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Facilitating Green Public Procurement in Europe through eForms: A Software Solution for GPP Criteria Management

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Abstract

Public procurement accounts for an average of 15% of EU members' GDP. Its ongoing digital transformation further enhances its capabilities as a driver for a sustainable transformation of the economy. Within this context, Green Public Procurement (GPP) emerged, aiming to reduce the environmental impact of procurement activities.

Nevertheless, our analysis shows that GPP is under-utilized in Europe. Only an estimated 13% of the notices published in TED incorporate GPP usage indicators. This limited adoption seems to stem from diverse challenges, in particular, a lack of awareness, GPP integration complexities, and the absence of effective software tools.

This thesis identifies and addresses a gap by developing a software solution that seeks to facilitate the management of GPP in e-Procurement using eForms. In 2023, the eForms standard became mandatory for the publication of high-value contracts in the EU, thus providing an opportunity to leverage a data layer common to all e-Procurement platforms in the EU.

The set of tools developed aims to integrate with the existing e-Procurement development environment to make the incorporation of GPP criteria seamless. These tools are part of a multi-level design. The key piece is a Java library that integrates GPP domain knowledge and eForm management. The functionalities provided by the library are then exposed by a service through a REST API. All functionality is brought together into a user-friendly interface that provides an intuitive flow to identify GPP criteria from an eForm contract notice and integrate the desired criteria directly into it.

Keywords: Green Public Procurement, GPP Criteria, eForms, Tenders Electronic Daily, e-Procurement.

Abstract in lingua italiana

Gli appalti pubblici rappresentano in media il 15% del PIL dei paesi membri dell'UE. La sua attuale trasformazione digitale ne potenzia ulteriormente le capacità come motore per una transizione sostenibile dell'economia. In questo contesto è emerso il Green Public Procurement (GPP), con l'obiettivo di ridurre l'impatto ambientale delle attività di appalto. Tuttavia, la nostra analisi mostra che il GPP è sottoutilizzato in Europa. Si stima che solo il 13% dei bandi pubblicati su TED (Tenders Electronic Daily) incorpori indicatori di utilizzo del GPP. Questa adozione limitata sembra derivare da diverse sfide, in particolare dalla mancanza di consapevolezza, dalla complessità nell'integrazione del GPP e dall'assenza di strumenti software efficaci. Questa tesi identifica e affronta una lacuna sviluppando una soluzione software che mira a facilitare la gestione del GPP nell'e-Procurement tramite l'utilizzo degli eForms. Nel 2023, lo standard eForms è diventato obbligatorio per la pubblicazione di contratti di alto valore nell'UE, offrendo così l'opportunità di sfruttare un livello di dati comune a tutte le piattaforme di e-Procurement europee. L'insieme di strumenti sviluppati mira a integrarsi con l'ambiente di sviluppo e-Procurement esistente per rendere fluida l'incorporazione dei criteri GPP. Questi strumenti sono parte di un progetto a più livelli. L'elemento chiave è una libreria Java che integra la conoscenza del dominio GPP e la gestione degli eForm. Le funzionalità fornite dalla libreria sono poi esposte da un servizio tramite una REST API. Tutte le funzionalità sono riunite in un'interfaccia utente che offre un flusso intuitivo per identificare i criteri GPP da un bando di gara in formato eForm e integrare i criteri desiderati direttamente in esso.

Parole chiave: GPP, Criteri GPP, eForms, Tenders Electronic Daily, e-Procurement.

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1 | Introduction

1.1. General Context and Motivation

Public procurement accounts for a significant part of the economy of the member states of the European Union. It accounts for approximately 15% of the GDP of the EU . The massive volume of spending that comes with public procurement makes it the largest business sector worldwide. Its influence thus goes beyond pure acquisition, it can be a driver for various policy objectives [34, 57].

Traditionally, public procurement proposals for goods, services, and works have prioritized cost-effectiveness, often overlooking its other impacts. Although this approach can be justified for the private sector, public procurement should serve wider socio-economic goals [4].

This narrow focus on cost has led the public authorities to overlook other long-term values, therefore missing an opportunity to focus on sustainability. Short-term goals that focus on immediate cost give an advantage to less environmentally friendly products [39]. As a potential solution to these problems, Green Public Procurement (GPP) emerged. GPP is a process in which public authorities procure goods, services, and works with the intention of reducing the environmental impact throughout their life cycle. [12]

1.2. Problem Definition

Despite the key role of public procurement in the economy and the potential of green public procurement to promote sustainable development, GPP continues to be under-used in Europe. There are several barriers that slow down the adoption of the GPP criterion [57]. First, the GPP criteria are voluntary, making their application a conscious decision of EU members and their public authorities [12]. This has resulted in significant differences in the regulations and implementations of the GPP targets between countries, and even between local and regional authorities [1].

As public procurement becomes increasingly digitized, it provides us with the opportunity

to facilitate the integration of GPP criteria into e-Procurement [14]. Nevertheless, this is faced with another obstacle: the heterogeneity of e-Procurement platforms. There are several different platforms in place that differ not only within countries, but even within regions and cities of the same country.

Given the large pool of directives and complexity, there may be a lack of awareness among public authorities on how to navigate the adoption of GPP techniques and its specific implementation on their corresponding e-Procurement platforms [59]. Furthermore, verification of the GPP criteria is far from a straightforward process, which requires public authorities to have sufficient domain knowledge to apply the defined criteria both at the initial contract award and further along the product life cycle [57].

In order to reduce the complexity of the application of GPP criteria in public procurement (in particular in e-Procurement), there is a need for a general software solution that can simplify the GPP process, thus increasing its usage. Ultimately, the benefits of GPP are limited by their ability to be conducted in practice [55]. A key development in this area came in 2019 with the introduction of eForms, which provides a standard format for the publication of most public procurement notices across Europe. In 2023, this standard became mandatory, providing us with the foundation to produce a generalizable solution for e-Procurement systems to incorporate GPP more effectively [22].

1.3. Research Objectives

The main goal of this thesis was to develop a software solution to address the challenges presented and to facilitate and promote the use of GPP criteria in European public procurement.

In order to accomplish the goal, comprehensive research was needed to understand, in Europe:

- The current state of Green Public Procurement.
- The existing e-Procurement platforms.
- The existing development environment surrounding public procurement.

Following the core research, the objectives were narrowed down to creating an end-to-end tool that would allow public authorities to:

- Identify GPP criteria applicable to a given contract notice.
- Incorporate the relevant GPP criteria into the contract notices.

- Evaluate the proposals made according to the selected GPP criteria.

In order to maximize the impact, the developed solution should be modular and compatible with the existing e-Procurement development environment. This creates the possibility for the tool to be integrated into other established e-Procurement platforms.

1.4. Scope and Limitations

This work focuses primarily on eForms, identified as the standard format for publishing procurement data across the European Union. Compatibility was ensured with eForms with major version 1, and minor versions 8 to 13. Further minor versions should be supported since it *"is incremented only when the new version of the software developer kit introduces changes that do not break backwards compatibility"* [54]. As it will be specified later, only contracts above a certain threshold will be required to use eForms, thus the smaller contracts may not be compatible with our approach.

The final solution shall include a ready-to-use software library that can be used by other existing e-Procurement platforms. It shall also include a user interface that can be directly used to access the functionality described revolving Green Public Procurement.

Given the dynamic nature of software engineering tools, the evolving eForm standard, and the evolving GPP criteria, the tools developed will require future maintenance and development to remain relevant. Further limitations to be acknowledged include:

- We cannot alter existing e-Procurement platforms. The integration of our tool into any existing systems would require their development team to apply the necessary changes.
- Formal user studies were not performed to evaluate the tool's usability, effectiveness or performance.
- There was no integration into a live production system.

The repositories containing the source code for the tools presented will be open source, well tested and well documented, leaving the possibility open for anyone to contribute to the maintenance and further feature development of this tool. Furthermore, their inclusion into a production environment should require minimal modifications to adapt to the external clients.

1.5. Thesis Outline

The following sections of this thesis are structured as follows:

- **Chapter 2: Background and Related Work** will give an overview of public procurement in Europe, it will define Green Public Procurement, present examples of the GPP criteria, define the eForms standard, showcase the existing software development kit, analyze GPP adoption across notices published in TED and review the state of the art in e-Procurement tools and GPP oriented tools.
- **Chapter 3: System Design and Implementation** will justify the design rationales, describe the overall system architecture, and detail the implementation of each of the components that make up our solution.
- **Chapter 4: Evaluation and Results** will discuss the methods used to validate the tool and compare it to other existing GPP solutions.
- **Chapter 5: Conclusions and Future Developments** will summarize the contributions made by this thesis, acknowledge the limitations, propose further tool improvements and suggest new research directions.

2 | Background and Related Work

2.1. Public Procurement in Europe

The procurement of goods, services, and works by public authorities is one of the main pillars of the European Union's economic and governmental infrastructure. This section looks at the significance and complexity of public procurement in the EU, follows its evolution towards digital systems (e-Procurement) and examines the potential broader impact of public procurement in society.

2.1.1. Economics and Law

Public procurement is a process through which public authorities purchase goods, services and works from various enterprises. According to data from the European Commission, approximately 250,000 public authorities throughout the EU together spend 14-16% of the union's GDP on such purchases, creating a market value of approximately 2 trillion EUR per year. This significant investment places the public sector as the largest single buyer in the EU, highlighting its key role in numerous economic sectors (e.g. healthcare, education, energy, transport, etc.). Thanks to this substantial purchasing power, public procurement becomes a potent tool for creating jobs, enabling entrepreneurship and promoting economic growth, in particular for small and medium-sized businesses. [3, 52].

Beyond the sheer size of the economics of public procurement in Europe, it is also subject to a complex regulatory framework that was designed to guarantee transparency, equality, and to avoid discrimination among potential suppliers. A particularly relevant directive is the Public Procurement Directive 2014/24/EU, which aims to empower public authorities to strategically pursue broader societal objectives through procurement [21]. This directive introduces the possibility to incorporate various strategic considerations, including environmental factors into the procurement process. This can be done through technical specifications, contract performance clauses and awarding criteria. These considerations set the groundwork to follow a different method to award contracts that follows the Most Economically Advantageous Tender (MEAT) principle [57].

The MEAT principle ensures that the contracts are awarded based on the best value for the best price, rather than awarding it solely on the basis of the lowest price [34]. Whenever tenders fall below EU thresholds, only national laws are applicable. However, the principles of EU law and World Trade Organization (WTO) regulations must still be followed by all public procurement activities. This regulatory oversight that is applied to public procurement ensures a higher standard of integrity and accountability compared to procurement in the private sector. This allows the public resources to be protected from potential fraud or corruption [34].

2.1.2. The Digital Transformation: e-Procurement

The digitization of purchasing processes for public authorities came in the form of e-Procurement. E-Procurement, or electronic procurement, refers to the whole set of technologies and tools used for the acquisition of goods, services, and works online. The goals of e-Procurement include [4, 56]:

- Increasing efficiency in public procurement procedures.
- Reducing the cost of the process: In 2010, these savings were reported to be 5-20% of the expenses.
- Enhancing transparency and accountability through visibility. This directly helps reduce the risks of corruption.
- Improving market access, thus driving competition.

The impact of e-procurement on the performance of public procurement performance has been studied to justify the approach. For instance, outside of the European Union, at the Maasai Mara University, Kenya, a study was conducted to determine the effects of several indicators of e-Procurement use on the performance of the procurement process. Their regression analysis, showed that e-Procurement contributed significantly to procurement performance, measured through certain indicators such as the processing of invoices and the number of supplied orders. This study confirmed the hypothesis that adopting electronic tools that allow for quick access and exchange of information can lead to improved efficiency and effectiveness [5].

Another study was conducted on the impact of e-Procurement, made in an Italian context, particularly in the healthcare sector in Calabria. Their findings showed that it significantly reduced the length of the tender process, achieved a 14% increase in the award rate for drug related procurement, and resulted in a decrease of 14% in cumulative purchase price. As part of their work, they also identified several barriers to early adoption of electronic

procurement, some of which are still relevant today. These included the lack of technical expertise of public authorities and the difficulty of standardization. Furthermore, it also found that the introduction of legislation, such as the mandatory membership for Central Public Administrations in late 2007 (Law 296/2006) led to a growth in the usage of e-Procurement platforms [4].

Viewing it as a key element for modernization, the European Union has established a framework of legislative measures to promote and standardize e-Procurement. Through this, a set of rules related to e-Procurement became mandatory in 2017 and 2018. These comprised requirements for full electronic means of communication, as well as an obligation for contracting authorities to allow for e-submission. All of this with the goal of streamlining public sector administration and encouraging commercial engagement. Other relevant legislative changes include: the European Single Procurement Document (ESPD) which replaces the requirements for full documentation for a self-declaration form (only requiring the full documentation from the winning tenderer), thus simplifying tendering between different countries; the e-Invoicing Directive that aims to reduce the obstacles for cross-border tenderers by setting a common European standard for electronic invoices [3].

The e-Procurement process can be divided into two basic parts [52]: the pre-awarding phase and the post-awarding phase. The pre-awarding phase consists of:

- e-Sourcing: activities whose goal is to prepare a call. Its used to raise interest across potential bidders.
- e-Noticing: involves the publication of calls for tenders in electronic format in the relevant board (in our case, the Official Journal of the EU). The tender documents should be available electronically.
- e-Tendering: involves e-Access (access to digital tender documents) and e-Submission (submission of the offer in an electronic format to the relevant public authority). The system may include an automatic validation of the bids.

Moreover, we have the post-awarding phase. This involves [52]:

- e-Awarding: the process of awarding the contract according to the preferred evaluation method.
- e-Contract: involves the conclusion, enactment and monitoring of a contract.
- e-Order:
- e-Invoicing: the contractor prepares electronic invoices for the public authority.

- e-Payment: payment for the goods, services, or works through electronic means.

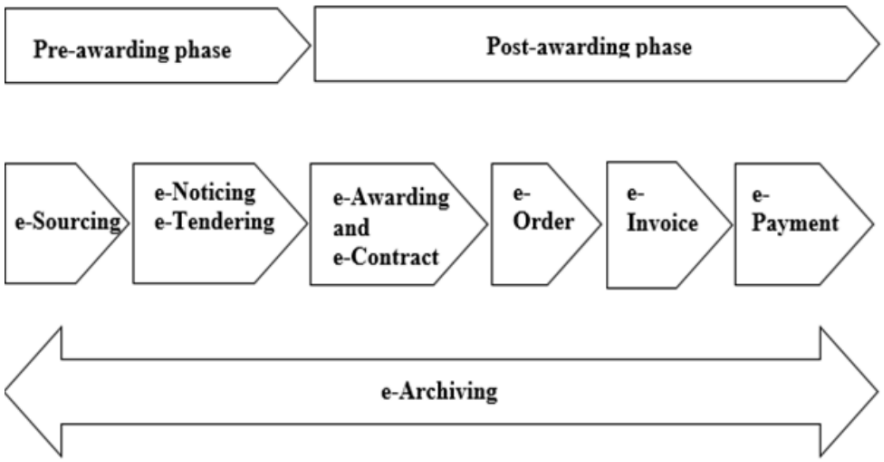


Figure 2.1: Phases of e-Procurement.

The stages that our software solution will focus on are e-Noticing and e-Tendering, hoping to influence the stage of e-Awarding.

2.1.3. Public Procurement as a Vehicle for Transformation

Public procurement in Europe has gone through several transformations. Initially, the focus was purely on its basic role of acquiring goods, works, and services, later on compliance, accountability, and efficiency. Eventually it move to higher level goals such as adding value to the internal public organization. Finally, it has evolved all the way to become a strategic tool that can add value to society and its external environment. Public procurement has been increasingly recognized as a means to drive broader societal and economical transformation. The massive economic scale of public procurement in Europe, covered in 2.1.1, serves as leverage to directly influence the market, businesses and the economy. Several policy objectives can now be pursued through procurement [34, 45].

EU directives have pushed the procurement process to include criteria beyond just cost, using awarding methods such as MEAT. This process through which the public authorities leverage their purchasing power to achieve broader societal objectives is commonly referred as **strategic procurement**. It is characterized by the usage of technical specifications, selection criteria, award criteria, and contract performance clauses aimed at goals such as ensuring safety, improving working conditions, encouraging innovation, and fostering sustainability, among others. Strategic procurement transforms public procurement from a reactive function into a proactive policy tool [34].

Another opportunity comes with Public Procurement for Innovation (PPfI). This refers to the practice of using public procurement to promote innovation. Studies have shown that the use of PPfI can be even more effective than R&D subsidies when it comes to fostering industrial innovation. One more benefit is the increased business opportunities for small and medium-sized companies [45]. Nonetheless, there is still work to do in order to bridge the gap between the claims made by academic research and actual procurement practices, particularly through multi-disciplinary integration (such as technology and sustainability).

Moreover, it is also argued that the technology chosen for e-Procurement influences their users, and thus also the procurement process. The impact of technology can have both intended and unintended consequences, as there are several legal and cultural factors at play. Regardless of whether the impact was foreseen, the effects of the technological choices can persist beyond the intended policy aims, directly influencing the next generation of e-Government architecture and policies [14].

The role of public procurement as a vehicle for higher goals has been identified by the European authorities, leading to concrete actions aiming to leverage its potential. A set of initiatives have been introduced to try and achieve policy objectives (for example: Innovation Union, Resource-Efficient Europe, Energy 2020). In particular, the Europe 2020 strategy aimed to encourage the use of Green Public Procurement (GPP) as a market-based instrument. It highlighted it as a key mechanism to pursue the policy objectives of the European Union with regards to sustainability. Concrete examples include a Swedish program, "light corridor", which by promoting the use of energy efficient lighting, led to a rapid market uptake of the winning technology, and subsequently caused sizable price decreases, essentially transforming the market segment. Another example is the a textile procurement pilot led by the Dutch Ministry of Defense, which rewarded the suppliers for using recycled materials, leading towards more resource-efficient supply chains [55].

However, there are still some obstacles to be overcome, in particular with regards to the practicality of implementing the strategic goals in public procurement, as ultimately, the benefits of strategic procurement depend on the ability to conduct it in practice.

2.1.4. Common Procurement Vocabulary

"The common procurement vocabulary (CPV) establishes a single classification system for public procurement aimed at standardizing the references used by contracting authorities and entities to describe procurement contracts" [9].

As stated in an official website of the European Union, the Supplement to the Official Journal of the EU [53]:

The use of CPV codes has been mandatory since 1 February 2006, the full list of CPV codes can be found in the Regulation (EC) No. 213/2008.

The main vocabulary of CPV serves to describe the goods, services, or works forming the subject matter of the contract; these nine digit codes are structured as follows:

- The first two digits identify the divisions (XX000000-Y);
- The first three digits identify the groups (XXX00000-Y);
- The first four digits identify the classes (XXXX0000-Y);
- The first five digits identify the categories (XXXXX000-Y);

The last three digits are used to provide an increasingly greater degree of precision. Lastly, the last digit (marked as 'Y') serves to verify the previous digits.

2.2. Green Public Procurement (GPP)

Green Public Procurement (GPP) is defined by the commission of the European communities 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"* [12].

GPP falls within the framework of Strategic Public Procurement, along with Socially Responsible Public Procurement and Innovation Procurement [20]. As previously mentioned in 2.1.3, GPP has been increasingly recognized as a means to drive broader societal and economical transformation. It is an instrument for implementing policies throughout the public and private sector [39].

The implementation of GPP is described as not merely an operational activity, but a reflection of a clear strategy of any public authority for implementing policies to support the sustainable growth of the economic system It is not only a set of operational activities, but a clear strategy to encourage public authorities to support the sustainable growth of the economic system. It is also worth contrasting the GPP with Sustainable Public Procurement (SPP), which may sometimes be used interchangeably. However, to be more precise, GPP can be seen as a subset of the broader framework of SPP, which prioritizes the environmental impact, while SPP seeks a balance across environmental, social and economic value [16].

2.2.1. Potential Benefits

As previously discussed, Green Public Procurement can leverage the purchasing power of the public authorities to benefit society and the environment. When strategically implemented, these benefits include:

Public procurement, when strategically implemented, offers a multitude of benefits, extending beyond mere cost-effectiveness to drive sustainable development, enhance economic value, stimulate market influence and innovation, and improve organizational practices.

- **Driving Sustainable Development**: GPP directly steers the purchasing power towards sustainability by prioritizing goods, services, and works with a reduced environmental impact throughout their life-cycle. In contrast to the conventional alternatives, this strategic approach helps to significantly reduce greenhouse gas emissions, limit pollution of air, water, and soil through contaminants, minimize waster generation and conserve natural resources, among others [12, 39].
- **Enhance Economic Value**: When following principles such as MEAT, public procurement can move away from focusing on the lowest price into getting the best value for the best price. This focus on value creates provides incentives and creates new opportunities for emerging "green" economies [12, 57].
- **Market Influence**: When looking at sheer size of the purchasing power of the public authorities, it is clear to see how a demand for more sustainable goods can create a significant market pull towards sustainability [39].

  When green standards are strategically referenced in tenders, GPP can stimulate competition among suppliers to meet the standards set. Therefore, a wider range of sustainable solutions is likely to emerge and diffuse through the market in order to meet demand. This market diffusion is key to achieve the goals of a larger environmental impact from GPP. Using GPP criteria broadly helps set an overall higher standard for the full market by increasing the availability of environmental criteria. This has a spillover to the private sector, which is forced into adaptation. It is also worth noting that given a a sufficient size of eco-innovations, public purchasers can also help establish early markets [55].
- **Innovation**: By demanding more environmentally friendly goods, services, and works, GPP is mitigating under-investment in eco-innovations, which usually suffer from the "double externality problem". This problem refers to the situation where both the knowledge spillovers of innovation and the environmental externalities

create a significant cost for the procurers, which without GPP requirements, lack the incentive to make the necessary investments. It's worth noting that the impact of GPP on eco-innovation is U-shaped. This means that the innovation is only really stimulated when GPP is applied on a sufficient proportion of public contracts. This threshold is estimated to be 16%, point at which every 1% increase in green contracts can lead to an average increase of 342 environmental patents [66].

- **Improve Organizational Practices**: The application of GPP in procurement requires a minimum level of knowledge from the procurers. This awareness can help cultivate a more sustainable procurement behavior among organizations, potentially driving their organizational practices in a greener direction [33].

2.2.2. GPP Criteria

The basic concept of GPP is not enough, its effectiveness relies on having clear environmental criteria for goods, services, and works. By 2008, there were already set of national criteria and approaches to GPP developed. Nevertheless, there was a need for a formalized approach to GPP in Europe, to have a common standard. Having a single set of criteria would help diminish the complexities of adopting GPP, equilibrate competition among EU member states and facilitate sustainable procurement for procurers operating in multiple countries.

In that year, through a communication from the commission to the European Parliament [12], it was proposed to formalize the GPP process by creating a set of common GPP criteria at the European level. These criteria would be voluntary, yet they encouraged the member states to integrate them into their national policies. A group of representatives, with expertise in GPP, closely cooperated with the Commission in order to define the criteria. These criteria were developed based on information collected from stakeholders and on existing eco-labels. For works, products, and services where no European criteria is defined, national GPP criteria, if available, would then be applied.

Priority Sectors

The aforementioned communication identified products and service groups in 10 "priority" sectors. These were selected based on a key factors such as their potential impact, their scope for environmental improvement, the public expenditure and the existence of criteria. The sectors that were defined are [12]:

1. Construction

2. Food and catering services
3. Transport and transport services
4. Energy
5. Office machinery and computers
6. Clothing, uniforms and other textiles
7. Paper and printing services
8. Furniture
9. Cleaning products and services
10. Equipment used in the health sector

Core vs Comprehensive

GPP criteria can be categorized as "core" or "comprehensive" depending on their ambition level. The core criteria aim to simplify the use of GPP, focusing on the factors that contribute the most to reducing the environmental impact of a given product or service. They also aim to reduce the friction by minimizing administrative costs. On the other hand, the comprehensive criteria set a higher standard of environmental performance. These are to be used by public authorities looking to maximize their environmental support.

