e., where the winning firm is the lowest bidder and is paid a price equal to his bid.

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