Types of GPP Criteria

There are 4 types of GPP criteria that can be specified for each sector [7, 8, 34]:

- **Selection Criteria (SC)**: These criteria relate to the suitability, professional abilities, economic and financial standing of the tenderer, not to the product being procured. For services and works contracts it may require the ability to apply environmental management measures when carrying out the contract.

  An example from the GPP Criteria for Indoor Cleaning Services: *"**SC1 Competences of the tenderer**: The tenderer must have relevant competences and experience in providing environmentally conscious indoor cleaning services that, at a minimum, included the following: use of cleaning products that have been awarded the EU Ecolabel..."*

- **Technical Specifications (TS)**: There are the minimum compliance requirements

that must be met by all tenders. They must be linked to the contract's subject matter and must refer to the characteristics of the product being procured. They can be the description of the product or a functional or performance based definition.

An example from the GPP Criteria for Furniture: *"**TS4: Refurbished furniture product warranty**: The tenderer shall provide a minimum two year (longer for more valuable items) warranty effective from the date of delivery of the product."*

- **Award Criteria (SC)**: These are considered at the awarding stage. They refer to the characteristics of the goods, services, and works or the way in which they will be performed. Contracts are to be awarded according to the MEAT principle (covered in 2.1.1). This principle includes the cost element, but also a set of other factors that may influence the value of the tender to the contracting authority (including environmental aspects). Anything that is scored for award purposes counts as an award criterion. They must be linked to the contract's subject matter, concerning any stage of the product's life-cycle. They can also be used to stimulate additional environmental performance without the necessity of being mandatory.

  An example from the GPP Criteria for Furniture: *"**TS1: Collection and reuse of existing furniture stock**: An assessment of the condition of the furniture to be collected shall be provided by the contracting authority (CA) in the ITT which also may define a minimum re-use target to be met (e.g. 50% of provided furniture)"*

- **Contract Performance Clauses (CPC)**: They are used to specify the manner in which a contract is to be executed and must also be linked to the contract's subject matter, which can be at any part of the product's life-cycle. They are not scored for award purposes. These clauses are not to be complied with at the procurement procedure, but rather monitored during the execution of the contract (i.e. after it has been awarded). To ensure compliance, penalties or bonuses may be applied.

  An example from the GPP Criteria for Furniture: *"**CPC1. Sourcing of legal timber**: "Upon request, the contractor should provide evidence to demonstrate compliance with the EU Timber Regulation."*

Application Examples

For instance, in the food sector, GPP can be applied to promote more sustainable food consumption through the incentivization of organic products. The amounts required (or suggested) vary significantly between countries, regions and product categories. For example, as of 2020, in Italy, 40% of fruit and vegetables are recommended to be organic,

while in Copenhagen this becomes a requirement of 100%. These targets often require verification through labels and certifications [44].

Another example, in the street lighting systems, where the application of GPP seeks to reduce the overall street light for reduced traffic through dimming technology (by reducing the intensity of LEDs during low traffic hours). This can reduce light pollution, electricity consumption and maintenance costs [51].

2.2.3. Eco-labels

Eco-labels are labels (such as logos or marks) that help identify products or services with a demonstrated reduced impact on the environment. They serve to provide consumers, businesses, and procurers with accurate information on the environmental impact of the products, so that they can make informed choices [38].

In particular, EU Eco-labels are a key part of the strategy of the European Union to promote more sustainable public procurement. To earn the right to use an EU Eco-label, the products or services must meet predefined criteria, and a fee must be paid. The compliance of these standards goes through rigorous verification and certification processes by competent bodies within the member states of the EU. Eco-labels serve as a crucial source of information [24].

At the time of formalization of GPP criteria at a European level, eco-labels already existed. In the official communication, it is also mentioned that not only were EU eco-labels considered, but they were even used as a reference to develop the GPP criteria. In particular, for product groups already covered by eco-labels, the relevant criteria for such eco-label would be divided between "core" and "comprehensive" to form the GPP criteria (according to the environmental impacts and simplicity of application) [12].

For instance, in the GPP Criteria for Indoor Cleaning Services, where the selection criteria SC1 requires that the cleaning products used have been awarded the EU Eco-label for hard surface cleaning or other relevant EN ISO 14024 type I eco-labels [7].

Figure 2.2: Multi Forte - 5l: Example of an indoor cleaning services product with an EU Eco-label [35].

Figure 2.3: EU Eco-label certified by the Belgian competent body[35].

2.2.4. Challenges

Although GPP is recognized as a powerful tool for promoting sustainability and is actively supported by the European Commission, it's effective implementation has encountered some challenges across Europe. Some of these are:

- **Knowledge and Awareness**: The public authorities often lack the knowledge regarding the existing GPP criteria at both the national and the European level, as well as the practical intricacies of their application throughout the procurement process. There is also ignorance regarding the life cycle costs and benefits of environmental products. In order to improve this situation, there is a need for tools that help identify and formulate the appropriate environmental criteria. Another solution to this problem could come in the form of better training for procurers on sustainability criteria, yet that could be limited by financial constraints. This lack of knowledge, along with the financial constraints are recognized as the key obstacles for a more widespread application of GPP throughout public procurement [1].

- **Financial Constraints**: Products with a reduced environmental impact are generally perceived as more expensive than their traditional counterparts. While this is not always true, the perception is enough to hinder the adoption of GPP practices. During times where public authorities are under budgetary constraints, GPP considerations are likely to be sacrificed, falling back to a cost-centric awarding approach, particularly for smaller public authorities with higher financial restrictions. While it has been argued that GPP can lead to economic benefits, the evidence is not yet sufficient to justify its use from a purely financial standpoint [6].
- **Legal Uncertainty**: The complexities legality around including environmental criteria in tender documents present yet another barrier for contracting authorities [12].
- **Organizational Issues**: Another issue is faced at the organization level, particularly when decision making and implementation is spread across various layers of the organizational structure. Different levels of the organization may have different priorities that might not be fully aligned with GPP. The organization issues are also exacerbated for smaller public authorities who are less likely to have dedicated personnel for the implementation of GPP and more likely to lack the sufficient expertise or resources to focus on effectively implementing GPP criteria [6].
- **Data Quality**: The lack of proper information management makes it hard to evaluate the impact of existing policies, thus hindering future improvements. In essence, the available procurement data, in 2019, was deemed to lack the necessary quality for data-driven policy-making. The non-standardization of form design was one of the main culprits of varying data structures and missing data. These issues were raised just before the introduction of eForms, which has as one of its objectives to face this challenge [37].
- **Complexities of Evaluating Environmental Criteria**: Because of the difficulties in using techniques like Life Cycle Assessment (LCA), evaluating environmental criteria for GPP can become quite complex. Despite its influence, the use of LCA is limited by the necessity of specialized skills that public procurement practitioners frequently lack (as already mentioned). Additionally, it can be fairly complex to aggregate diverse environmental impacts, and other factors, into a single, understandable score, often leading to a trade-off between the accuracy and usability of scoring techniques [65].

2.3. The eForms Standard

eForms were established by the Commission Implementing Regulation (EU) 2019/1780 [22] to standardize electronic forms used for publishing notices in the context of public procurement. They replaced the previous regulation from 2015 with the goal of adapting to a digital environment and are crucial for the digital transformation of public procurement. This standard was built for electronic notices, rather than paper documents. It intends to reduce the administrative burden and improve data reliability.

The regulation established six different types of standard forms, each covering different stages of the procurement process (as defined in [22]):

1. **Planning**: This form is used for publishing notices related to prior information notices.
2. **Competition**: This form is used for notices related to calls for competition. In particular, it covers contract notices, which will be the focus of our software application.
3. **Direct award prenotification**: This form is used for voluntary ex-ante transparency notices under various directives.
4. **Result**: This form is for notices related to the outcome of procurement procedures.
5. **Contract modification**: This form is specifically for notices concerning modifications to contracts.
6. **Change**: This form is used for changing or canceling any of the other standard notices listed above.

Each of these standard forms consist of several fields or Business Terms (BTs) which may be either mandatory or optional. There is some flexibility to eForms related to the labels, optional fields, which may become mandatory at national levels, and in the order of the fields displayed.

2.3.1. Contract Notices

The notices that we focus on for this project are contract notices, which fall under the category of "competition" forms. As a reminder, the definition of these forms consists of a template of fields that with the appropriate information, becomes a notice.

It is worth noting, that this table contains the values as amended through the Commission Implementing Regulation (EU) 2022/2023 [23], where several fields were updated

and introduced that significantly affected green public procurement. These include BT-774 Green Procurement Code, BT-805 Green Procurement Criteria Code, although not covered by our application, the codes related to enhanced reporting for clean vehicles: BT-717 Clean Vehicles Directive Indicator, BT-735 CVD Contract Type Code, BT-723 Vehicle Category Code, BT-715 Vehicles Number, BT-716 Clean Vehicles Number.

In the following table (2.1), we'll describe the fields in a contract notice that are relevant to the implementation of the software solution presented in this thesis, as described in [22], even if not directly used.

Table 2.1: Key Fields in Contract Notice Relevant to this Thesis

ID	Name	Description
BT-03	Form Type	The type of form according to procurement legislation.
BT-02	Notice Type	The type of notice according to procurement legislation.
OPP-070	Notice Subtype	The subtype of notice.
BT-23	Main Nature	The main nature (e.g. works) of what is being bought.
BT-531	Additional Nature	The nature (e.g. services) of what is being bought, additional to Main Nature.
BT-21	Title	The name of the procurement procedure or lot.
BT-24	Description	The description of the nature and quantity of what is being bought or of the needs and requirements that shall be met in this procedure or lot.
BT-27	Estimated Value	The estimated value of the procurement procedure or lot, over its whole duration, including options and renewals.
BT-26	Classification Type	The type of classification describing the purchase (e.g. the CPV).
BT-262	Main Classification Code	The code from the classification that best characterizes the purchase.
BT-263	Additional Classification Codes	An additional code from the classification that also characterizes the purchase.
BT-105	Procedure Type	The type of procurement procedure.

Table 2.1: Key Fields in Contract Notice Relevant to this Thesis

ID	Name	Description
BT-67	Exclusion Grounds	The brief description of criteria regarding the personal situation of tenderers that may lead to their exclusion.
BT-747	Selection Criteria Type	The criteria (or criterion) concern(s), for example, economic and financial standing or technical and professional ability.
BT-749	Selection Criteria Name	The name of the selection criteria (or criterion).
BT-750	Selection Criteria Description	The brief description of the selection criteria.
BT-70	Terms Performance	The main information about the performance of the contract.
BT-539	Award Criterion Type	Whether the criterion concerns the price, the cost, or a non-price non-cost attribute of the tender.
BT-734	Award Criterion Name	The name of the award criterion.
BT-540	Award Criterion Description	The description of the award criterion.
BT-541	Award Criterion Number	A number linked to an award criterion.
BT-5421	Award Criterion Number Weight	Whether the number linked to an award criterion is a type of weight (e.g. a percentage).
BT-5422	Award Criterion Number Fixed	Whether the number linked to an award criterion is a fixed value (e.g. a fixed price, a fixed cost).
BT-5423	Award Criterion Number Threshold	Whether the number linked to an award criterion is a type of threshold.
BT-543	Award Criteria Complicated	The mathematical equation or any other description used for complicated weighing of criteria (e.g. non-linear weighing, the analytic hierarchy process) when a weighing cannot be expressed per criterion.

Table 2.1: Key Fields in Contract Notice Relevant to this Thesis

ID	Name	Description
BT-733	Award Criteria Order Justification	The justification for only indicating the award criteria's order of importance, not their weighing.
BT-15	Documents URL	The internet address for accessing (the non-restricted part of) the procurement documents
BT-702	Notice Official Language	The language(s) in which this notice is officially available. These linguistic versions are equally legally valid.
BT-06	Strategic Procurement	The procurement procedure aims at reducing the environmental impacts of the procurement, fulfilling social objectives and/or buying an innovative work, supply or service.
BT-777	Strategic Procurement Description	Description of how the procurement procedure is aiming at reducing the environmental impacts of the procurement, fulfilling social objectives and/or buying an innovative work, supply or service.
BT-805	Green Procurement Criteria	The procurement procedure includes the use of established green public procurement criteria (selection criteria, technical specifications, award criteria and contract performance clauses), at national, Union or other level, if applicable.
BT-774	Green Procurement	A process to procure goods, services and works with reduced environmental impact throughout their life cycle.
BT-776	Procurement of Innovation	An indication that innovative works, supplies or services are being bought.
BT-717	Clean Vehicles Directive	The procurement falls within the scope of the European Parliament and Council 2009/33/EC (Clean Vehicles Directive – CVD).
BT-632	Tool Name	The name of the electronic tool or device used for electronic communication.
BT-514	Organization Country Code	The country of the organization's physical address.

Table 2.1: Key Fields in Contract Notice Relevant to this Thesis

ID	Name	Description
OPT-002	Customization ID	Version of the SDK used.
BT-300	Additional Information	Any further information not mentioned in other sections of the notice.

For more details on the fields presented and information on other fields, please refer to the full table provided in [22, 23].

The fields defined for each form type, along with their respective values are then structured into an XML file, according to the definitions in the eForms SDK 2.4. Below, a very short and reduced snippet of a sample XML eForm Contract Notice [48] is presented:

```
<?xml version="1.0" encoding="utf-8"?>
<!-- Voluntary form E3 with minimal amount of information.
-->
<ContractNotice
↪  xmlns:cac="urn:oasis:names:specification:ubl:schema:xsd:CommonAggregateComponents-2"
↪  ...>
    ...
  <cbc:NoticeTypeCode listName="competition">cn-standard</cbc:NoticeTypeCode>
  <cbc:NoticeLanguageCode>ENG</cbc:NoticeLanguageCode>
    ...
  <cac:TenderingTerms>
    <cac:TendererQualificationRequest>
      <cac:SpecificTendererRequirement>
        <cbc:TendererRequirementTypeCode listName="exclusion-grounds-source">
        ↪  epo-procurement-document</cbc:TendererRequirementTypeCode>
      </cac:SpecificTendererRequirement>
    </cac:TendererQualificationRequest>
  </cac:TenderingTerms>
    ...
  <cac:ProcurementProject>
    <cbc:Name languageID="ENG">Provision of IT Services related to ...</cbc:Name>
    <cbc:Description languageID="ENG">Provision of IT services related to the information
    ↪  systems of ...</cbc:Description>
    <cbc:ProcurementTypeCode listName="contract-nature">services</cbc:ProcurementTypeCode>
    <cac:MainCommodityClassification>
      <cbc:ItemClassificationCode listName="cpv">72230000</cbc:ItemClassificationCode>
    </cac:MainCommodityClassification>
        ...
  </cac:ProcurementProject>
  <cac:ProcurementProjectLot>
    <cbc:ID schemeName="Lot">LOT-0001</cbc:ID>
        ...
  </cac:ProcurementProjectLot>
</ContractNotice>
```

Figure 2.4: Modified snippet from an eForm Contract Notice

2.3.2. TED

TED, short for "Tenders Electronic Daily" is the official online version of the Official Journal of the European Union, where all notices published using the eForms standard become publicly available. It's the central hub for EU tenders.

From information extracted directly from TED [53]: On 25 October 2023, it became a requirement to use eForms for publication on TED. Furthermore there is a set of contract value thresholds that when surpassed, an invitation to tender must be published throughout the EU following EU directives.

The contract value thresholds above which an invitation to tender must be published

throughout the EU are laid down in EU directives. The following table provides the current thresholds that contracting authorities must respect for the publication of tender notices in the Official Journal of the EU (also specified in the official TED website [53]).

Contract Value Thresholds

Type of Contract	Threshold (EUR)
Public works	5,538,000
Service contracts	143,000
Supplies contracts	143,000
All other supplies and services in the sectors of water, energy and transport	443,000

Table 2.2: Current thresholds that contracting authorities must respect for the publication of tender notices in the Official Journal of the EU.

Essentially, any contract whose goods go beyond these thresholds must be published in the Official Journal of the European Union (TED being the online version), and therefore must use eForms to represent the notice. This is the reason why **eForms are the central element for the software tools developed in this thesis**, since it allows us to maximize the impact on electronic public procurement in Europe.

2.4. TED Developer Tools

TED provides a set of APIs (Application Programming Interface), an SDK (Software Development Kit) and open standards that can be used by developers to create applications related to public procurement in Europe.

The information presented in this section all originates from the official source of information, the TED Developer Documentation [54] and their official GitHub repositories, all contained within the TED & EU Public Procurement GitHub Organization [49].

In the following subsections we'll go into the details of the developer tools provided that are relevant to this thesis project. As a quick overview, these are main elements presented in the TED developer portal:

- **TED API**: The TED API is a collection of public interfaces allowing 3rd party applications to validate and submit eForms notices, publish tender documents, and search the TED archives.

- **TED Apps**: A range of applications for the submission, validation, processing, visualization, and dissemination of eForms notices. These went into production on 14 November 2022.
- **eForms SDK**: The eForms SDK is a collection of resources, models and schemas providing the foundation for building eForms applications. This set of tools is central to this thesis.
- **eProcurement Ontology**: The eProcurement Ontology provides the formal, semantic foundation for the creation and reuse of linked open data in the domain of public procurement in the EU. This tool is not particularly relevant to this thesis and won't be covered any further.
- **European Single Procurement Document (ESPD) Exchange Data Model**: The ESPD enables accelerated processing of preliminary evidence in EU public procurement. The ESPD-EDM enables applications to integrate with national ESPD service providers. This tool is not particularly relevant to this thesis and won't be covered any further.

2.4.1. TED API

APIs are tools that allow software applications to communicate and interact with each other. A set of rules and specifications must be followed to enable such cooperation.

In particular, these are REST (Representational State Transfer) APIs. REST being a specific type of web-based communication architecture which uses HTTP as the standard protocol. REST APIs are generally recognized as the standard for building web services [42].

The Publications Office developed an API that allows third-party developers to integrate their e-Procurement applications with the TED ecosystem. This API is essential for any entity that works with public procurement notices in Europe (in particular e-Senders). These tools make up the backbone that enables efficient interaction with TED services across Europe. The latest version of the TED API, version 3, brings the functionalities together to simplify its use.

The TED API includes:

- **Publications API**: Allows to submit and manage notices for publication. It includes operations to query submitted notices (*GET /v3/notices/*), stop publication (*POST /v3/notices/businessId/stop-publication*), retrieve validation reports (*GET*

/v3/notices/businessId/validation-report) and submit notices for publication (*POST /v3/notices/submit*).

- **Search API**: Allows to retrieve the procurement notices published in TED. It only provides one endpoint to search and retrieve published notices (*POST /v3/notices/search*).
- **Validation API**: Allows to validate the procurement notices before publication by identifying errors, and ensures compliance with EU standards. It only provides one endpoint to validate procurement notices (*POST /v3/notices/validate*)
- **Visualization API**: Allows to transform the procurement notices from a non-user friendly XML format into readable formats such as PDFs or HTML. It includes operations to render notices in synchronous and asynchronous modes (*POST /v3/notices/render, POST /v3/notices/render-async*).
- **Conversion API**: Enables the transition from legacy TED XML notices to eForms. It only provides one endpoint to convert TED XML notices (*POST /v3/notices/convert*).

The TED Developer Docs [54] provide a public API documentation in the form of a Swagger API interface with the precise details on expected query parameters and request and response bodies.

For procurement notices that have already been published, anonymous access to these endpoints is allowed. For notices that have not yet been published, an API key is required to authenticate the caller. These API keys can be obtained through the TED Developer Portal.

Who uses these APIs? There are 3 types of users: **TED Apps**, also part of the TED ecosystem; developers, researchers and **eSenders**. eSenders are procurement service providers that operate their own e-Procurement platforms and use the TED API to integrate with the TED ecosystem.

2.4.2. TED Apps

As previously mentioned, TED also published a set of applications for the submission, validation, processing, visualization, and dissemination of eForms notices. These include:

- **eNotices2**: This is a free web application that offers a user-friendly interface that allows contracting authorities to create, validate, and submit their public procurement notices for publication on TED. It uses the Publication API for publication management. Integrates the TED CVS to validate notices before submission.
- **TED Central Validation Service (TED CVS)**: A service that provides an API

for ensuring the compliance of procurement notices with the relevant standards. It exposes the functionalities of the Validation API.

- **TED Viewer**: Allows to render notices into readable formats like HTML and PDF using the Visualization API. Can be used by third-parties to preview XML notices.
- **TED Website**: This is the platform that is typically used by the public to explore published notices. It uses the Search API to power its functionalities.
- **TED XML Data Converter (TEDXDC)**: A service that provides the functionality of an API designed to convert legacy TED XML schema notices into eForms. It uses the Conversion API.

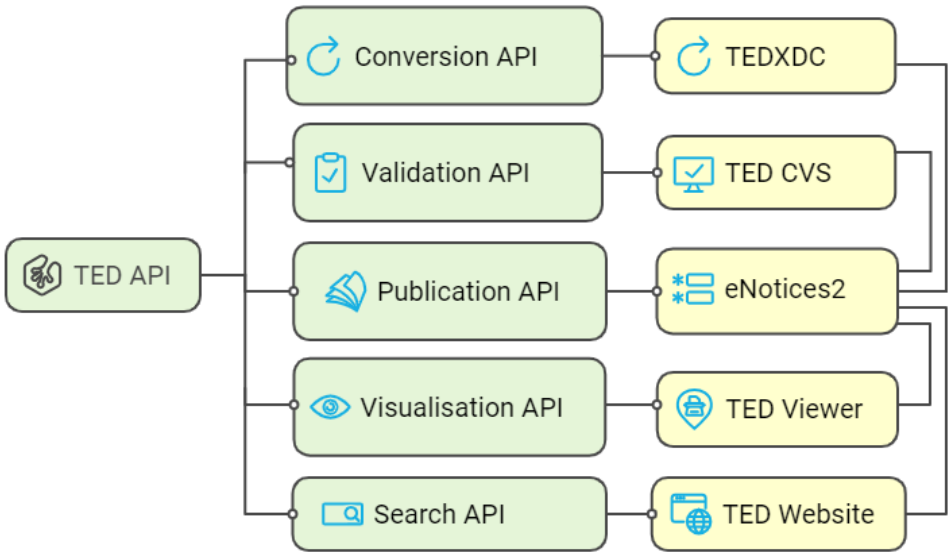


Figure 2.5: How TED API links to TED Apps (diagram from the TED Developer Docs [54]).

2.4.3. eForms SDK

The eForms Software Development Kit available at a GitHub repository [48] is a collection of resources that can be used to build eForms applications. In general, the developed eForms applications aim to visualize, create and edit eForm notices, and potentially, submit for publication. This SDK is **vital** for e-Procurement platforms.

The resources contained in the eForms SDK include:

- **Schemas**: The XML schemas used for eForms notices. The schemas are based on Pre-Award document types of the UBL 2.3 standard.
- **Schematrons**: The Schematron rules used to check the validity of notices as per the eForms regulation. All rules and constraints are implemented in Schematron.
- **Code Lists**: The controlled vocabularies used in eForms notices. Practically, it provides the valid options available for different fields in the notices.
- **Notice Types**: Defines the structure required for each notice sub-type.
- **Fields**: Details on the fields that make up a notice.
- **View Templates**: Metadata used to visualize notices.
- **Translations**: Contains the translations of the various text used in notices.
- **Examples**: Concrete examples of notices, both valid and invalid cases.

Particularly relevant to this project are the notice types, the fields and the code lists.

Notice Types

The notice types includes a JSON (JavaScript Object Notation) file where the notice subtypes are described, referencing a separate JSON file where the exact structure of the given notice subtype is defined. For this thesis, we are only focusing on contract notices. Therefore, the only subtypes that are deemed relevant are:

- **16**: Contract notice – general directive, standard regime
- **17**: Contract notice – sectoral directive, standard regime
- **18**: Contract notice – defense directive, standard regime
- **20**: Contract notice – general directive, light regime
- **21**: Contract notice – sectoral directive, light regime
- **E3**: Voluntary Contract Notice

Fields

This refers to a single JSON file, where all of the fields that any given notice may contain are defined hierarchically. It contains key information on each field, such as: Business Term (BT) ID, name, XPath, a reference to the code-list for valid values, and data on whether it's forbidden or mandatory to include it in different notice subtypes.

Below, you can see the (reduced) field definition for the "Classification Type (e.g. CPV)":


```
{
    "id" : "BT-26(a)-Lot",
    "parentNodeId" : "ND-LotAdditionalClassification",
    "name" : "Classification Type (e.g. CPV)",
    "btId" : "BT-26",
    "xpathAbsolute" :
    ↪  "/*/cac:ProcurementProjectLot[cbc:ID/@schemeName='Lot']/cac:ProcurementProject/
    ↪  cac:AdditionalCommodityClassification/cbc:ItemClassificationCode/@listName",
    "xpathRelative" : "cbc:ItemClassificationCode/@listName",
    "xsdSequenceOrder" : [ { "cbc:ItemClassificationCode" : 5 } ],
    "type" : "code",
    "attributeName" : "listName",
    "attributeOf" : "BT-263-Lot",
    "businessEntityId" : "lot",
    "legalType" : "CODE",
    "repeatable" : {
      "value" : false,
      "severity" : "ERROR"
    },
    "forbidden" : {
      "value" : false,
      ...
    },
    "mandatory" : {
      "value" : false,
      ...
    },
    "codeList" : {
      "value" : {
        "id" : "classification-type",
        "type" : "flat"
      },
      "severity" : "ERROR"
    }
}
```


Figure 2.6: Snippet from `https://github.com/OP-TED/eForms-SDK/tree/develop/fields/fields.json`

XPath stands for XML Path Language. It goes beyond standard XML syntax to provide an even more flexible access to different parts of an XML document. It is a powerful tool to navigate through XML-like documents. To do this, XPath uses a path notation to navigate through the structure of an XML document and non-XML syntax that can be used in URIs and XML attribute values [15].

Every field (and thus every BT ID) correspond to a precise XPath in the eForm notice.

This concept is key to how eForms work and to how the software tools in this thesis are developed.

Code Lists

The code lists contain the controlled vocabularies used in eForms notices. This refers to a directory with several files, each containing a set of valid codes, along with their translation in the official languages of the EU.

Below, you can find an example (reduced) that correlates to the field presented in 2.6, where the *classification-type.gc* file is invoked. This file can be understood as: the only valid value for a classification type is "cpv" (see 2.1.4.

```
<?xml version="1.0" encoding="UTF-8"?>
<!--File generated from metadata database-->
<gc:CodeList xmlns:gc="http://docs.oasis-open.org/codelist/ns/genericode/1.0/">
   <Identification>
      <ShortName>ClassificationType</ShortName>
      <LongName>classification-type</LongName>
      ...
   </Identification>
   <SimpleCodeList>
      <Row>
         <Value ColumnRef="code">
            <SimpleValue>cpv</SimpleValue>
         </Value>
         <Value ColumnRef="Name">
            <SimpleValue>Common Procurement Vocabulary</SimpleValue>
         </Value>
         ...
         <Value ColumnRef="eng_label">
            <SimpleValue>Common procurement vocabulary</SimpleValue>
         </Value>
         <Value ColumnRef="ita_label">
            <SimpleValue>Vocabolario comune per gli appalti pubblici</SimpleValue>
         </Value>
         ...
      </Row>
   </SimpleCodeList>
</gc:CodeList>
```

Figure 2.7: Snippet from `https://github.com/OP-TED/eForms-SDK/blob/develop/codelists/classification-type.gc`

2.4.4. Tools Related to the eForms SDK

On top of the aforementioned tools, the Publications Office of the EU also provides us with a few other projects that are aimed at helping developers integrate the eForms SDK, either directly or as a reference on how to use it.

At the lowest level, we have the eForms Core Java Library [48]. This library provides a set of classes that can be used to solve some common "problems" in eForms Applications. Firstly it helps with the management of the eForms SDK, including handling multiple SDK versions. Secondly, it provides us with helper for basic parsing and processing of XPath expressions.

Furthermore, there are two sample applications that seek to demonstrate the use of concepts and resources available in the eForms SDK. Both of these are also implemented using the Java programming language. They can be used as an inspiration or starting point new e-Procurement applications.

The eForms Notice Viewer is a command-line application meant to visualize eForms notices. It uses the eForms SDK and the eForms Core Java Library. It takes as input an eForms notice XML file and generates as output a HTML page that displays a user-friendly content of the notice.

For reference, the original XML eForm looks as presented in the figure 2.4. The readable version of the notice produced by the eForms Notice Viewer looks as follows:

2 Procedure

2.1 Procedure

Title: Procedura aperta finalizzata alla conclusione di un accordo quadro come definito dall'art. 59 del d. lgs. n. 36/2023 per la fornitura con posa in opera di arredi e complementi di arredo per nidi d'infanzia per la durata di anni 2

Description: Procedura aperta finalizzata alla conclusione di un accordo quadro come definito dall'art. 59 del d. lgs. n. 36/2023 per la fornitura con posa in opera di arredi e complementi di arredo per nidi d'infanzia per la durata di anni 2

Procedure identifier: f91d0a61-8085-4942-9bf4-038d2338623f

Type of procedure: Open

2.1.1 Purpose

Main nature of the contract: Supplies

Main classification (cpv): 39161000 Kindergarten furniture

2.1.3 Value

Estimated value excluding VAT: 597,260 Euro

Maximum value of the framework agreement: 597,260 Euro

Figure 2.8: Snippet from a rendered contract notice published in TED [53]

The eForms Notice Editor is a simple web application that has the basic functionality for creation and modification of eForms. It also integrates the eForms SDK and the eForms Core Java Library. It uses the Notice Types files previously mentioned in the eForms SDK to determine the structure of new notice files.

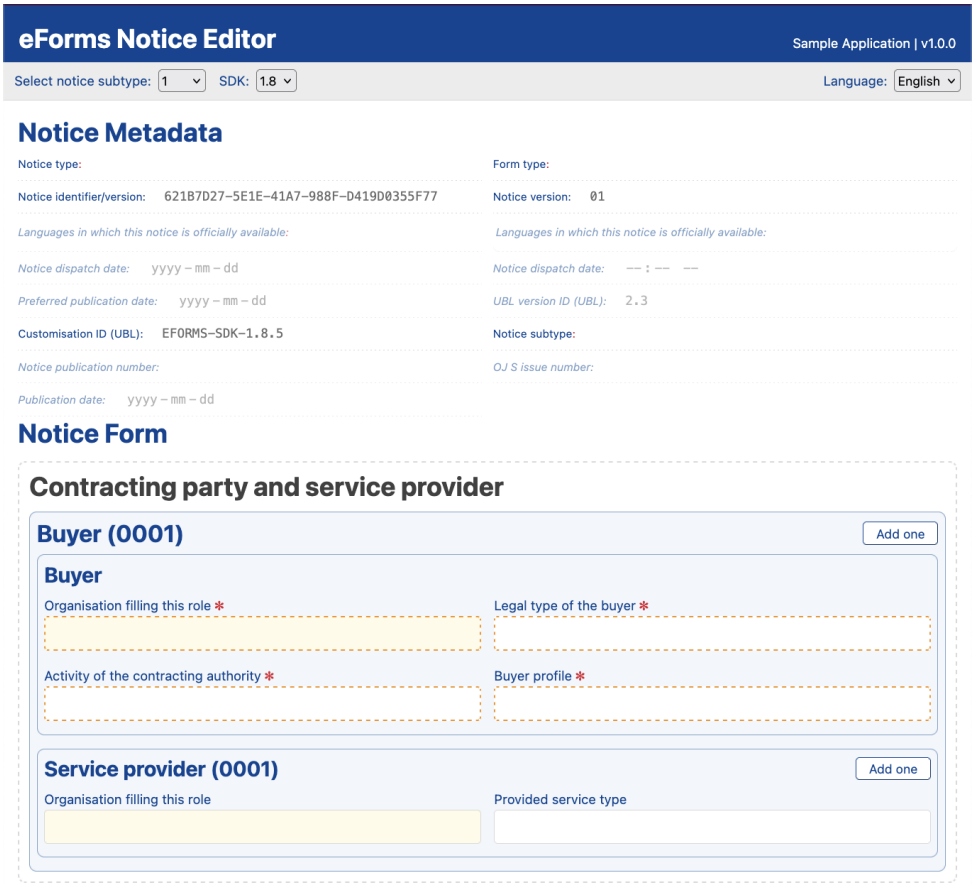


Figure 2.9: Snippet from the creation screen of the eForms Notice Editor

2.5. State of the Art

2.5.1. Empirical Analysis

While the EU actively promotes Green Public Procurement, and provides criteria for many goods, the use of these GPP criteria is facing many challenges as discussed in 2.2.4.

To understand the extent of the usage of GPP criteria and other GPP related data, this section presents a targeted data analysis of eForms notices submitted to Tenders Electronic Daily (TED), along with data readily provided by TED. By examining key fields in a sample of these notices, this analysis aims to understand the current status of GPP in European public procurement. Further analysis will be done to build an

understanding of the panorama of e-Procurement tools.

This findings will be critical to the design of the proposed software solution.

Methodology

The data considered for this empirical analysis all originates from the TED official website [53]. In particular, the eForm notices published in TED were downloaded using their XML bulk download functionality (available at https://ted.europa.eu/en/simap/xml-bulk-download), which allows you to download both daily and monthly packages. In this case, we will be using the data from March 2025, since it was the latest complete notice package at the time of the analysis. Since each day in any given notice package contains around 3,000 notices (only a subset of these are contract notices), we will sample a random set of 5 days from the month to stay within our computational constraints. This sample size should be enough to represent the data.

In order to perform the data analysis, a Jupyter Notebook, hosted on Google Colab was used. The programming language used was Python. The libraries that are relevant to our analysis are:

- **lxml**: This is the most feature-rich and easy-to-use library for processing XML and HTML in the Python language [10]. In particular, we care about the module "etree", which provides us with support of XPath (previously explained at 2.4.3. Using this module and the XPath paths defined in the fields module of the eForms SDK, we are able to access specific fields for filtering or for direct analysis.
- **matplotlib**: Matplotlib is a comprehensive library for creating static, animated, and interactive visualizations in Python [19]. In particular, we care about the module "pyplot", which provides us with functionalities to create a variety of plots to visualize our data.

We have identified a set of fields from the eForms to be extracted. Some will help us filter through the notices published. The rest will provide us with the information for our analysis. Please note that missing values will be categorized as "undefined". Moreover, the indicators of usage of a given field refer to the notice containing at least one lot that references such a field. For instance, if a single lot in a multi-lot notice indicates the usage of GPP criteria, this notice would then be counted as "using GPP criteria". For more details on the fields presented, please refer to the table 2.1.

As previously mentioned in 2.4.3, only the Contract Notices are relevant to this project, in particular the subtypes 16, 17, 18, 20, 21, E3. Before any further analysis on the fields

is done, we'll filter out this subset of notices using the OPP-070: notice subtype field.

In general each of the analysis will be done only at a European level, with some exceptions where it is also replicated at the Italian level, to provide different levels of granularity.

Findings

Firstly, TED provides an excel sheet with data providing immediate value about the source of the TED notices, grouped by country. The possible sources are: eNotices2 (the "in-house" e-Procurement platform, see 2.4.2) and eSenders (related to external e-Procurement platforms, see 2.4.1).

Below, you can find a subset of the table, with the data for March, 2025 for Italy and for all EU countries.

TED Notices by Country and Source

Country of Main Buyer	eSender	eNotices2	Total
Italy (ITA)	2,443	203	2,646
All Countries (Total)	**57,560**	**12,485**	**70,045**

Table 2.3: Distribution of TED notices submitted by country and by their primary submission source (eSender vs. eNotices2) for a given period.

This shows us that the large majority of the TED Notices are published through independent e-Procurement services, 82% to be precise. For Italy, this percentage increases to 92%. This is relevant to highlight the heterogeneity that we have previously mentioned regarding e-Procurement platforms.

To further understand the e-Procurement platform ecosystem, the first field that we'll analyze in our notices is the **BT-632: Tool Name** field, corresponding to the name of the electronic tool or device used for electronic communication.

Tool Name	Frequency
Undefined	7080
AW Solutions	404
"CAIS EOP"	186
https://www.meinauftrag.rib.de	154
simap.ch	135

Table 2.4: Observed frequencies of different eProcurement tools or platforms identified in a sample of procurement notices. Only showing the tools with more than 100 appearances

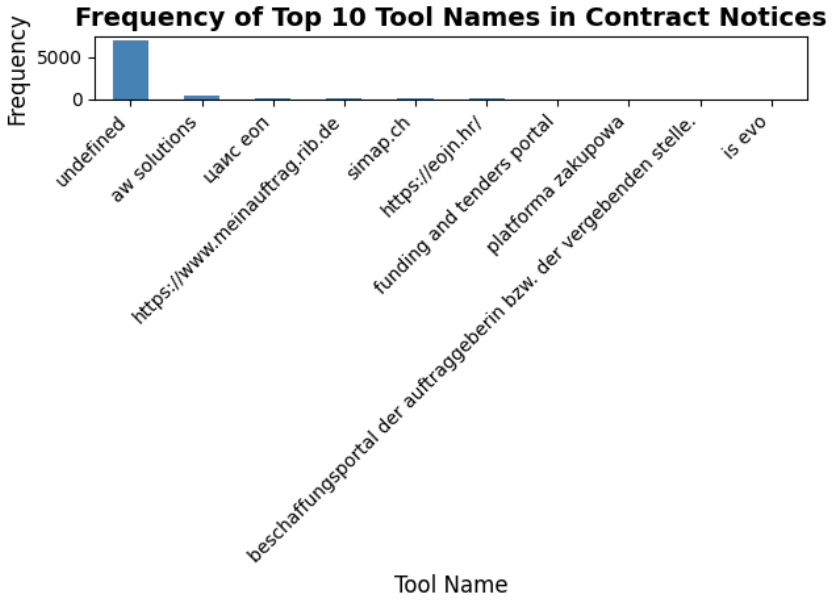


Figure 2.10: Bar chart that displays the distribution of different e-Procurement Tools found in the analyzed contract notices

Unfortunately, here we encounter another of the challenge: missing data. Being an optional field, we are unable to gather proper data for the exact e-Procurement tools being used. This would have enabled us to dig deeper into specific popular e-Procurement platforms that make up the eSenders.

Furthermore, we'll look at the **OPT-002: Customization ID** field, which contains the eforms-sdk version used by the sender. This is relevant since it will give us an understanding of what SDK versions our software solution should support.

Frequency of SDK Versions in Contract Notices

SDK Version	Frequency
eforms-sdk-1.12	2637
eforms-sdk-1.10	2453
eforms-sdk-1.7	1067
eforms-sdk-1.11	1047
eforms-sdk-1.8	550
eforms-sdk-1.9	509
eforms-sdk-1.13	294

Table 2.5: Observed frequencies of different eForms SDK versions used in a sample of procurement notices.

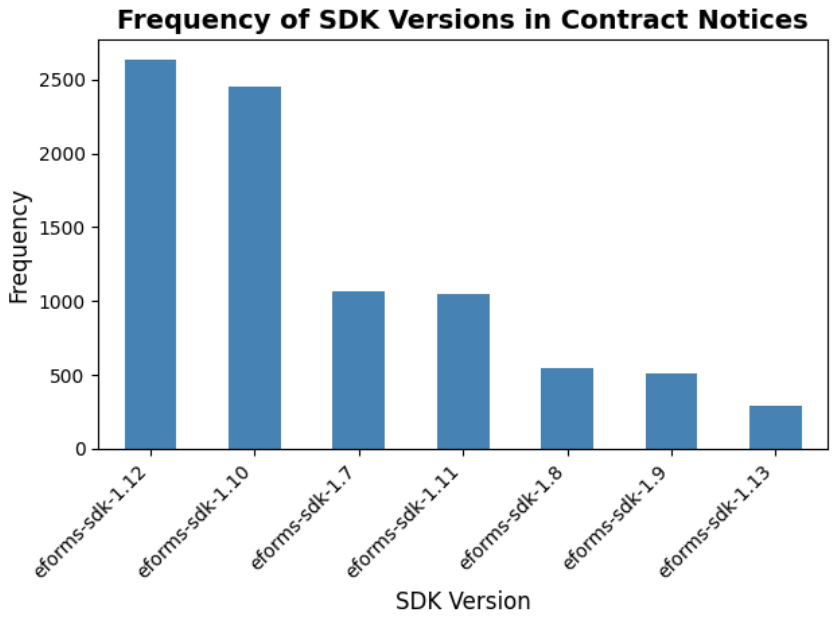


Figure 2.11: Bar chart that displays the distribution of different eForms SDK versions found in the analyzed contract notices

From this numbers we can see that the tendency is to use fairly recent SDK versions. This is a positive aspect since we can focus on the later versions of the SDK for the development of the tools.

Next up, we'll start looking at the usage of the eForm fields related to GPP. We first look

at the usage of the **BT-774: Green Procurement** field. This field indicates a process to procure goods, services and works with reduced environmental impact throughout their life cycle. For this one, we must first introduce the range of possible values, as defined in the eForms SDK code lists:

Category	Description
Biodiv-eco	The protection and restoration of biodiversity and ecosystems.
Circ-econ	The transition to a circular economy.
Clim-adapt	Climate change adaptation.
Clim-mitig	Climate change mitigation.
Pollu-prev	Pollution prevention and control.
Water-mar	The sustainable use and protection of water and marine resources.
Other	This category encompasses environmental impacts not covered by the specific defined categories.

Table 2.6: Green Procurement (GPP) categories with their descriptions.

Green Procurement Categories Frequencies

Green Procurement Category	Frequency
Undefined	7527
Other	607
Pollution Prevention	180
Climate Mitigation	104
Circular Economy	75
Climate Adaptation	40
Biodiversity	17
Water	7

Table 2.7: Observed frequencies of different Green Procurement categories in a sample of procurement notices.

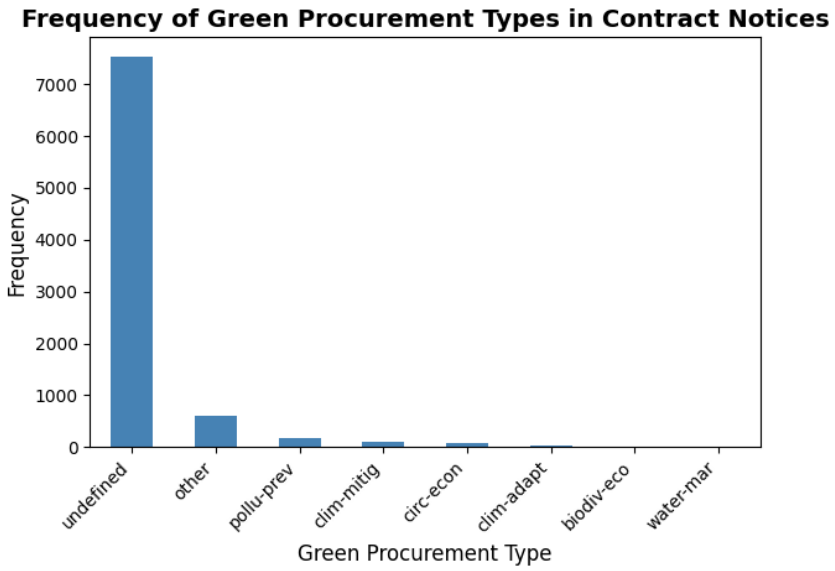


Figure 2.12: Bar chart that displays the distribution of different Green Procurement categories found in the analyzed contract notices

The overwhelming majority contract notices don't indicate that the process intends to procure goods, services and works with reduced environmental impact throughout their life cycle.

Another field related to GPP is the **BT-06: Strategic procurement** field that whenever it's value is set to "env-imp", indicates that the procurement procedure aims at reducing the environmental impacts of the procurement.

Has Strategic Procurement "Environmental Impact"	Frequency
False	7988
True	569

Table 2.8: Observed frequency of tender notices indicating whether strategic procurement objectives include a focus on environmental impact.

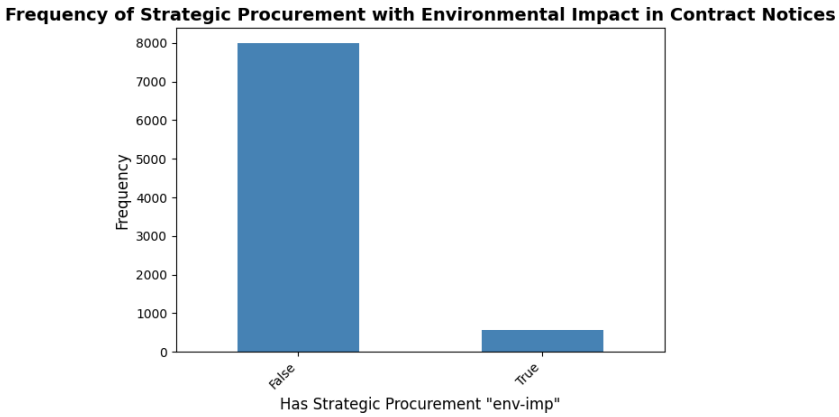


Figure 2.13: Bar chart that displays the distribution in tender notices of whether strategic procurement objectives include a focus on environmental impact.

Once again, the vast majority of the contract notices don't indicate that the procurement procedure aims at reducing the environmental impacts of the procurement.

Another key field related to GPP is the **BT-805: Green Public Procurement Criteria** field. This field indicates that the procurement procedure includes the use of established green public procurement criteria (selection criteria, technical specifications, award criteria and contract performance clauses), at national, Union or other level, if applicable.

Frequency of GPP Criteria Usage

GPP Criteria Source	Frequency
Undefined	8044
None	278
National	154
Other	41
EU	40

Table 2.9: Observed frequencies of GPP criteria usage, categorized by their source or absence, in a sample of procurement notices.

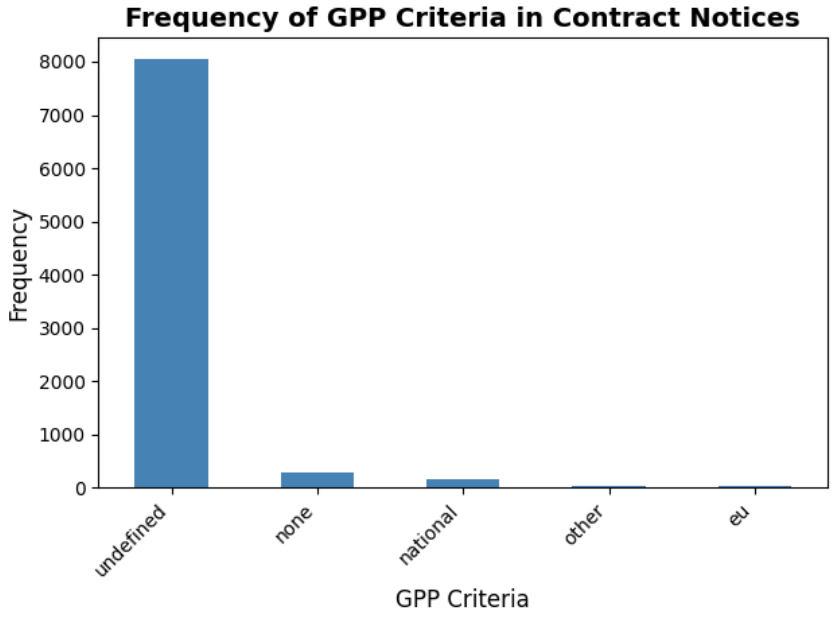


Figure 2.14: Bar chart that displays the distribution of different GPP criteria sources found in the analyzed contract notices

In this case, we notice that the explicit usage of GPP criteria, at both the national and EU level are almost non-existent.

Finally, we look at the **BT-539: Award Criterion Type** field, which is loosely related to GPP, since GPP Award Criteria could be indicated through this field. The possible values for an Award Criterion Type are: cost, price, and quality. Quality is an ambiguous term, that may refer to It gives us a loose indication of what the To maximize the insights provided by this field, we created a set of custom categories, according to the full list of award criteria in a given notice. These are notices that only award based on: only cost, only price, only quality, only cost and price, any other mix that includes quality.

Frequency of Notice Award Criteria Categories

Award Criteria Category	Frequency
Any mix with quality	3616
Only price	2749
Undefined	2077
Only cost	84
Only cost & price	31

Table 2.10: Observed frequencies of different Award Criteria categories used in procurement notices.

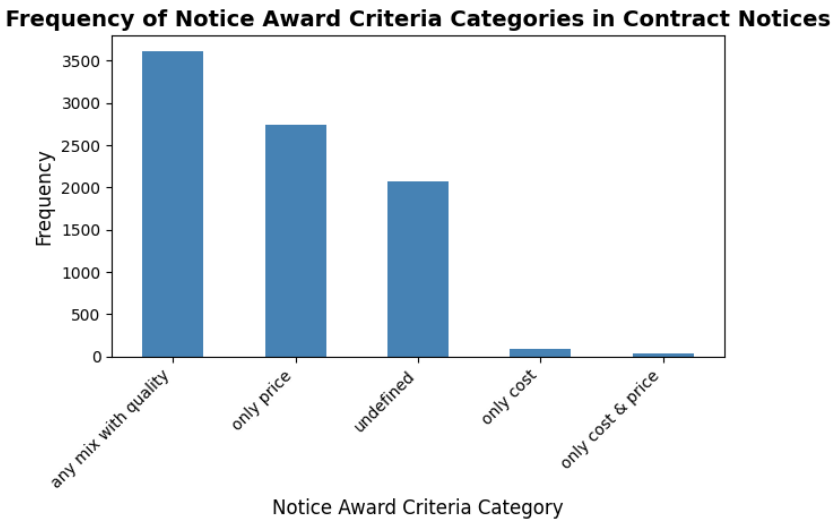


Figure 2.15: Bar chart that displays the distribution of different (custom) award criteria found in the analyzed contract notices.

From this we can see that the quality award criteria do have a solid representation in our contract notices. This however, doesn't directly indicate that any of these criteria are directly related to GPP. This information is contained in the description, which is a free text field. With no further simple means of narrowing down the type of quality they refer to, we find these award criteria results inconclusive.

Finally, to get a more representative statistic, we'll count the number of **notices that contains at least one of the main three indicators of GPP**: BT-774: Green Procurement, BT-06: Strategic procurement (with "environmental impact"), and BT-805: Green Public Procurement Criteria.

GPP Indicator Presence in Contract Notices

Category	Frequency
Contract Notices with at least one GPP indicator	1,155
Total Contract Notices	8,557

Table 2.11: Observed frequency of contract notices containing at least one GPP indicator compared to the total number of contract notices analyzed.

In essence, after analyzing around 25% of all of the notices published in TED in the month of March, 2025, 8,557 were contract notices. Out of this 8,557 contract notices, 1,155 used at least one GPP indicator in at least one of their lots. This leaves us with the estimation that only 13% of contract notices take into consideration the environmental impact of the procurement.

2.5.2. Existing e-Procurement platforms

To understand how GPP can be better integrated into existing e-Procurement platforms, we must first look into the experience that contracting authorities go through when completing contract notices. To do so, we will look at a few popular e-Procurement platforms. In particular, these are the largest platforms of Italy and Spain, as well as the eNotices2 platform provided by TED.

eNotices2

As previously mentioned, this is a free web application, offered by the Publications Office of the European Union, that provides a user-friendly interface that allows contracting authorities to create, validate, and submit their public procurement notices for publication on the TED portal [53]. It is available at `https://enotices2.ted.europa.eu`.

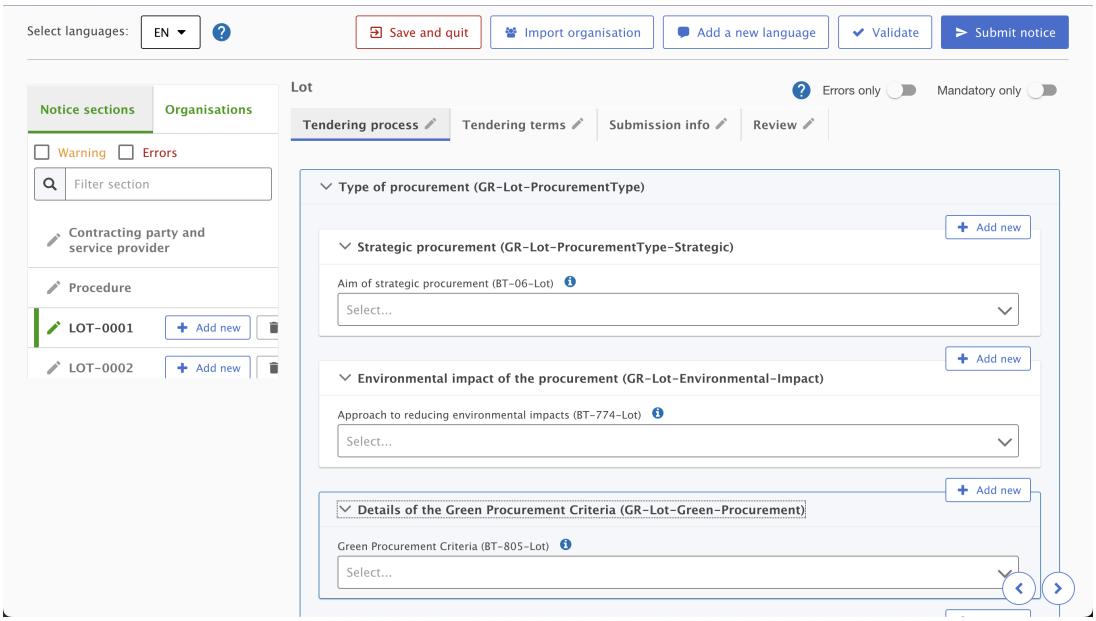


Figure 2.16: Screenshot of notice creation with GPP related fields.

The service provided by eNotices2 is pretty straightforward. It allows you to add and edit every valid field, according to the notice type selected. There is no particular guidance on the types of strategic procurement, including GPP. While it is not hard to find the GPP related fields when looking for them, they can easily be overseen by an average user due to the numerous fields available and the option of a "mandatory only", which reduces this fields to the bare minimum (which clearly does not include GPP elements).

Acquisti in Rete

Acquisti in Rete is the operational Portal where all activities of the Public Administration Procurement Rationalization Program take place. This includes everything from conducting tenders and qualifying businesses to publishing offer catalogs and public administrations making purchases, whether through direct orders or negotiations [18]. It is managed by the Italian Ministry of Economy and Finance. It is available at `https://www.acquistinretepa.it/`.

Due to restrictions on access to the platform, the experience of this platform was evaluated using an extensive video tutorial on the process of purchasing through MePA (part of Acquisiti in Rete) [13] as well as information present in the official website.

In the homepage of the Acquisiti in Rete portal, there is a section with information related to Green Public Procurement, which provides some information on GPP and its objectives.

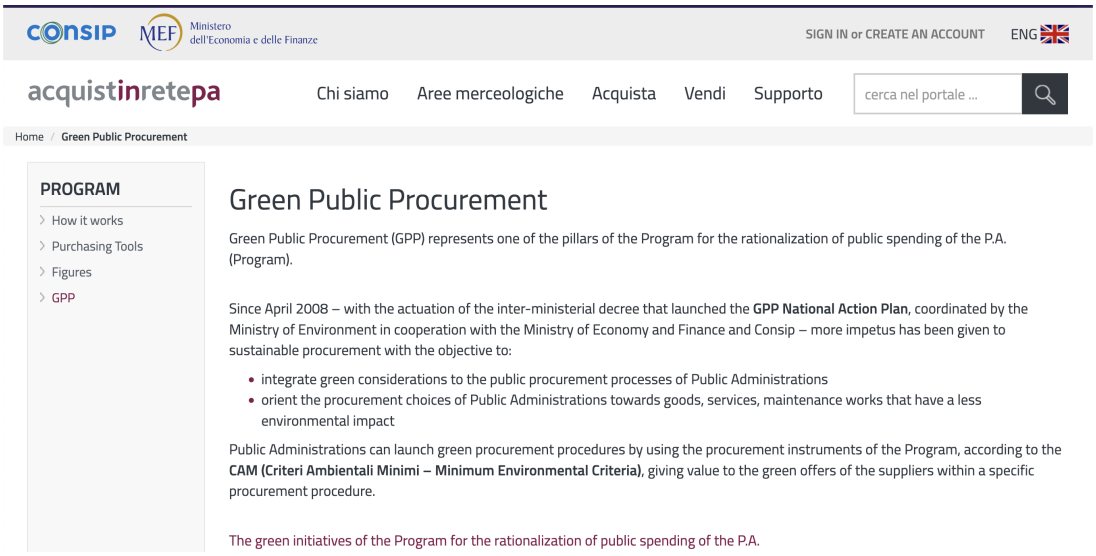


Figure 2.17: Screenshot of GPP information on the Acquisiti in Rete website.

During the natural flow of creating and submitting contract notices for a couple of use cases (shown in [13]), there was no further additional emphasis made on GPP.

When it comes to eForms, which are optional in the Acquisiti in Rete portal (as a reminder, below a certain value threshold, publication on TED is optional), the portal provides a basic input based interface, similar to the one in eNotices2. It is also possible to directly submit the XML eForm notice directly to the website.

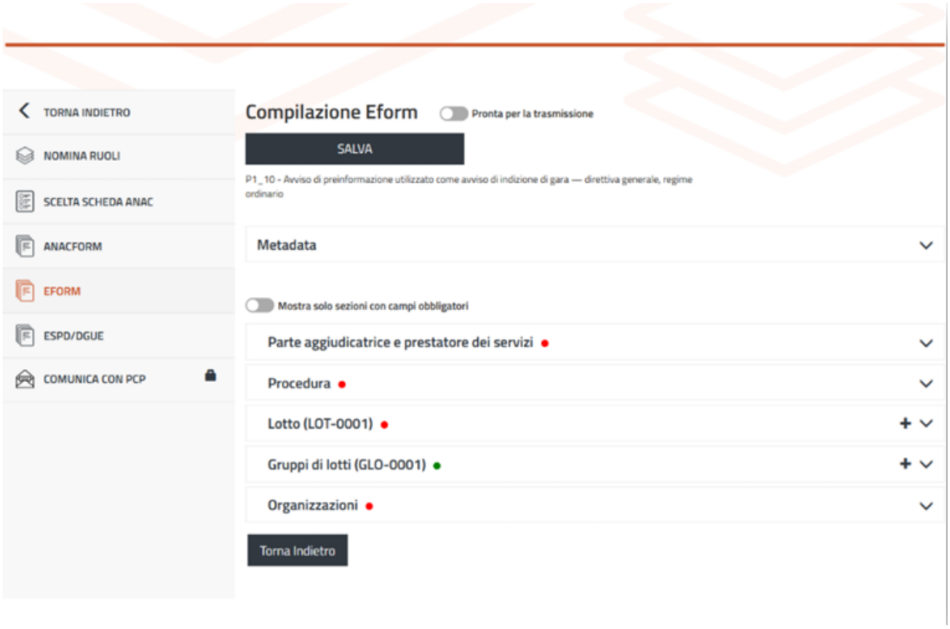


Figure 2.18: Compilation for eForms in Acquisiti in Rete.

Plataforma de Contratación del Sector Público

Translated to "Public Sector Contracting Platform", is the official and central e-Procurement portal for the public sector in Spain. It serves as the primary gateway for information on public contracts in the country [17]. This tool is available at `https://contrataciondelestado.es/wps/portal/plataforma`.

This platform was analyzed through a tutorial video [43] since the access to notice creation is restricted to Spanish public authorities.

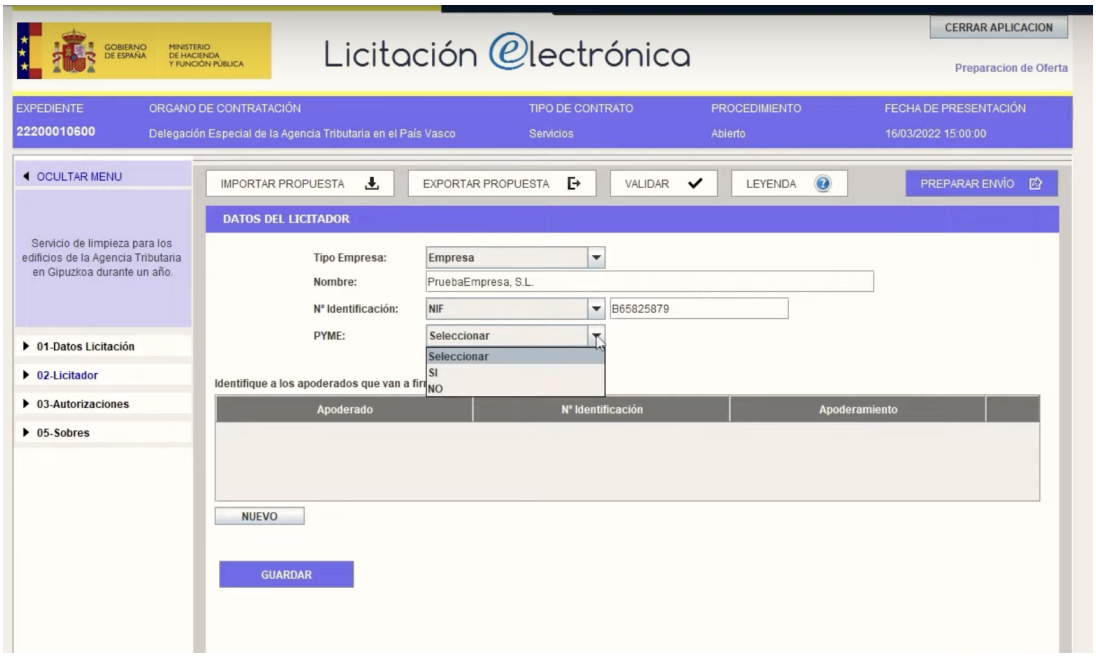


Figure 2.19: Screenshot of creating a notice in the "Plataforma de Contratación del Sector Público" website.

From the video we can tell that the process followed to create contract notices is an incredibly straight forward application made for data input, with no additions related to GPP.

2.5.3. Existing GPP Tools

In this subsection, we will look into tools that have been explicitly developed for Green Public Procurement.

We must be able to distinguish between knowledge-based tools and performance-based tools. Knowledge-based tools focus on the management of information and theoretical knowledge; they are built to help users build a solid foundation of a given topic. On the

other hand, performance-based tools focus on the practical application of knowledge [30].

While the majority of tools available related to GPP are knowledge-based tools, some performance-based tools related to the calculation of life-cycle costs will also be reviewed.

Green Public Procurement Toolkit

The GPP Toolkit, found in the Green Forum [26], an official website of the an official website of the European Union, is a knowledge-based tool. It is provided by the Directorate-General for Environment of the European Commission. It can be accessed at `https://green-forum.ec.europa.eu/green-public-procurement/gpp-training-toolkit_en`. It is a comprehensive set of training resources designed to guide public authorities in implementing GPP practices. It can also be integrated into other general GPP training courses and workshops.

It consists of six independent modules and ten operational modules. The independent modules introduce GPP as a tool for achieving environmental benefits and covers foundational topics. It presents the strategic and legal aspects of GPP, explains how to carry out the assessment of GPP before tendering and provides guidance on using GPP to transition towards a circular economy.

The operational modules go into details about the GPP criteria, environmental impacts, and green alternatives of different product groups, such as furniture, indoor cleaning services, etc.

Figure 2.20: Screenshot of the introduction of the GPP Toolkit, as a powerpoint presentation.

Buying Green! Handbook

This handbook is offered by the Publications Office of the European Union through their official website `https://op.europa.eu/en`.

This knowledge-based tool is designed to help public authorities successfully plan and implement GPP by providing practical approaches of reducing the environmental impact of the procurement. It covers a broad range of topics, while also going into detail when necessary. It goes from providing general knowledge on environmental requirements to details on navigating the European Union law. It also provides several real-life examples of GPP across the EU. It is produced for public authorities, but it can be just as relevant to private purchasers [11].

Figure 2.21: Cover of the Buying Green! handbook, 3rd edition

Other Knowledge-based GPP Criteria Search Tools

Furthermore, there are a some more knowledge-based tools that gather GPP resources, fine-tuned for different countries, to be accessed in a more user-friendly manner. The general approach of these tools is to provide a user interface where the user can choose a sector, an ambition level, and the portals narrow down the GPP criteria according to the search query.

The MVI Criteria Tool, provided by the Government of the Netherlands [47].

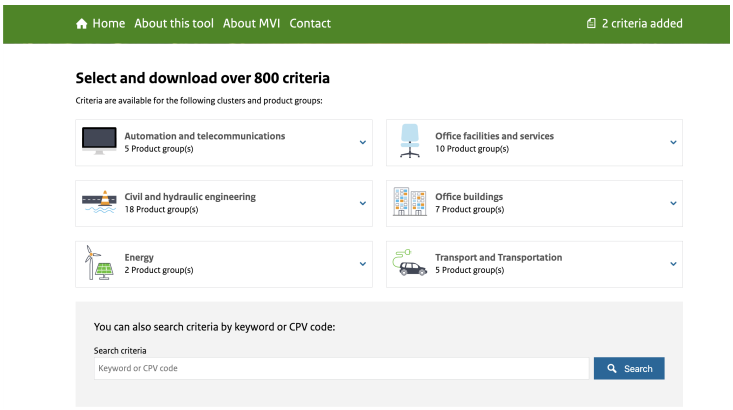


Figure 2.22: Screenshot of the MVI Criteria Tool

The Criteria Guide, provided by the Directorate for Administration and Financial Management (DFØ) of Norway [25].

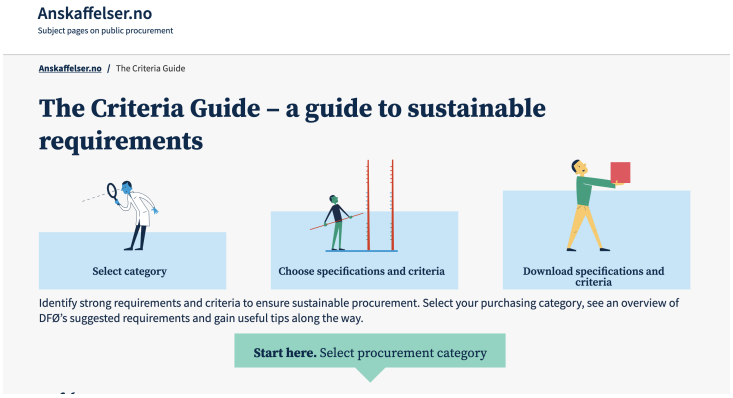


Figure 2.23: Screenshot of the Criteria Guide

The GPP Criteria Search Tool, provided by the Office of Government Procurement of Ireland [46].

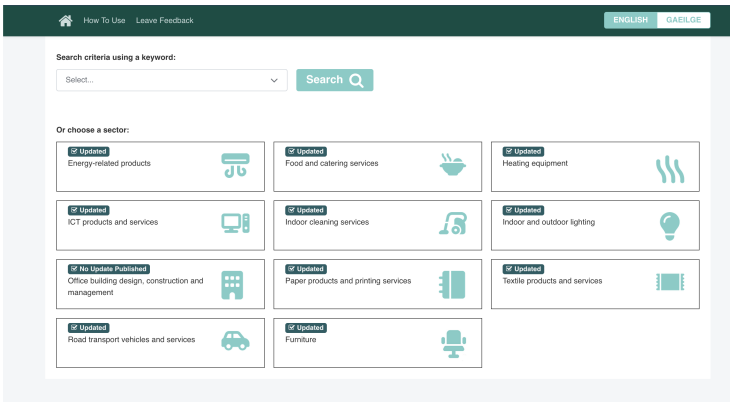


Figure 2.24: Screenshot of the GPP Criteria Search Tool

So far we have introduced knowledge-based GPP tools that focus on understanding the full GPP process and identifying GPP Criteria, yet require the public authority to absorb and apply the knowledge themselves.

Now, we'll look at some of the performance-based tools that are available in the space of GPP. These tools focus on the later parts of the procurement, aiding the decisions of awarding the contracts, in general by providing quantitative assessment and deeper integration of the environmental impact.

Life-cycle Costing (LCC) Calculation Tools

These performance-based tools, developed by the European Commission, are also available in the Green Forum [26].

Firstly, life-cycle costing (LCC) means considering all the costs that will be incurred during the lifetime of the product, work or service.

The European Commission developed this set of sector specific LCC calculation tools that aim to facilitate the consideration of all costs incurred over the entire lifetime (LCC) of a product, service, or work, beyond just the purchase price, among public procurers.

The calculations used consider many cost elements such as the purchase price, purchase associated costs, operating costs, end-of-life costs and environmental externalities. It uses assessment methods such as the "ReCiPe" method to quantify the environmental impacts.

These tools come in the form of an excel files with the appropriate instructions to manually input the necessary data and obtain a numerical and graphical result.

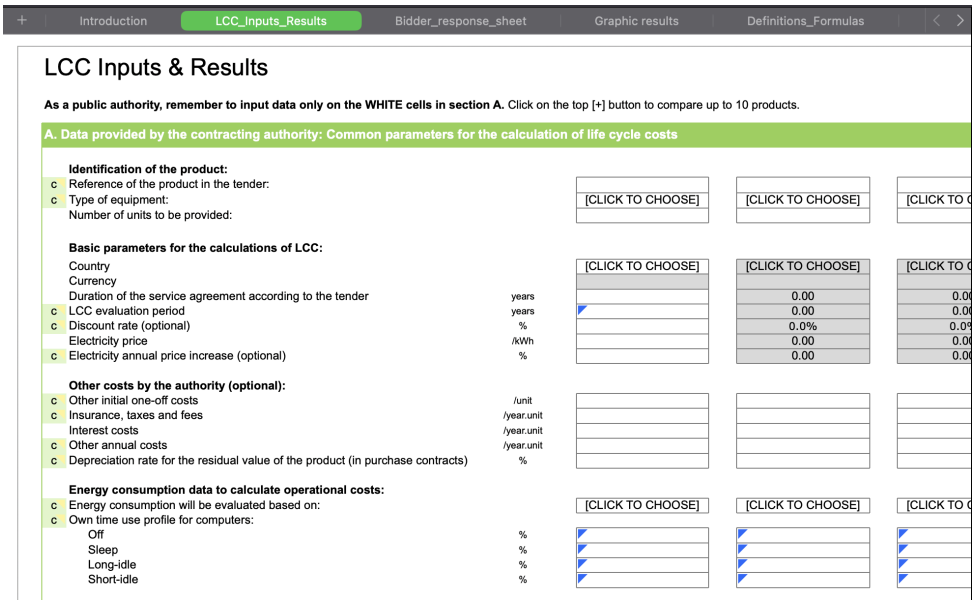


Figure 2.25: Screenshot of the LCC inputs and results from the LCC Computers Tool

SimaPro

SimaPro is one of the leading Life Cycle Assessment (LCA) software designed to help organizations and experts measure and manage the environmental performance of products and services. It allows to perform comprehensive life-cycle assessments. It quantifies the environmental impacts (e.g. carbon footprint, pollution) associated with a product or service across its entire life cycle. It provides fact-based insights into sustainability by tracing environmental impacts back to their sources. The goal of this tool is to enable solid decision-making and create a positive environmental impact [58].

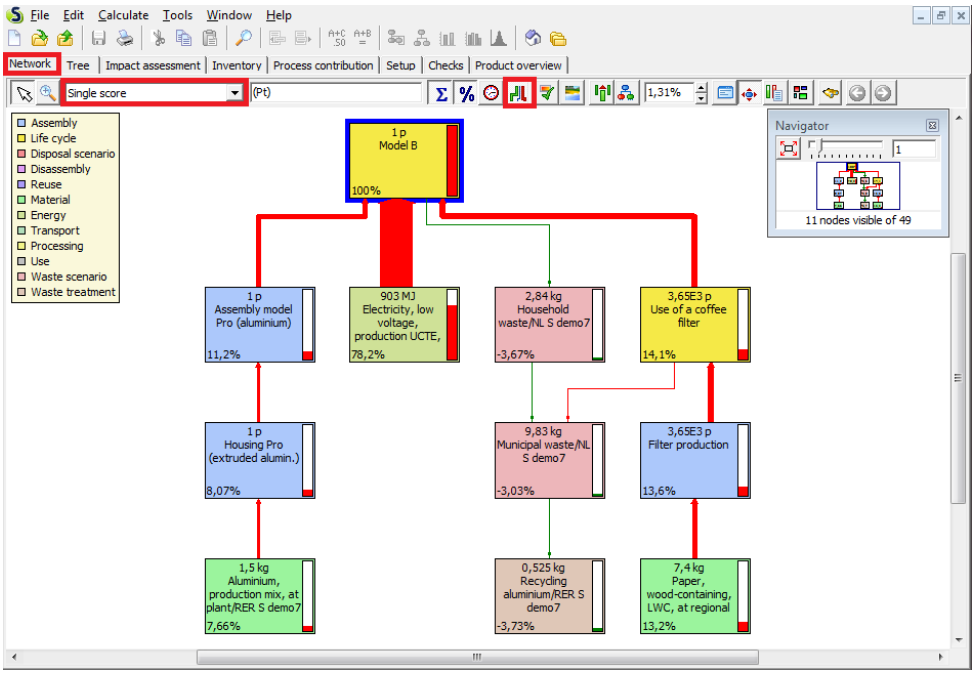


Figure 2.26: Screenshot of the SimaPro LCA software

Finally, we'll dive deeper into one of the most recently developed frameworks for integrating environmental award criteria into public procurement. This tool is accompanied by a paper that explains its approach in further detail [65].

GUF Tool

It is a tool with a novel method designed to fill the existing gap for integrating environmental award criteria into public procurement. It remarks that decision-making in GPP requires clearer assessment methods for them to be usable by public authorities and companies.

Overall, the tool implements a performance-based method, described in [65], which uses a simplified life cycle assessment (LCA) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) multi-criteria decision-making method to generate a single environmental score that can better describe the environmental benefits. The core principle of the proposed method is that "input data must be simplified to ensure their usability, even if this makes environmental assessment less precise".

The tool that is accessible for GPP practitioners since 2018 and it was tested through the LIFE FUTURE project. It follows a nine-step procedure for the assessment of green criteria.

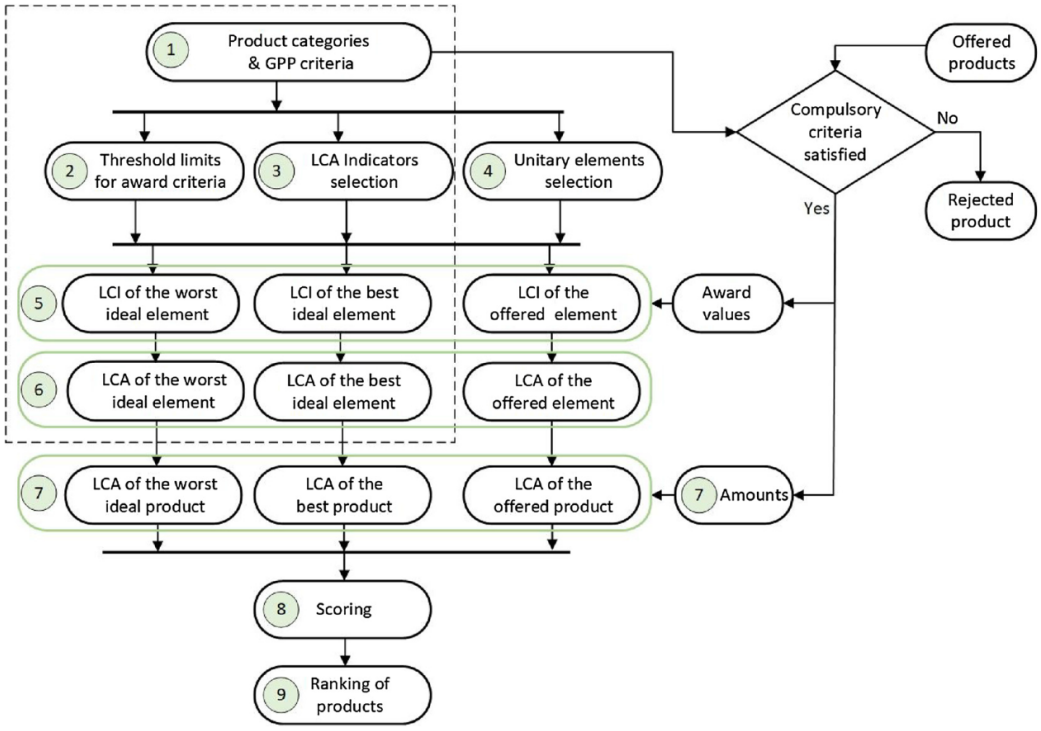
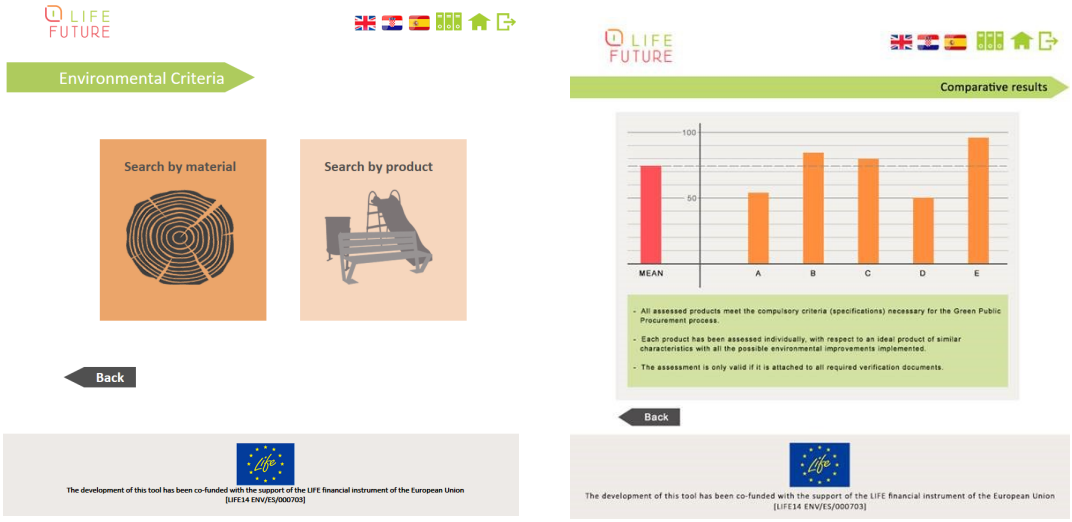


Figure 2.27: Procedure followed by the GUF Tool

The paper discusses the existing decision-making methods and their respective tools, drawing a comparison between simple methods such as Linear Weighted Sum (LWS), with other more complex multi-criteria decision-making (MCDM) methods that emerged as alternatives. It acknowledges that a trade-off must be made between accuracy and usability.

It argues that simple methods such as LWS fail to capture the interdependency of the indicators being aggregated. Among the MCDMs, it compares the Analytical Hierarchy Process (AHP) with the (TOPSIS). The TOPSIS method ranks alternatives by calculating how close each option is to the ideal best solution and how far it is from the ideal worst solution. The AHP method evaluates choices by comparing them against each other in pairs based on individual preferences for a set of criteria. Eventually, the TOPSIS method is identified as the preferred method since it avoids subjective judgments and is viewed to perform better than other methods in calculating a single environmental score.

Some limitations are acknowledged, including the reduced accuracy of the tool's environmental assessment due to the reliance on simplified, predefined material inventories. Furthermore, the method is currently limited in its application, having only been developed for urban furniture that does not require energy for its use. This tool was developed before the appearance of eForms, so they have no influence in its design or implementation.



(a) (b)

Figure 2.28: Screenshots of the GUF Tool

2.5.4. Identified Gaps and Opportunities for Improvement

From our empirical analysis, the lack of usage of environmental indicators in EU public procurement is evident. Only an estimated 13% (see table 2.11) of the contracting authorities used any of the GPP indicators (BT-774: Green Procurement, BT-06: Strategic procurement (with "environmental impact"), and BT-805: Green Public Procurement Criteria).

When it comes to the concrete usage of GPP criteria, this number drops even further, where only 235 out of 8,557 contract notices (see table 2.9) (barely a 3% of the total) indicate the usage of GPP criteria for the evaluation of the proposals, whether the source of these GPP criteria be national, EU or other.

These numbers confirm the common topic of discussion: despite the efforts of the European Commission, the effective implementation of GPP is not ideal.

The potential reasons for this have been discussed previously (see subsection 2.2.4). These could go from a simple lack of knowledge of the existence of these criteria, to the complexity of identification and evaluation, or further economical barriers.

Our analysis of the existing e-Procurement platforms also shows that generally, there is no emphasis made on any of these GPP indicators, and no elements are designed to raise awareness or help with understanding how to integrate GPP into the procurement process.

Furthermore, the analysis of the existing GPP related tools reveals some shortcomings, primarily their lack of direct integration with the existing e-Procurement platforms or environment.

Most seem to be confined as knowledge bases, leaving users to manually extract GPP knowledge and criteria, and integrate it themselves. This extra integration step demands additional effort and a certain level of domain knowledge on how to include these GPP elements into the contract notices.

The panorama looks more optimistic on the evaluation process, where we have a some solid tools to do a life-cycle assessment of the procured goods to evaluate their environmental performance. The main challenges here remain the requirements for expertise in the use of these tools, along with the complexity of quantifying the environmental impact into a score.

The **gap identified** comes from the absence of automation and seamless integration of GPP elements into existing e-procurement platforms that often translates into a high dependency on procurement or environmental expertise, making broad GPP adoption challenging. This creates an opportunity to improve the adoption statistics of GPP by developing a set of tools that can automate, end-to-end, the process of identifying relevant GPP criteria and indicators, integrating these GPP elements into the contract notices to be published and evaluating the proposals according to their environmental impact. Given the heterogeneity of e-Procurement tools, these tools should also be able to integrate into the existing ecosystem for them to have a chance of spreading across the different platforms used across Europe. Given the recently-made mandatory nature of eForms for most notice publications in Europe, they can be leveraged as the central point of an integration with the existing e-Procurement environment.

3 | System Design and Implementation

3.1. Introduction

The software solutions presented in this thesis have been designed as an attempt to address the lack of GPP use in European public procurement by filling the gap identified through the analysis of the state of the art (see 2.5.4). As a brief reminder, this involves the identification and integration of GPP elements directly into e-Procurement systems, rather than as external knowledge-based tools.

The goal of these tools is to promote the use of GPP by facilitating the identification and integration of GPP elements into eForms, in hopes of addressing the challenges that widespread GPP adoption is facing. In particular, this will involve both indicators of an environmentally-aware procurement process, as well as concrete GPP criteria. The design will focus on the e-Noticing process of the pre-awarding phase (see 2.1.2). Although the ideal scenario would be to create a full end-to-end solution, the e-Tendering and e-Awarding steps, where the tender proposals are evaluated against the selected GPP criteria, will not be covered by this project. Due to the limited resources and time constraints of having a single developer, the focus is put on the earlier steps of the pipeline, which are identified as the bottleneck, hoping to raise awareness of the existing GPP indicators and criteria, and facilitating the communication of their usage to the tenderers.

There is significant heterogeneity of e-Procurement tools used across Europe, and even across localities in the same country. There are however some commonalities and standards that can be leveraged to make an integration of this tool possible with existing platforms. Concretely, these are software development tools provided by TED, along with the eForms standard, which as a reminder, is mandatory for all European procurement notices that exceed certain thresholds (see 2.2). The design and implementation decisions made for each of the components of the software tools presented were made with the objective of integrating into this existing environment.

To accomplish the objectives set, these are the components that make up our solution:

- **Domain Knowledge Integrator**: Integrates the GPP domain knowledge into a data format that can be consumed by the rest of the tools.
- **GPP Library**: A Java library that provides an interface to identify GPP criteria from an eForm notice and apply the necessary changes onto it.
- **GPP Service**: A service that provides a REST API to access the functionalities of the GPP Library.
- **GPP UI**: A user interface that gives access to the functionalities provided in a user friendly way.

The diagram below should help get a conceptual understanding on how the components of the solution interact with each other and with the development environment of TED.

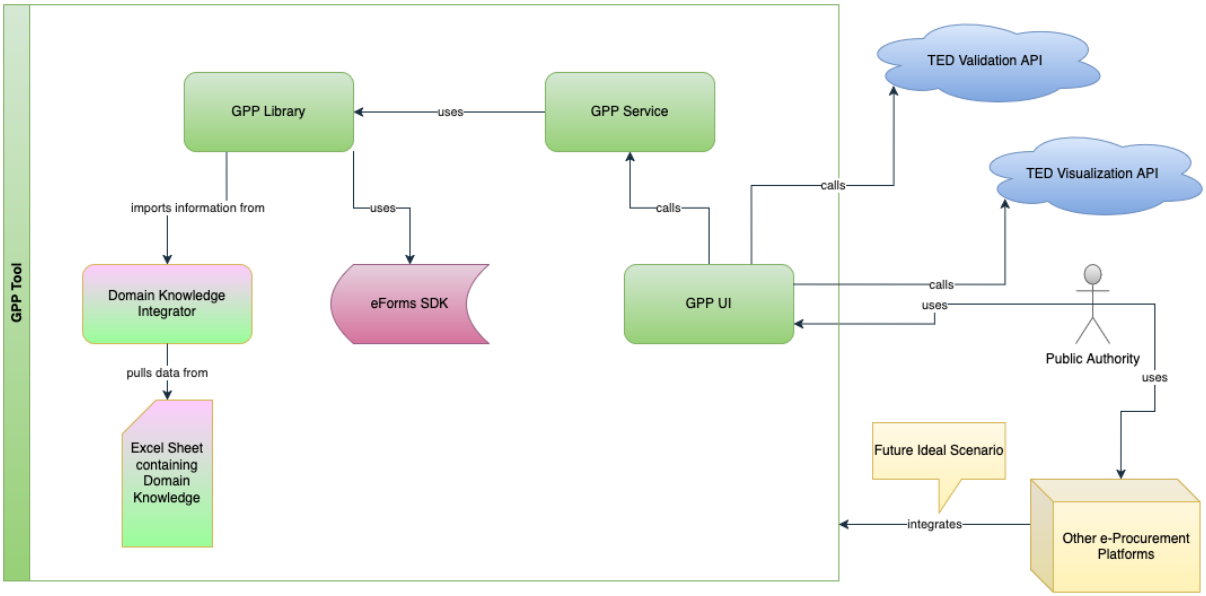


Figure 3.1: GPP Tool System Architecture Diagram.

In the following subsections, we'll go further into the details of the design, implementation, and limitations of each of the components that make up the solution presented.

3.2. Development Methodology and Practices

3.2.1. Overall Development Approach

First, let us understand a key concept: Agile. Agile is fundamentally the ability to create and respond to change. It can be thought of as a mindset for successfully navigating uncertain environments by being highly adaptive and responsive to variation. Agile software development encompasses a set of frameworks and practices based on the values and principles expressed in the Manifesto for Agile Software Development [2].

Agile is widely recognized as the standard for software development, and while it's generally directed towards multi-member teams, its principles were highly applicable to this single-developer project, mainly due to the uncertainties present in an unknown domain and development environment.

The development process that led to the application presented in these thesis followed plenty of the principles that govern Agile software development, these include:

- **Adaptiveness and response to change**: This allowed us to quickly respond to changes according to feedback and new discoveries.
- **Iterative process**: Breaking down the work into smaller cycles.
- **Traceability**: Through the use of GitHub Issues and Pull Requests (later we dive into the specifications).
- **Structured progress tracking**: By gathering the tasks for all tools into a single project encompassing the full solution.
- **Focus on "Doing It"**: Following this principle implies that the best way to uncover the best path forward is by simply developing software.

Concretely, the initial phases of development were done using Python within Jupyter Notebooks to enable rapid prototyping. This speed of iteration allowed us to receive almost immediate feedback on the direction the project was going from a stakeholder with more GPP domain knowledge. Once the ideas were consolidated, the transition of most tools was made into Java with the objectives of both integrating more seamlessly into the existing European e-Procurement environment and achieving a higher level of robustness, scalability, and maintainability.

Furthermore, the use of many of the features of GitHub were pivotal for the agile development life-cycle, enabling a systematic and traceable approach.

3.2.2. GitHub as a Central Tool

Throughout the entire development life-cycle of this project, GitHub served as a central platform, covering version control, project management, and enabling the open-source nature of the project. Even as a single developer, the comprehensive feature set provided allowed for a better organization and ensured the traceability of changes.

GitHub was used as the centralized code repository for the main components of the solution. The robust version control that GitHub provides will be crucial for the future maintainability of the repositories. The inherent design of this platform, along with our licensing model (further discussed), enables open-source development, great for encouraging transparency, potential future contributions and achieve wider applicability within the public procurement community.

Beyond its basic role as a code hosting platform, it also served as a project management tool.

GitHub Issues were used to breakdown the requirements into manageable work items. Each issue served as a record for a specific feature, improvement or bug fix, allowing for clear objectives.

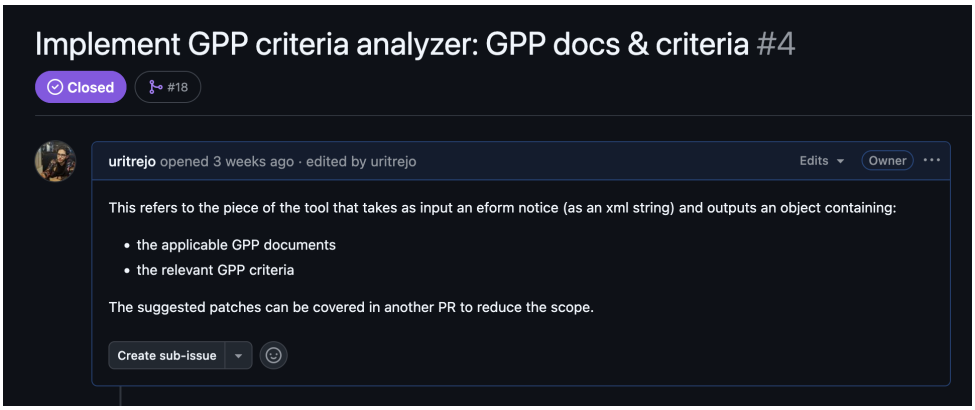


Figure 3.2: GitHub issue created for the GPP Library

GitHub Projects were used to visualize and prioritize the issues created for all of the components, all in one view. This allowed for effective prioritization. In particular, the GitHub project used to track the development of this project can be found at [61].

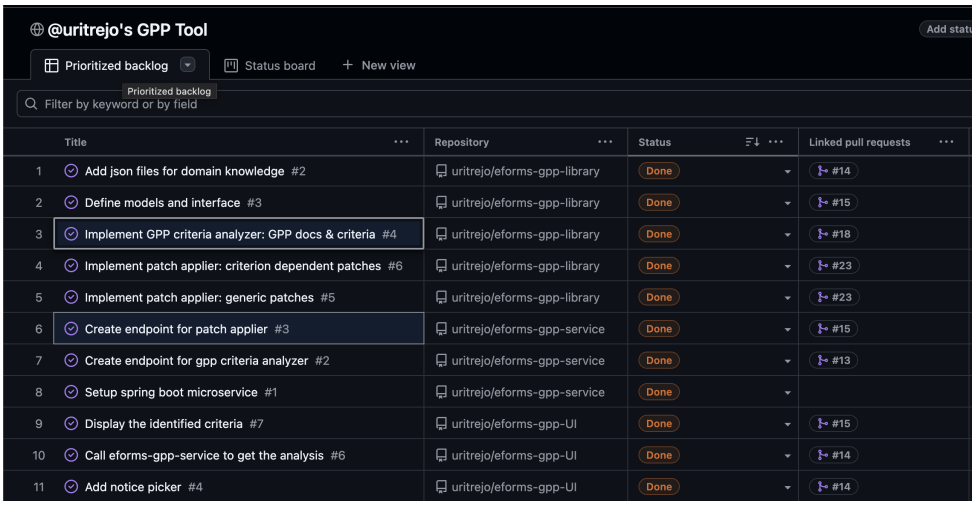
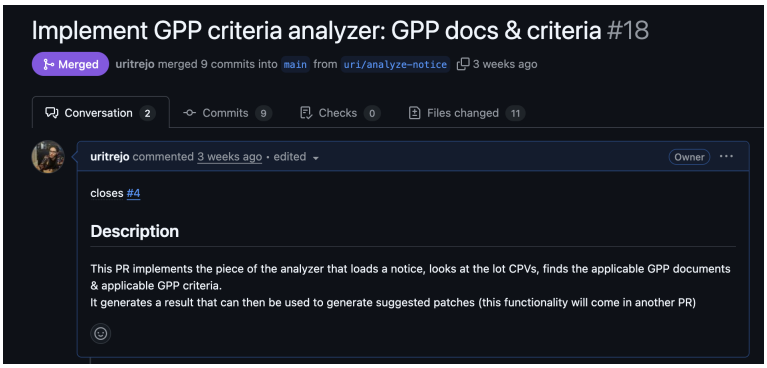
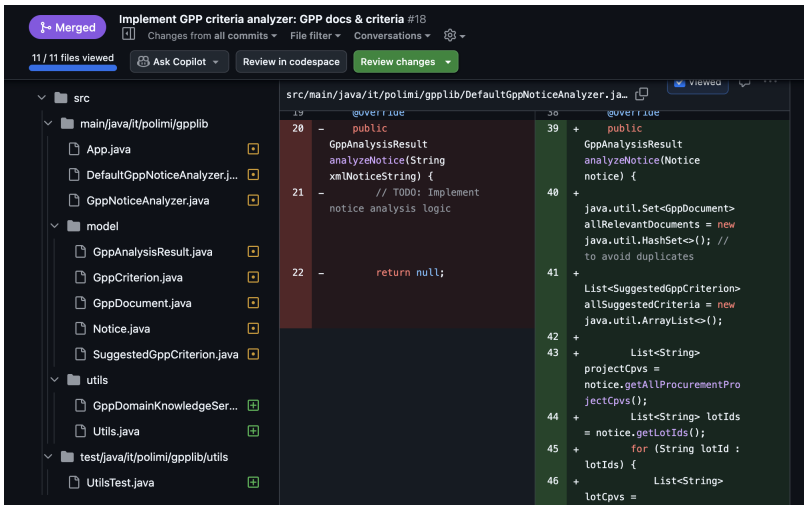


Figure 3.3: View of the GPP Tool GitHub project

GitHub Pull Requests (PRs) were used to introduce new changes to the repositories, always through specific development branches. Each PR encapsulated the changes required to complete the objectives described in the issues, most generally, one PR per issue. This practice enabled a self-review process, which improved the quality assurance. It also improves traceability and simplifies the integration and testing.



(a)



(b)

Figure 3.4: Screenshots of a Pull Request on the GPP library

GitHub Copilot, an AI-powered coding assistant [31] was used to during the development with Visual Studio Code, an Integrated Development Environment (IDE). Its use was key in augmenting productivity through its features such as code completion, real-time suggestions and PR reviews.

3.2.3. Licensing

Given the overall goal of having an open-source project, accessible for anyone to use and contribute, the choice of licensing was based on putting as few restrictions as possible. To accomplish this, the license selected was the MIT License.

The MIT License is one of the most popular and permissive open-source licenses available. Some of the key characteristics of this license are [50]:

- **Permissiveness**: It has a very permissive nature, allowing to use, copy, modify,

merge, publish, distribute, sub-license, and sell the code in the repository.

- **Minimal Requirements for Reuse**: For it to be used, it only requires the original copyright notice and the full text of the MIT License.
- **No Warranty or Liability**: It explicitly states that there is no warranty of any kind, and the author cannot be held liable for any damages incurred from its use.

3.3. Domain Knowledge and Integration

This is a crucial section of this multi-disciplinary thesis. For the effective implementation of a GPP solution, both the technical skills and the domain knowledge are required. The mechanism described in this section is the component that allows to integrate the GPP domain knowledge expertise into the technical system.

3.3.1. Domain Knowledge Required

In addition to the eForms SDK, to extract the fields from the given eForm notices, identify the relevant GPP criteria and apply changes onto the eForm, we need to have certain data manually input by someone with a minimum level of expertise in GPP.

Such domain knowledge required includes the GPP criteria documents, the GPP criteria, and a mapping of eForm fields.

This knowledge is primarily captured and managed through an Excel file. This format was chosen to allow for a flexible collaboration of anyone with no technical knowledge, thus removing the entrance barriers.

Subsequently, this Excel data is converted into a format that is more machine-friendly, as specified in the following subsection.

Below, we go into the details of each of them.

GPP Criteria Documents

This contains the basic information of the documents from which the GPP criteria are extracted. For each document, it contains:

- **Document Name**: Name of the document from which GPP criteria have been extracted. For example: "EU GPP Criteria for Furniture"
- **Source**: The source for the GPP Document. For example: `https://green-forum.`

ec.europa.eu/green-public-procurement/gpp-criteria-and-requirements_en

- **Document Reference**: URL at which the document can be accessed directly. For example: https://circabc.europa.eu/ui/group/44278090-3fae-4515-bcc2-44fd57c1d0d1/library/0788fd30-083f-4f9e-ba9e-86e9e432e822?p=1&n=10&sort=modified_DESC
- **Publication Date**: The date in which the document was published in the format YYYY-MM-DD. This is key to communicate to the user the version of the criteria defined. For example: 2018-07-27

GPP Criteria

This contains each of the GPP criteria defined in the GPP Criteria Documents as a row. For each GPP criterion, it includes:

- **GPP Document**: This refers to the name of the GPP document from which the criteria originate. For example: "EU GPP Criteria for Furniture"
- **GPP Source**: The source from which the GPP criteria originate. This maps to the BT-805: Green Public Procurement Criteria field in the contract notice. This is described in the eForm fields table (see 2.1. The four possible values (self-explanatory) are: eu, national, other, none.
- **Subcategory**: Optional field. This represents the subcategory of the criterion, as specified sometimes in the GPP criteria document. For example: "Procurement of new furniture"
- **Type**: The type of GPP criterion as specified in the GPP criteria document. Its value may be any of: Award criteria, Selection criteria, Contract performance clauses, and Technical specification.
- **Ambition Level**: The ambition level of the criterion as specified in the GPP criteria document. May be any of: core, comprehensive, and both. The value "both" means that this criterion will be considered for both the core and comprehensive levels.
- **ID**: The ID of the criterion as specified in the GPP criteria document. For example: TS2.
- **Name**: The name of the criterion as specified in the GPP criteria document. For example: Extended warranty periods.
- **Applicable CPV Codes**: Refers to the list of CPV codes that might be relevant to the given GPP criterion. This must be manually defined by someone with sufficient

domain knowledge on a case to case basis. For example: [39100000, 45233293, 45421153]

- **Environmental Impact Type**: Refers to the type of environmental impact to be reduced through the use of the GPP criterion. It maps to the BT-774: Green Procurement field in the contract notice. The allowed values are defined and described in **??**. In summary, they are: biodiv-eco, cir-econ, clim-adapt, clim-mitig, pollu-prev, water-mar, other. It must be manually defined by someone with sufficient domain knowledge on a case to case basis.
- **Description**: The description for the GPP criterion. It may be a reduced version of the description found in the GPP document since the document is also referenced. For example: "A maximum of X additional points shall be awarded for each additional year of warranty and service agreement offered that is more than the minimum technical specification."
- **Selection Criterion Type**: This only applies to the Selection Criteria. It refers to the selection criterion type code, which in the context of sustainabilty, may be one of two options: `slc-abil-mgmt-env`, referring to "Environmental management measures" or `slc-sche-env-cert-indep`, referring to "Certificates by independent bodies about environmental management systems or standards". If not specified for a selection criterion, it will default to `slc-abil-mgmt-env`.

Mapping of eForm Fields

This contains key information on how to map the GPP criteria and GPP indicators into an eForm notice, in particular into a given lot of a notice. In contrast to the other pieces of domain knowledge, this doesn't require direct GPP knowledge but rather a good understanding of the underlying structure of eForms. The data as present should stay valid for any further minor version of the SDK, as they are non-breaking with respect to previous versions. A new major version would require a re-mapping of these fields, yet a breaking change is usually slow to happen, with a generous transition period, since every EU e-Procurement software would need to adapt.

For each row, it includes:

- **Name**: The name of the eForm element, typically as defined in the fields from the eForms SDK. For example: "Green Public Procurement Criteria"
- **BT IDs**: Optional field, used as a reference during input. Identifies the Business Terms that are covered by the given eForm element. For example: [BT-06-Lot,

BT-777-Lot]

- **Depends On**: Identifies the parent structure that must be present in order to insert this eForm element. The name of the parent element shall be used as defined in the same document. It may be empty if the parent is a mandatory element that will always be present. For example (for "Awarding Criterion"): "Awarding Criteria"
- **Path Relative to Lot**: This refers to the XPath path where the element should be inserted, relative to a given Lot in the notice. This is extracted from the eForms SDK. For example: `"cac:TenderingTerms/cac:AwardingTerms/cac:AwardingCriterion"`
- **Value**: This is the XML value that should be inserted at the specified position. There may be arguments embedded within the value, which shall be populated from the GPP criteria arguments defined in the previous list. For instance, for CPCs, the "Description" argument defined in the criteria table would be used by the GPP Library to populate the "Description" argument of the CPC element in the eForm Mappings table. A concrete example of a simple XML value: `"<cac:ProcurementProject xmlns:cac="cac"></cac:ProcurementProject>"`

3.3.2. Mechanism of Integration

The domain knowledge discussed in the previous subsection is contained within an Excel file to facilitate data input without technical barriers. Excel data however, is not a format that can be easily consumed by our Java GPP library. To bridge this gap, we use a Python script. This was the preferred tool for this component due to its simplicity and the existence of appropriate libraries.

This script uses the libraries OpenPyXL and JSON. OpenPyXL is a library used to read and write Excel files [32]. JSON is a built-in package used to encode and decode JSON files [27].

The functionality of the script is very simple: It uses the OpenPyXL package to load the excel file containing the domain knowledge data, it does some basic validation, and converts it into a JSON format, finally writing this JSON data into a file. The file created is placed in the resources directory of the GPP Library so that it can be directly consumed. This script, along with instructions for its use, are stored inside of the GPP library, since it is deemed a direct dependency.

3.3.3. Limitations

Despite its effectiveness in representing and structuring GPP domain knowledge, the current domain knowledge integration approach has a couple of key limitations:

- **Manual Maintenance**: The process of extracting the information on the GPP documents, GPP criteria and eForms mapping is a manual process.
- **Language Dependence**: In any given eForm notice, the language dependent fields contain a language tag (e.g. `ENG`). These fields must be completed in all of the official languages specified in the contract notice.
- **GPP Expertise Dependence**: In order to be able to interpret the nuances of GPP criteria defined in official documents, and correctly inserting them into our documents demands specialized GPP domain knowledge.
- **Sensitivity to Changes**: The data contained in the domain knowledge documents is all sensitive to changes in their source documents. Although the frequency of revision is relatively low, the GPP documents are generally updated every few years. Furthermore, the eForms mapping information is tightly coupled with the current version of the eForms SDK. Any change to the major version would require significant re-alignment.

3.4. GPP Library Design and Implementation

The GPP library [62] is the central piece of the eForms GPP Tool presented in this thesis. The rest of the components presented all revolve around it. It integrates the domain knowledge and encapsulates the main logic necessary for processing eForms, identifying relevant GPP criteria, and applying the necessary modifications onto the notice.

This component was designed as a standalone Java (21) library, built using Maven, a build tool for Java projects that manages the project's compilation, testing, and documentation [28]. Similar to the eForms Core Java Library (see 2.4.4), the GPP Library is published on the Maven Central Repository, which makes allows for the easy inclusion of the library as a dependency to any Java project. This aims to maximize its potential for adoption across other platforms.

3.4.1. Architectural Design

This section describes the internal design of the GPP Library. It will provide an overview of the key components and their interactions that work together to provide the functionalities provided. The design leverages the object-oriented programming paradigm that is intrinsic to Java, which helps increase robustness and facilitate maintainability and future enhancements.

To provide a clear contract of the functionality provided by the GPP Library, it is encapsulated into an interface: `GppNoticeAnalyzer`.

```
public interface GppNoticeAnalyzer {
    Notice loadNotice(String xmlString);

    GppAnalysisResult analyzeNotice(Notice notice);

    List<SuggestedGppPatch> suggestPatches(Notice notice, List<SuggestedGppCriterion>
    ↪  suggestedCriteria);

    Notice applyPatches(Notice notice, List<SuggestedGppPatch> patches);
}
```

Figure 3.5: GppNoticeAnalyzer interface definition

Furthermore, there is a set of key components that work together to provide the required functionalities, as seen in the diagram below.

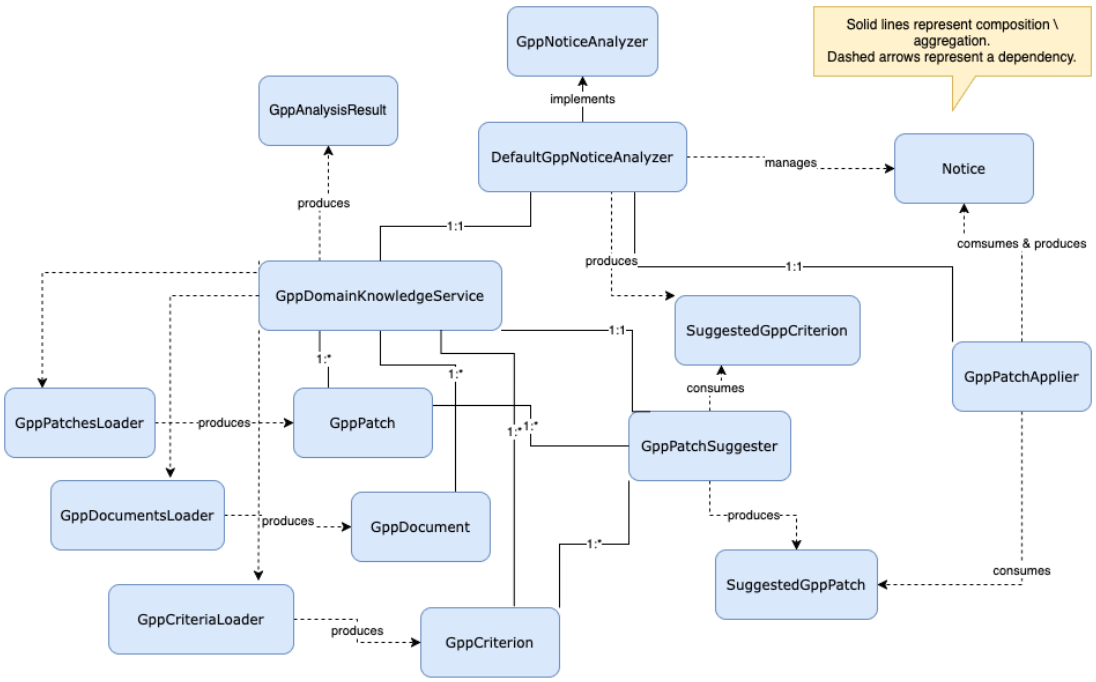


Figure 3.6: Simplified class diagram of the GPP Library

The key components, most of which are shown in figure 3.6, are:

- **XmlUtils**: Omitted from the diagram due to widespread use. A utility class that provides helper functions to for working with XPath and eForms in XML format. Incorporates several classes from the `javax.xml` and the `org.w3c.dom` libraries to accomplish its goals.
- **Utils**: Omitted from the diagram due to widespread use. A utility class that provides helper functions related to the core subject matter of the library, such as working with CPV codes.
- **Constants**: Omitted from the diagram due to widespread use. A utility class (final) that centralizes the access to all of the constant values used throughout the GPP Library.
- **Notice**: Represents an eForm notice. It provides easy access to the relevant content of the notices. At its core, it uses a `org.w3c.dom.Document` to store the eForm as an XML document.
- **GppDocument**: Represents a GPP Document from the integrated domain knowledge, as defined in the previous subsection 3.3.1.
- **GppCriterion**: Represents a GPP Criterion from the integrated domain knowl-

edge, as defined in the previous subsection 2.2.2

- **GppPatch**: Represents an entry of the eForms mappings from the integrated domain knowledge, as defined in the previous subsection 3.3.1.
- **GppDocumentsLoader**: This class reads the JSON document containing the domain knowledge on GPP Documents and creates a list of `GppDocument`. It uses the `Jackson` library to work with JSON.
- **GppCriteriaLoader**: This class reads the JSON document containing the domain knowledge on GPP Criteria and creates a list of `GppCriterion`.
- **GppPatchesLoader**: This class reads the JSON document containing the domain knowledge on eForms mappings and creates a list of `GppPatch`.
- **SuggestedGppCriterion**: Based on the internal representation `GppCriterion`. Some attributes are added and some are removed to create the version of the suggested GPP criterion that is presented to the user.
- **SuggestedGppPatch**: Based on the internal representation `GppPatch`. This represents the eForm patches that are suggested to the user. The variable arguments mentioned in the domain knowledge subsection 3.3.1 are defined in this object using the domain knowledge.
- **GppDomainKnowledgeService**: Provides a central hub to access the domain knowledge to the other components. It incorporates the services and models previously defined to load, store, and serve the domain knowledge.
- **GppPatchSuggester**: Provides the methods to suggest a list of `SuggestedGppPath` from a given `Notice` and the list of `SuggestedGppCriterion`.
- **GppPatchApplier**: Provides the functionality to apply any given list of `SuggestedGppPatch` into a `Notice`.
- **GppAnalysisResult**: This represents the result of the GPP analysis of a notice. Essentially, it contains a list of `GppDocument` and a list of `SuggestedGppCriterion` objects that have been deemed relevant to the particular notice analyzed.
- **GppNoticeAnalyzer**: This is the interface that encapsulates the functionality provided by the GPP Library, as defined in the figure 3.5.
- **DefaultGppNoticeAnalyzer**: This is the default implementation of the `GppNoticeAnalyzer` interface. It incorporates the services and models previously defined to implement the methods.

- **GppException**: Not shown in the diagram for simplicity. This is used to wrap any exceptions in the analyzer and give the appropriate context to determine whether it was due to an invalid output or an unexpected error.

3.4.2. Criteria Suggestion Logic

This refers to this function of the interface provided:

```
GppAnalysisResult analyzeNotice(Notice notice);
```

The key component supporting this logic is the `GppDomainKnowledgeService`. The goal of this step is to identify the GPP criteria that may be relevant to a notice. It uses the list of `GppDocument` and `GppCriterion` objects, along with the utility functions in `Utils` to propose a set of relevant `GppDocument` and `SuggestedGppCriterion` for the given `Notice`.

In summary, the process is as follows:

1. **Load Domain Knowledge**: Containing the list of GPP Documents and GPP Criteria defined by the domain expert.
2. **Load Notice**: Load the notice to be analyzed and extract the main and additional classification codes (CPV codes) for each of the lots.
3. **Check Applicability of GPP Criteria**: The applicability function is relatively simple. For the current implementation, the applicability relies only on the CPV codes. The CPV codes deemed applicable for each GPP criterion are compared to the CPV codes contained in the main and additional classification codes of each lot of the notice. As a reminder, the CPV codes are hierarchical, therefore, if at least one CPV code referenced in the notice matches or is a child of any of the CPV codes deemed applicable to the GPP criterion, the GPP criterion will be added to the list of suggested criteria for that specific lot. As the tool's functionality grows, further elements could be considered to the applicability of a GPP criterion, such as country or procurement type.
4. **Check Applicability of GPP Documents**: The applicability of GPP Documents relies directly on the applicability of GPP Criteria. If at least one GPP criterion from a GPP document is deemed relevant to any lot, then the GPP document is considered as applicable to the notice.

The final result of this process is a `GppAnalysisResult`.

```
public class GppAnalysisResult {
    private List<GppDocument> relevantGppDocuments;
    private List<SuggestedGppCriterion> suggestedGppCriteria;
    ...
}
...
public class GppDocument {
    private String name;
    private String source;
    private String documentReference;
    private LocalDateTime publicationDate;
    private List<String> relevantCpvCodes;
    private String summary;
    ...
}
...
public class SuggestedGppCriterion {
    private String gppDocument;
    private String category;
    private String criterionType;
    private String ambitionLevel;
    private String id;
    private String name;
    private List<String> relevantCpvCodes;
    private List<String> matchingCpvCodes;
    private String lotId;
    ...
}
```

Figure 3.7: GppAnalysisResult Overview

3.4.3. eForm Patching Mechanism

This refers to these functions of the interface provided:

```
List<SuggestedGppPatch> suggestPatches(Notice notice, List<SuggestedGppCriterion> suggestedCriteria);
Notice applyPatches(Notice notice, List<SuggestedGppPatch> patches);
```

The eForm patching mechanism encompasses both the patch suggestion and the patch application processes.

Patch Suggestion

This mechanism follows the criteria suggestion. From the list of criteria suggested resulting from the analysis of a notice, the caller may select a subset of the suggested GPP criteria that they wish to apply onto the notice. The patch suggestion mechanism takes as input the corresponding list of `SuggestedGppCriterion`. The goal of this step is to suggest a list of eForm patches, representing modifications to be made to reflect the use of the provided GPP criteria and its environmental impact focus. The key component supporting this logic is the `GppDomainKnowledgeService`.

In essence, the GPP criteria provided are mapped to the domain knowledge GPP Criteria and eForms Mapping. To provide the patch, we first take the eForm mapping corresponding to the criteria type (e.g. Award Criteria). The value of the eForm Mapping will contain placeholders that require a set of arguments that are contained in the GPP Criteria domain knowledge. Using string replace operations, the placeholders in the eForm Mapping (for example criterion ID, name and description) are replaced with the the concrete values for the GPP criterion that we're trying to add.

The result of this process is a patch object with an operation (e.g. create), a path (e.g. `cac:TenderingTerms/cac:AwardingTerms` and a value for each of the GPP criteria. If needed, the parent structures are also inserted as patches to enable the insertion of the criteria (in a recursive process).

```
<cac:SubordinateAwardingCriterion>
   <!-- Award Criterion Type (BT-539-Lot) -->
   <cbc:AwardingCriterionTypeCode
   ↪  listName="award-criterion-type">quality</cbc:AwardingCriterionTypeCode>

   <!-- Award Criterion Name (BT-734-Lot) -->
   <cbc:Name languageID="EN">TS1: Sourcing of legal timber for furniture
   ↪  production</cbc:Name>

   <!-- Award Criterion Description (BT-540-Lot) -->
   <cbc:Description languageID="EN">...</cbc:Description>
   ...
<cac:SubordinateAwardingCriterion>
```

Figure 3.8: Snippet of a patch value for an Award Criterion

Additionally, it also suggests patches for the GPP indicators, according to the GPP criteria provided.

- **BT-774: Green Procurement**: This indicates the type of environmental impact

that the procurement intends to reduce. Each GPP criterion defined in the domain knowledge has one Environmental Impact Type. A Green Procurement patch is suggested for each unique Environmental Impact Type in the GPP criteria selected.

- **BT-06: Strategic procurement**: This has a single value related to GPP: "environmental impact". If there is at least one GPP criterion considered, this patch will be suggested.
- **BT-805: Green Public Procurement Criteria**: This refers to the source of the GPP criteria (eu, national, other). Each GPP criterion defined in the domain knowledge has one GPP Criteria Source. A GPP Criteria patch is suggested for each unique GPP Criteria Source in the GPP Criteria selected.

The final result of this process is a list of `SuggestedGppPatch`.

```
public class SuggestedGppPatch {
    private String name;
    private List<String> btIds;
    private String dependsOn;
    private String path;
    private String value;
    private String op;
    private String description;
    private String lotId;
    ...
}
```

Figure 3.9: SuggestedGppPatch Overview

Patch Application

This mechanism follows the patch suggestion. From the previous step, the caller receives a list of `SuggestedGppPatch` objects that are each meant to insert either a GPP criterion directly, or a GPP usage indicator. The caller may select a subset of such patches that they wish to apply onto the notice.

The goal of this step is to directly apply the patches provided into the notice. The output of this process is the final notice object.

The patch application process works by processing each individual patch (as seen in figure 3.9) in the order provided. For each, we access the internal nodes of the notice document until we are in the path specified. The patch value is then parsed into the proper format. For "create" operations, the parsed value is inserted directly in the current node. For

"update" operations, the value at the given path is removed, followed by the insertion of the new parsed value.

The final result of this process is a `Notice` object whose internal representation contains the GPP fields added from the patches provided.

3.4.4. Quality Assurance

Being the instrumental piece of the GPP Tool, the GPP Library followed a robust quality assurance (QA) process. This is to ensure the reliability, validate the core logic and ensure the correctness of the eForms XML processing.

This QA process included:

- **Unit Testing**: All the classes followed a comprehensive unit testing plan implemented using `JUnit`. This is essential to ensure that the components are behaving as expected, and to ensure that edge-cases are handled correctly.
- **Integration Testing**: The end-to-end flow of the interface functionalities was also tested using `JUnit`. This involved loading a notice, analyzing it, suggesting patches and applying such patches.
- **Manual Testing**: Mostly used during the development process, manual testing and careful review of the results were used to constantly validate the functionalities of the library.

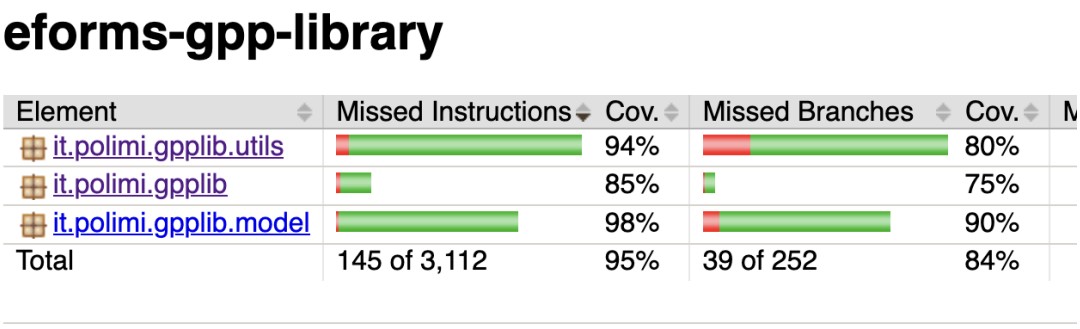


Figure 3.10: Coverage report for the GPP Lib

3.4.5. Limitations

Due to the dependence of the GPP Library on the domain knowledge (see subsection 3.3.3), this component also depends on manual maintenance to stay up to date.

Furthermore, this component was developed in Java to allow for the best integration into the European e-Procurement developer environment. Nevertheless, this library will only be compatible with other Java projects, thus being incompatible with other tools written using different programming languages.

Finally, and most importantly, despite the extensive testing of the library, there is a tremendous number of distinct variables in the contract notices that can be published. Therefore, it requires even further real-life testing to assess its reliability.

3.5. GPP Service Design and Implementation

The GPP Service [63] acts as an intermediary layer within the system architecture. It serves to expose the core functionalities of the GPP Library to external applications. By exposing the functionalities for GPP criteria identification and eForm patching capabilities through a REST API, the service gives maximal flexibility to be integrated into client applications, regardless of their development environment. For instance, the GPP UI later presented, implemented using JavaScript and React, accesses the GPP functionalities through this REST API, without needing to consider the internal Java architecture.

This service is functionally complete, yet it may lack some features needed to be a production ready service, as stated in the subsection 3.5.4. Nevertheless, this service could serve as a template on how to integrate the capabilities of the GPP Library via a REST API, and with minimal modifications, could be directly integrated into existing e-Procurement applications with a service oriented architecture.

3.5.1. API Design

This subsection outlines the architectural design of the REST API used to expose the functionalities of the GPP Library. The key principles driving this design are usability, ease of integration and clarity. Furthermore, it follows the principles of REST, an acronym for Representational State Transfer, a preferred style for distributed systems and widely used for building web-based APIs [36]. Within the principles of REST, the most relevant to this project are: the client-server design, which enforces a separation of concerns, allowing the client and server to be developed independently; the stateless nature of the API, meaning that each request made to the server must contain all the information needed to process the request, without relying on stored context in the server.

The core GPP functionalities of the GPP Library are exposed through a set of intuitive endpoints designed around the key resources manipulated: eForm notices, GPP criteria

and GPP patches. All of the endpoints are prefixed with `/api/v1`, and they all consume and produce `JSON` content.

Below, the expected requests and responses will be detailed for each endpoint. However, the error handling for the endpoints is constant between all of them. The response status may contain any of:

- **400: Bad Request**: This error status will be returned in case of any invalid input. This may related to a malformation in any of the possible inputs, such as the overall JSON request body, the eForm XML string, the GPP criteria or the patches.
- **404: Not Found**: This error status will be returned if the caller attempts to access an unknown endpoint or path.
- **500: Internal Server Error**: This error status may be returned in case of any unexpected server error. Ideally, it should not happen.

The error response body will contain:

- **Status**: The HTTP status code received (as presented in the previous list).
- **Code**: A custom error code for internal use.
- **Detail**: A brief description of the error incurred.

Analyze Notice Endpoint

The analyze endpoint is used to identify the GPP criteria and GPP documents that are relevant to the eForm contract notice provided. The endpoint is defined as `POST /api/v1/analyze-notice`.

The request body expected only contains one element: `noticeXml`, which corresponds to the eForm contract notice as an XML string.

```
{
    "noticeXml": "<ContractNotice>...</ContractNotice>"
}
```

Figure 3.11: Request body for `POST /api/v1/analyze-notice`

In case of success, the response status will be `200 (OK)` and the body will contain the result of the analysis, representing its GPP Library counterpart, as shown in figure 3.7.

- **relevantGppDocuments**: A list of the GPP documents relevant to the notice provided.
- **suggestedGppCriteria**: A list of the GPP criteria suggested to be used for the procurement.


```
{
    "relevantGppDocuments": [
        {
            "name": "EU GPP Criteria for Furniture",
            "source": "https://green-forum.ec.europa.eu/green-public-procurement/...",
            "publicationDate": "2018-07-27T00:00:00",
            "relevantCpvCodes": [
                "39100000",
                "45233293",
                "45421153",
                "50850000"
            ],
            "summary": "This document provides the EU GPP criteria developed for the product
            ↪  group \"Furniture\"."
        }
    ],
    "suggestedGppCriteria": [
        {
            "gppDocument": "EU GPP Criteria for Furniture",
            "category": "Procurement of new furniture",
            "criterionType": "Technical specification",
            "ambitionLevel": "Core",
            "id": "TS1",
            "name": "Sourcing of legal timber for furniture production",
            "relevantCpvCodes": [
                "39100000",
                "45233293",
                "45421153"
            ],
            "matchingCpvCodes": [
                "39100000"
            ],
            "lotId": "LOT-0001"
        },
        ...
    ]
}
```


Figure 3.12: Response body for `POST /api/v1/analyze-notice`

Suggest Patches Endpoint

The suggest patches endpoint is used to suggest a set of patches to be applied on the eForm notice, given the set of GPP criteria provided that wish to be included into the

notice.

The endpoint is defined as `POST /api/v1/suggest-patches`.

The request body expected contains only contains two elements: `noticeXml`, which corresponds to the eForm contract notice as an XML string and `criteria`, which contains a subset of the criteria suggested by the analyze endpoint. These are the criteria that the caller wishes to insert into the eForm notice.

```
{
    "noticeXml": "<ContractNotice>...</ContractNotice>",
    "criteria": [
        {
            "gppDocument": "EU GPP Criteria for Furniture",
            "category": "Procurement of new furniture",
            "criterionType": "Technical specification",
            "ambitionLevel": "Core",
            "id": "TS1",
            "name": "Sourcing of legal timber for furniture production",
            "relevantCpvCodes": [
                "39100000",
                "45233293",
                "45421153"
            ],
            "matchingCpvCodes": [
                "39100000"
            ],
            "lotId": "LOT-0001"
        }
    ]
}
```

Figure 3.13: Request body for `POST /api/v1/suggest-patches`

In case of success, the response status will be `200 (OK)` and the body will contain a singe element: `suggestedPatches`, which refers to a list of patches suggested to modify the notice according to the GPP criteria provided. These patches will contain both general GPP indicators and a direct insertion of the GPP criteria.

```
{
    "suggestedPatches": [
        {
            "name": "Green Public Procurement Criteria - eu",
            "btIds": [
                "BT-805-Lot"
            ],
            "dependsOn": "Procurement Project",
            "path": "cac:ProcurementProject",
            "value": "<cac:ProcurementAdditionalType
            ↪  xmlns:cac=\"urn:oasis:names:specification:ubl:schema:xsd:CommonAggregateComponents-2\"
            ↪  xmlns:cbc=\"urn:oasis:names:specification:ubl:schema:xsd:CommonBasicComponents-2\">\n
            ↪  <!-- Green Public Procurement Criteria (BT-805-Lot) -->\n
            ↪  <cbc:ProcurementTypeCode
            ↪  listName=\"gpp-criteria\">eu</cbc:ProcurementTypeCode>\n</cac:ProcurementAdditionalType>",
            "op": "create",
            "description": "Indicates the usage of GPP criteria",
            "lotId": "LOT-0001"
        },
        ...
    ]
}
```


Figure 3.14: Response body for `POST /api/v1/suggest-patches`

Apply Patches Endpoint

The apply patches endpoint is used to apply a set of patches onto the eForm notice

The endpoint is defined as `POST /api/v1/apply-patches`.

The request body expected contains only contains two elements: `noticeXml`, which corresponds to the eForm contract notice as an XML string and `patches`, which contains a subset of the patches suggested by the suggest patches endpoint.

```
{
    "noticeXml": "<ContractNotice>...</ContractNotice>",
    "patches": [
        {
            "name": "Green Public Procurement Criteria - eu",
            "btIds": [
                "BT-805-Lot"
            ],
            "dependsOn": "Procurement Project",
            "path": "cac:ProcurementProject",
            "value": "<cac:ProcurementAdditionalType
            ↪  xmlns:cac=\"urn:oasis:names:specification:ubl:schema:xsd:CommonAggregateComponents-2\"
            ↪  xmlns:cbc=\"urn:oasis:names:specification:ubl:schema:xsd:CommonBasicComponents-2\">\n
            ↪  <!-- Green Public Procurement Criteria (BT-805-Lot) -->\n
            ↪  <cbc:ProcurementTypeCode
            ↪  listName=\"gpp-criteria\">eu</cbc:ProcurementTypeCode>\n</cac:ProcurementAdditionalType>",
            "op": "create",
            "description": "Indicates the usage of GPP criteria",
            "lotId": "LOT-0001"
        }
    ]
}
```

Figure 3.15: Request body for `POST /api/v1/apply-patches`

In case of success, the response status will be `200 (OK)` and the body will contain a singe element: `patchedNoticeXml`, which refers to the new eForm notice XML string, after applying the requested patches. This is the final result of the GPP criteria and GPP indicators integration process.

```
{
    "patchedNoticeXml": "<ContractNotice>...</ContractNotice>"
}
```

Figure 3.16: Response body for `POST /api/v1/apply-patches`

Visualize Notice Endpoint

The visualize notice endpoint is used to render an XML notice into a readable HTML format.

The endpoint is defined as `POST /api/v1/visualize-notice`.

The request body expected contains only contains one element: `noticeXml`, which corresponds to the eForm contract notice as an XML string (similar to previous endpoints).

The handler for this endpoint acts as a proxy for the TED API visualization endpoint as described in subsection 2.4.1. It then wraps the response into a body containing: `visualizationStatus`, containing the status received from the TED API; `noticeHtml`, containing the HTML string that can be used to display the notice; `summary`, containing either a success or an error message summarizing the status of the request.

```
{
    "visualizationStatus": 200,
    "summary": "Rendering completed successfully",
    "noticeHtml": "<!DOCTYPE HTML>..."
}
```

Figure 3.17: Response body for `POST /api/v1/visualize-notice`

Validate Notice Endpoint

The validate notice endpoint is used to validate an eForm notice according to the schematron rules in the SDK.

The endpoint is defined as `POST /api/v1/validate-notice`.

The request body expected contains only contains one element: `noticeXml`, which corresponds to the eForm contract notice as an XML string (similar to previous endpoints).

The handler for this endpoint acts as a proxy for the TED API validation endpoint as described in subsection 2.4.1. It then wraps the response into a body containing: `validationStatus`, containing the status received from the TED API; `summary`, containing either a success or an error message summarizing the status of the request; `validationReportXml`, containing the resulting validation report as an XML string.

```
{
    "validationStatus": 200,
    "summary": "Validation completed successfully",
    "validationReportXml": "<?xml..."
}
```

Figure 3.18: Response body for `POST /api/v1/validate-notice`

3.5.2. Implementation Technologies

The GPP Service is built using the Spring framework, provides a comprehensive programming and configuration model for modern Java-based enterprise applications [60]. In particular, it leverages Spring Boot, an opinionated view of the Spring platform, which significantly accelerated the development. As a key to exposing a REST API, it also leverages Spring WEB MVC to handle the HTTP request routing, data binding and response generation, allowing for a clear separation between the web layer it provides and our business logic. The application is written using Java 21, a long-term support (LTS) version.

As a build tool and dependency manager, the GPP Service uses Apache Maven. As a reminder, the GPP Library is published to Maven Central, and through this means, it is imported into this project. The GPP Library is the driving component of the service, providing all the necessary functionalities to implement the business logic of the GPP Service.

To allow for effective consumption of the API provided, the endpoints are documented using OpenAPI specifications, which provide a formal standard for describing HTTP APIs [29]. This documentation is key to communicate to any external clients how the API can be used.

3.5.3. Quality Assurance

This QA process that was followed for the GPP Service included:

- **Unit Testing**: All the handlers were covered with unit tests using `JUnit`, achieving a full coverage. This serves to verify the expected behavior of the handlers.
- **Integration Testing**: Used to verify the end-to-end flow of the service, including the serialization, de-serialization and interactions with the GPP library. To accomplish this, `Spring Boot Test` was used.
- **Manual Testing**: Mostly used during the development process, manual testing and careful review of the results were used to constantly validate the functionalities of the service.

3.5.4. Limitations

While the API provided by the GPP Service is functionally complete, it's important to acknowledge certain limitations, inherent to its nature as a thesis project that hinder it

from being a production-ready service.

- **Lack of Authentication of Authorization Mechanisms**: While a basic Cross-Origin Resource Sharing (CORS) configuration is provided for basic access-controls, there are no methodologies implemented for user authentication nor authorization mechanisms to restrict access (although as it stands, the authorization mechanism would likely not be needed).
- **Limited Security Audit**: The service did not undergo a comprehensive cyber-security audit nor penetration testing of any kind.
- **Lack of Load Testing**: There was no load test plan implemented to demonstrate the capabilities of the service under high-volume requests, as it would happen in production environments.
- **Sensitivity to Changes**: Just like the rest of the components, the timeliness and validity of the service depends on using the latest GPP Library, thus it also inherits its limitations.

3.6. GPP UI Design and Implementation

The GPP User Interface (UI) [64] is the interactive layer of the software solution presented in this thesis. It is a ready-to-use web application that provides an intuitive workflow that aims to demystify GPP integration in Europe through the manipulation of eForms.

It can also provide insights on how the capabilities of the GPP Library and GPP service can be integrated into an e-Procurement application.

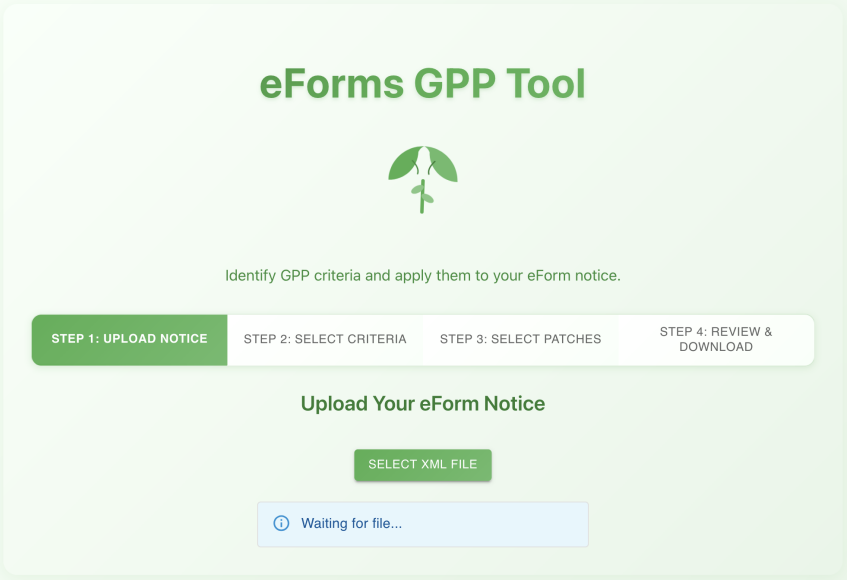


Figure 3.19: GPP UI Home Screen

3.6.1. Application Design

The design of the GPP UI was driven by a user-centric approach, aiming to facilitate the process of integrating GPP elements into eForm notices, which may be complex to public authorities with no expertise in the GPP resources available and / or ignorant to the intricacies of eForms.

The main goal is to reduce the manual burden that is currently needed to identify and integrate GPP elements by providing a guided experience.

The UI is structured around a clear and sequential workflow, naturally guiding the user through the steps, from the initial eForm notice submission, all the way to downloading the patched eForm notice that contains the desired GPP elements.

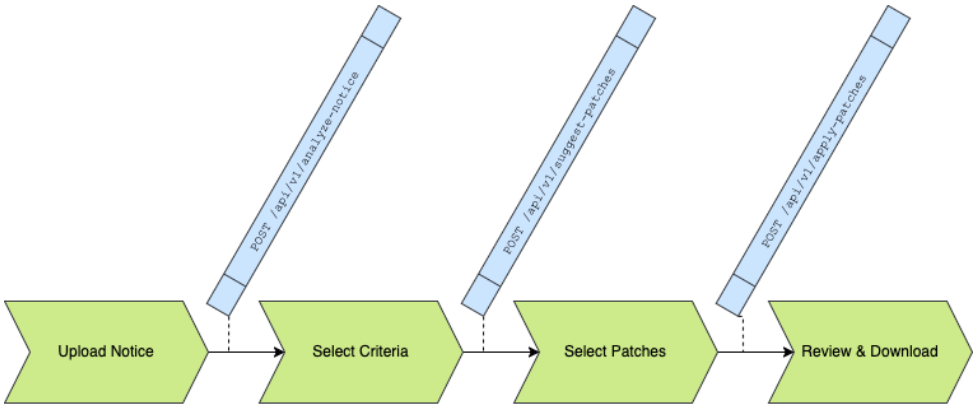


Figure 3.20: GPP UI Steps

The steps that are involved in the end-to-end process are:

1. **Upload Notice**: The goal of this step is to allow the user to submit an XML eForm notice. Once the notice file is submitted, the notice is previewed to provide instant feedback to the user, and the option to move onto the next step will become available. This step also allows the user to visualize the notice uploaded using the TED API visualize endpoint.

2. **Select Criteria**: The goal of this step is to allow the user to view the list of relevant GPP documents and suggested GPP criteria. Furthermore, it allows the user to select the criteria that are deemed relevant to the notice for them to be integrated into the notice. Each element in the list containing a specific GPP criterion may also be clicked to display all the available information.

   By default, no criteria are selected so that the user must consciously verify that the suggested criteria are indeed relevant to the notice.

3. **Select Patches**: The goal of this step is to display the suggested patches and give an understanding of what exactly will be changed in the eForm notice. Each element in the list containing a specific patch may also be clicked to display all the available information. In this screen the user may deselect any patches that are undesired.

   Notice that by default, all of the patches are selected, contrary to the criteria selection, where by default none are selected. This is a conscious decision made to indicate that the recommended behavior is selecting all the patches corresponding to the selected criteria.

4. **Review & Download**: This step allows the user to review the eForm after the modifications made by the GPP Service / Library, and to download it as an XML file. Assuming that the eForm submitted was already complete and valid, the patched eForm notice provided shall be ready for submission to the TED portal. This step also allows the user to visualize and validate the notice patched using the TED API visualize and validate endpoints.

Notice that between the step transitions there is a confirmation modal with a summary of the response received from the service that provides the options of revising the current screen or moving to the next one.

Overall, the design of the GPP UI provides a clear layout with intuitive navigation and effective feedback mechanisms, all with the goal of providing a smooth user experience.

The full set of screenshots containing the end-to-end flow of the GPP UI will be included

in the section 4.1.

3.6.2. Implementation

The GPP UI was implemented as a single-page application using React, a declarative JavaScript library for constructing user interfaces [40]. React was used due to its component-based architecture, which promotes modularity, re-usability and maintainability. It also provides features used for state management, central to developing an interactive application. For its easy deployment on any web server, the application is compiled into a set of optimized static assets (HTML, CSS, and JavaScript) using Vite's build process. Vite is a modern front-end build tool used not only for optimized production builds, but also for an accelerated startup and update development process [41].

A key React component library used is the Material UI, which provided many of the UI components present in the application, helping to make it visually appealing. In particular, the app features a stepper, built using Material UI Tabs, that is used to to guide users through the four steps: Upload Notice, Select Criteria, Select Patches, and Review & Download.

Each transition between the steps triggers an API call to the GPP Service library, made by using asynchronous JavaScript requests. The endpoints called are as follows:

- **Upload Notice –> Select Criteria**: The notice uploaded is sent to the `POST /api/v1/analyze-notice` endpoint. The response received is used to populate the criteria available to select in the next screen.
- **Select Criteria –> Select Patches**: The criteria selected by the user are sent to the `POST /api/v1/suggest-patches` endpoint. The response received is then used to populate the patches available to select in the next screen.
- **Select Patches –> Review & Download**: The patches selected by the user are sent to the `POST /api/v1/apply-patches` endpoint. The response received is the patched notice which is ready to be visualized and downloaded.

3.6.3. Quality Assurance

The quality assurance of the GPP UI was ensured primarily through manual testing of a comprehensive set of success and error cases. Furthermore, unit testing was used to cover the business logic functionalities.

3.6.4. Limitations

The GPP UI has certain limitations to be acknowledged:

- **Limited Accessibility**: The UI application has not been publicly deployed in a server and therefore, it requires users to manually launch it in a local environment, which limits its immediate accessibility for widespread, real-world use by public authorities.
- **Lack of Formal User Validation**: The user experience has not been formally evaluated through structured studies with actual public authorities, leaving the possibility open to gaps in its functionality.
- **Partial e-Procurement Features**: The GPP UI focuses exclusively in the Green Public Procurement workflow as described. It does not provide the base functionalities required for a full e-Procurement system. Therefore, its use must be complementary to an existing system.

4 | Evaluation and Results

This chapter aims to empirically demonstrate the the capabilities of the software solution designed for this thesis, to validate its practical effectiveness, and to discuss its success against the objectives defined. It also serves to highlight the contributions made to the state of the art of integrating Green Public Procurement into the current European e-Procurement ecosystem.

4.1. Demonstration of Functionalities

This section provides a step-by-step walkthrough of how the software tools presented in this thesis can be used by a public authority to easily integrate Green Public Procurement elements into their procurement process.

This will be done by using the GPP UI, which as a reminder, is structured around a clear and sequential workflow, naturally guiding the user through the steps necessary, as shown in figure 3.20.

4.1.1. Setup

To get started, there are some pre-requisites:

- **Launch GPP Service**: In an ideal scenario, this would be deployed in a remote server. For demonstration purposes, this service can be deployed locally following the instructions in the GPP Service repository [63].
- **Launch GPP UI**: In an ideal scenario, this would be deployed in a remote server. For demonstration purposes, this application can be deployed locally following the instructions in the GPP UI repository [64].
- **Download eForm XML Notice**: This refers to the process of downloading the eForm notice that has been completed. From the information collected, it is a standard feature for e-Procurement platforms to allow for the download of the eForm XML notice after completion (such as the Spanish platform and eNotices2). In our

particular case, the contract notice used for this demonstration comes from the TED website [53] where the notices are published. This notice was chosen due to its involvement with furniture goods, which was the key product category used through this project.

4.1.2. Notice Upload

The goal of this step is to allow the user to submit an XML eForm notice. Once the notice file is submitted, the notice as a raw XML is previewed to provide instant feedback to the user. By clicking on "PREVIEW RENDERED NOTICE", the user may visualize the notice in a readable format (through the use of the TED API). By clicking on "ANALYZE NOTICE", the request is sent to the GPP Service to perform the analysis. A confirmation dialog with a brief message is shown before moving on to the next step.

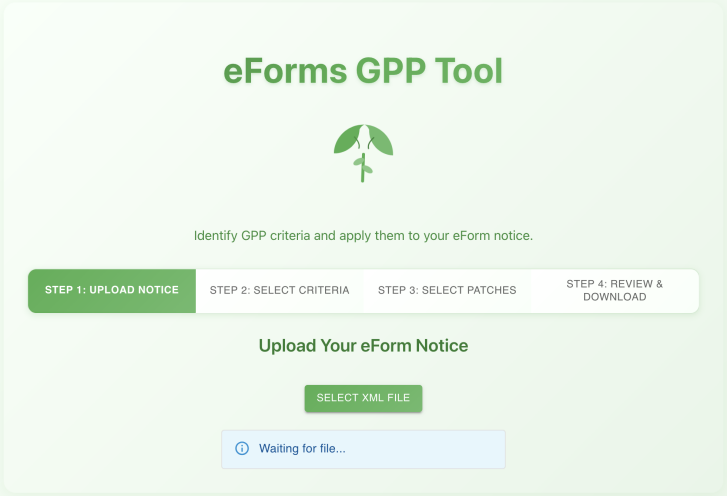


Figure 4.1: Home screen, awaiting notice submission.

Figure 4.2: Home screen, after notice submission.

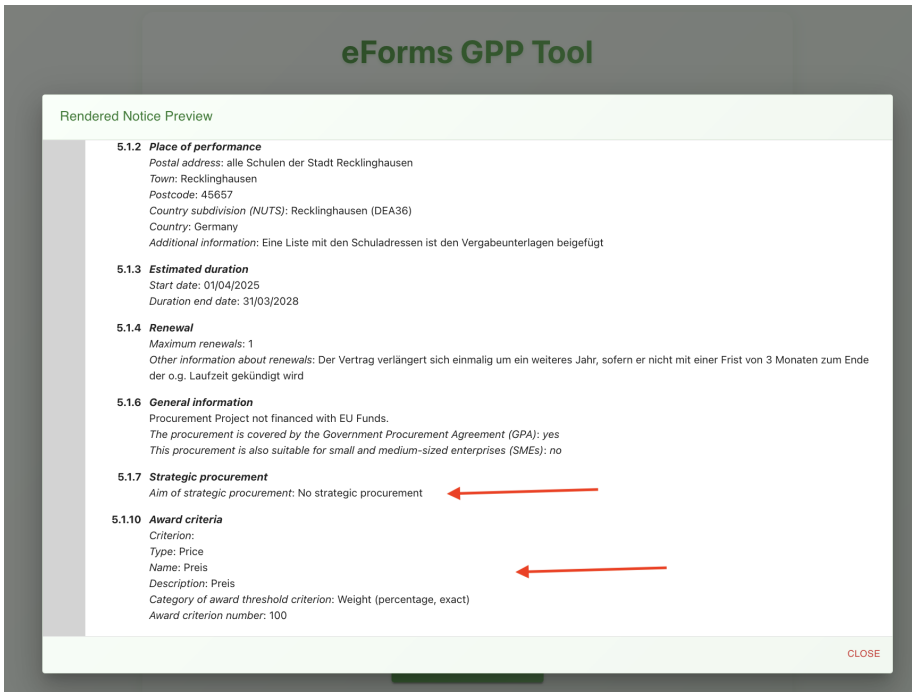


Figure 4.3: Visualize uploaded notice.

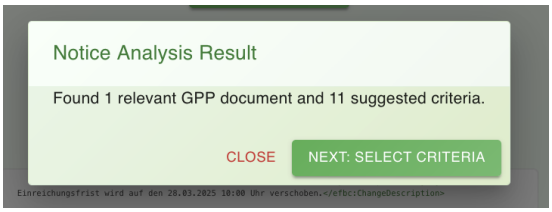


Figure 4.4: Confirmation dialog for analysis.

4.1.3. Criteria Selection

The goal of this step is to allow the user to view the list of relevant GPP documents and suggested GPP criteria. Furthermore, it allows the user to select the criteria that are deemed relevant to the notice for them to be integrated into the notice. Each element in the list containing a specific GPP criterion may also be clicked to display all the available information. By default, no criteria are selected so that the user must consciously verify that the suggested criteria are indeed relevant to the notice.

By clicking on "SUGGEST PATCHES", the request is sent to the GPP Service to suggest patches based on the selected criteria. A confirmation dialog with a brief message is shown before moving on to the next step.

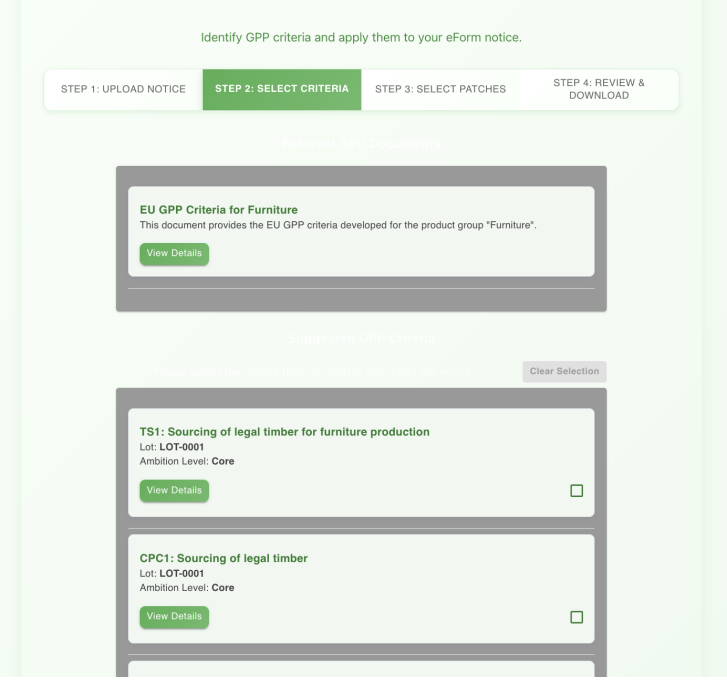


Figure 4.5: Display analysis result: show relevant GPP Documents and GPP Criteria.

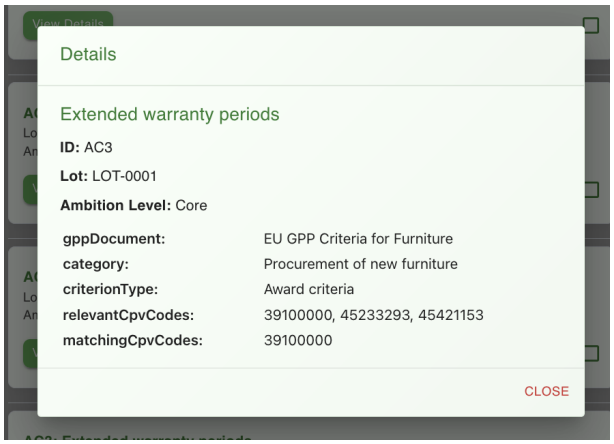


Figure 4.6: Show the details of a specific GPP Criterion.

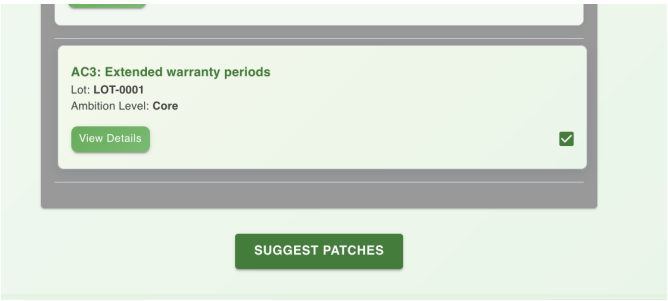


Figure 4.7: Select one patch (AC3: Extended Warranty Periods).

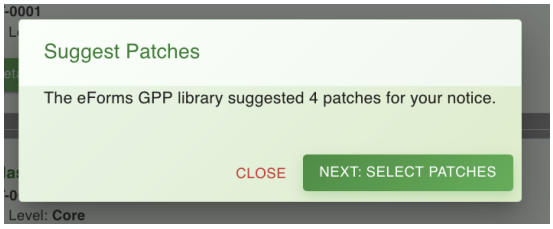


Figure 4.8: Confirmation dialog for criteria selection

4.1.4. Patches Selection

The goal of this step is to display the suggested patches and give an understanding of what exactly will be changed in the eForm notice. Each element in the list containing a specific patch may also be clicked to display all the available information. In this screen the user may deselect any patches that are undesired. Notice that by default, all of the patches are selected. This is a conscious decision made to indicate that the recommended behavior is selecting all the patches corresponding to the selected criteria.

By clicking on "APPLY PATCHES", the request is sent to the GPP Service to apply the selected patches. A confirmation dialog with a brief message is shown before moving on to the next step.

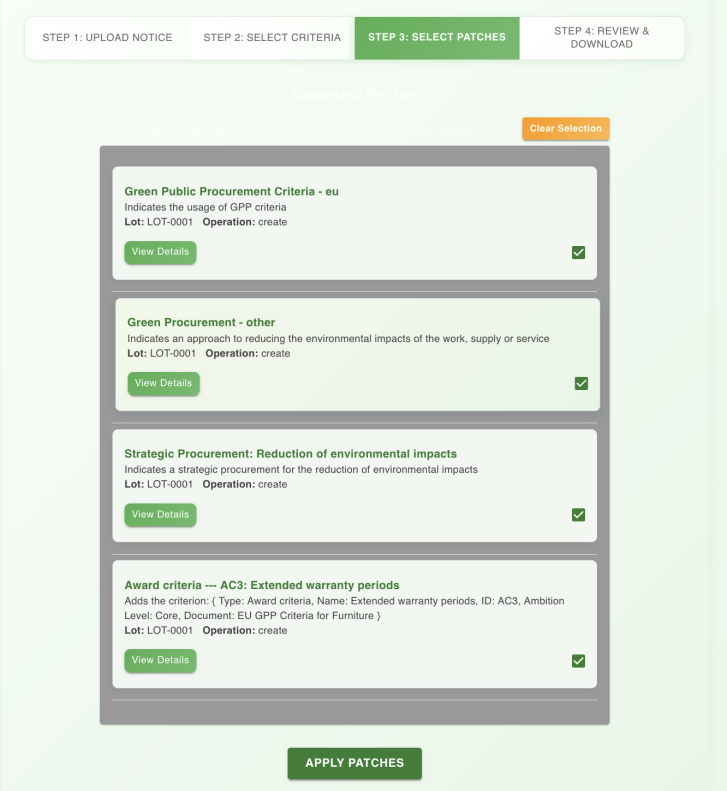


Figure 4.9: Display suggested patches for selected criteria (AC3).

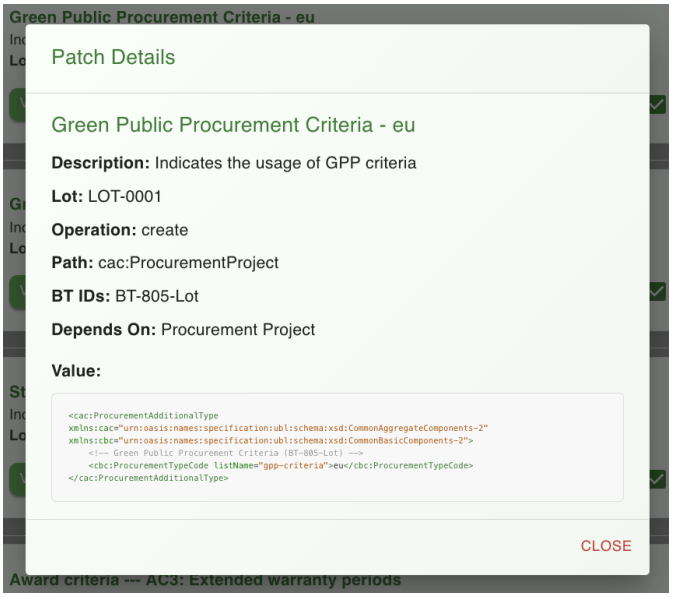


Figure 4.10: Show patch details.

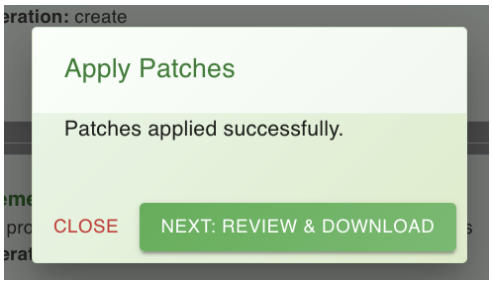


Figure 4.11: Confirmation dialog after patch application.

4.1.5. Review & Download

This step allows the user to review the eForm after the modifications made by the GPP Library, validate it and to download it as an XML file. Assuming that the eForm submitted was already complete and valid, the patched eForm notice provided should be ready for submission to the TED portal through another e-Procurement platform or tool.

By clicking on "PREVIEW RENDERED NOTICE", the user may visualize the patched notice in a readable format (through the use of the TED API). By clicking on "VALIDATE NOTICE", the user may validate the patched notice through the use of the TED API validation endpoint. The result of the validation will be shown in a dialog. By clicking on "DOWNLOAD PATCHED NOTICE", the user may download the patched notice.

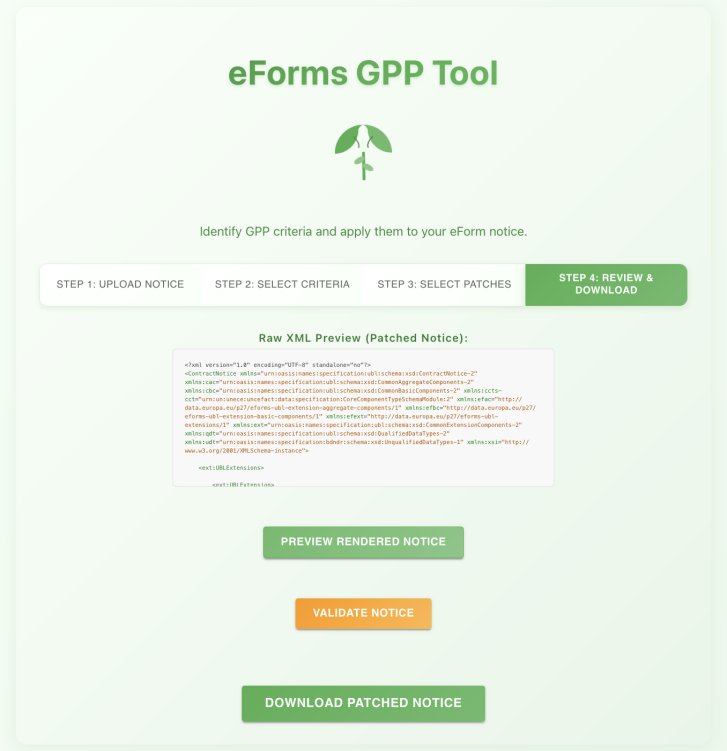


Figure 4.12: Review and download screen.

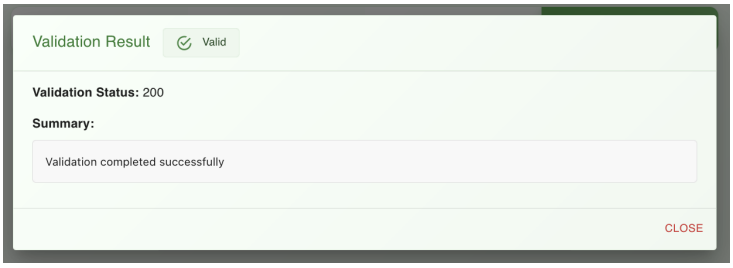


Figure 4.13: Dialog showing result of validation of patched notice.

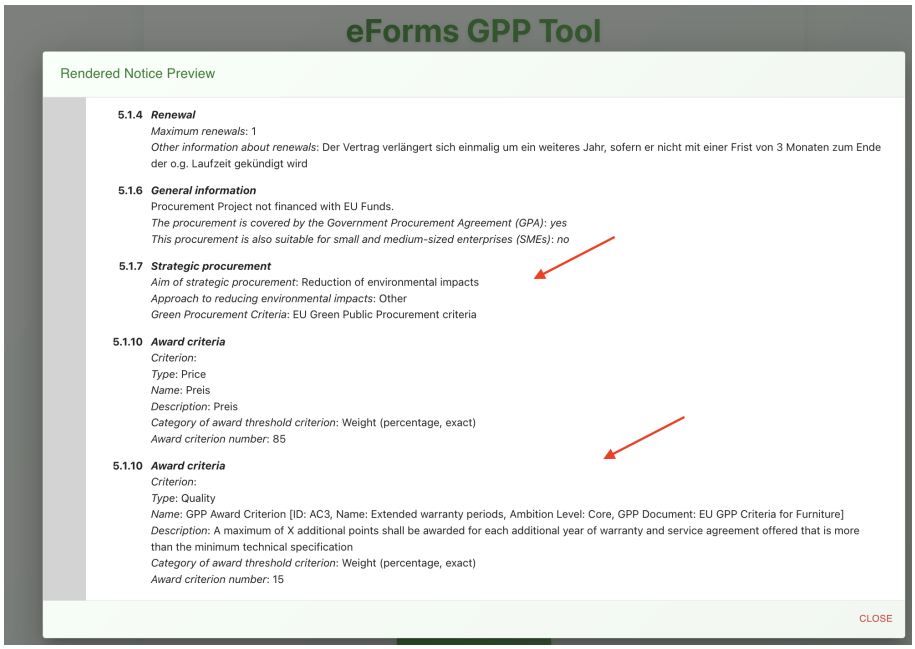


Figure 4.14: Visualize notice with GPP patches applied.

4.2. Discussion of Results

This section provides a general discussion of the GPP Tools' effectiveness and results, and validates them against the initial research objectives. Finally, it examines the contributions made to the state of the art by drawing a comparison with the existing tools.

4.2.1. General Discussion

From the evaluation of the GPP UI, we can emphasize its usability. The UI provides a highly intuitive workflow that requires very little interaction: The submission of the notice is a straightforward process. The criteria and patches selection process provide all the necessary information to the user for them to make an informed decision on what elements to include in the notice. Overall, the end-to-end flow is a user-friendly process, and the information provided by the GPP Library, exposed by the GPP service, and displayed by the GPP UI is comprehensive on what each of the elements added signify.

The overall process also proved to be constantly reliable, by correctly inserting the required GPP elements and maintaining the validity of the eForm notice, as verified through the validation endpoint of the TED API, as seen in subsection 2.4.1.

Furthermore, the performance of the tool as a whole can also be highlighted. The latency of analysis, patches suggestion, and patches application functions are minimal at the

library level, and the user experience is practically immediate at the UI level (although it is worth noting that some latency could be added by a remotely hosted GPP service).

Given the points discussed, the GPP tools developed have the characteristics necessary to decidedly simplify the process of using GPP to public authorities. Nevertheless, as mentioned repeatedly, this analysis remains theoretical due to the lack of formal user studies, which would be key to a comprehensive evaluation of the tool's usability and effectiveness.

4.2.2. Validation of Objectives

As mentioned in our research objectives, in section 1.3, the main goal of this thesis was to develop a software solution to address the challenges presented and to facilitate and promote the use of GPP criteria in European public procurement.

Furthermore, following sufficient research on the current state of GPP, a set of more concrete objectives were defined for the final software tools:

1. Identify GPP criteria applicable to a given contract notice.
2. Incorporate the relevant GPP criteria into the contract notices.
3. Evaluate the proposals made according to the selected GPP criteria.
4. Be compatible with the existing e-Procurement development environment.

As we can see in the demonstration of the GPP UI, in section 4.1, the tool is capable of identifying GPP criteria applicable to the eForm notice submitted by the user, and through minimal interaction, it enables the incorporation of the GPP criteria, and other GPP indicators into the notice. The objectives #1 and #2 are therefore considered accomplished.

When it comes to the objective #3, referring to the evaluation of proposals made according to a set of GPP criteria, the solution presented in this thesis fails to provide the required capabilities to achieve it. The data gathered from the empirical analysis, in section 2.5.1, showed that the usage of GPP elements in eForm notices across Europe is far from widespread. Therefore, the priority was put on the initial steps of the procurement pipeline, these being the identification and integration of GPP elements into contract notices. Furthermore, due to the depth required to design and implement software solutions in initially unknown domains, such as GPP and e-Procurement, the implementation of the proposal evaluation features fell beyond the practical reach of this project.

The design decisions of the components developed were all directed towards achieving a

maximal compatibility with the existing e-Procurement development environment. The modularity of the design, and the programming language decisions, allow for integration with external applications at different levels, both as a Java library (GPP Library) and as a REST service (GPP Service). Moreover, leveraging the standard for publishing procurement notices in Europe, eForms, these tools ensure the presence of a common point of contact with the existing e-Procurement platforms, thus achieving objective #4.

Overall, despite the limitations aforementioned, the GPP Library, the GPP Service and the GPP UI, provide the functionalities required to accomplish the main objective of this thesis: to facilitate the use of GPP criteria in European public procurement.

4.2.3. Comparison with the State of the Art

The analysis of the state of the art of GPP, presented in section 2.5, analyzed the current e-Procurement experience, and evaluated the capabilities of the GPP tools available today in the European procurement environment. From such analysis, we drew a division between three concepts: e-Procurement platforms, GPP knowledge-based tools, and GPP performance-based tools. It became clear that there was no integrated approach of GPP into the existing e-Procurement platforms, but rather a set of tools to be used separately.

The GPP knowledge-based tools provide a comprehensive background on GPP practices, as well as valuable and accessible information on the current GPP criteria. Nevertheless, the identification of GPP criteria and their incorporation into the contract notices becomes a manual task that demands additional effort and a certain level of domain knowledge on how to include these GPP elements into the contract notices.

The tools introduced in this thesis: the GPP Library, the GPP Service, and the GPP UI, provide a modular software solution that can identify and integrate GPP elements with minimal expertise or interaction required. They aim to simplify and automate a previously manual and potentially complex procedure. Through the use of these new tools, the use of GPP in e-Procurement is expected to become a more seamless and intuitive process.

Furthermore, the heterogeneity of e-Procurement platforms was identified, which raises challenges for the development of a common solution that can work in a variety of contexts. Fortunately, the eForms standard, centric to our solution, was recently rendered mandatory for high-value public contracts in Europe (after the development of all of the previously existing GPP tools presented), providing a commonality at the data layer between all the e-Procurement platforms in Europe. Therefore, the eForms standard, and a compatibility with the existing TED development environment are leveraged by the developed GPP tools to facilitate a potential integration into existing e-Procurement

platforms.

As previously stated, the proposal evaluation process was not implemented in this project, therefore, the integration of an evaluation tool, such as the ones presented in the state of the art, remains an available opportunity.

5 | Conclusions and Future Developments

This chapter offers a concise summary of the research and work presented in this thesis, along with a brief description of the key achievements and impact of the developed software solution. Additionally, it examines the overall limitations of this project, acknowledging its current boundaries. Finally, it proposes future work and development paths that could help further achieve the objectives of this thesis: to facilitate the use of GPP in European procurement through the use of a software tool.

5.1. Summary of Contributions

Public procurement, was recognized as a major driving force of the economy of the European Union. It has gone through a digital transformation that has accentuated its potential as a vehicle for the transformation of the economy towards sustainability. Central to this concept, Green Public Procurement (GPP) is introduced as a process that can help reduce the environmental impact of procurement activities.

Despite the efforts from the European Commission to promote GPP, our empirical data analysis shows that the usage of the GPP indicators and GPP criteria across the notices published to TED is only present in approximately 13% of the contract notices published in TED, the Supplement to the Official Journal of the EU. The benefits of GPP are limited by their practical application, which is facing many challenges to its wide-spread application. Within the main challenges identified, we have the lack of awareness of GPP criteria, the complexity of integration of GPP, and the limitations of the existing tools.

Most of the current tools revolving GPP criteria identification and integration are knowledge-based, requiring manual efforts and a level of expertise to properly integrate GPP into the contract notices. Moreover, the existing e-Procurement platforms provide only the basic procurement functionality, and offer no deeply integrated GPP elements.

This thesis aims to address that gap, by providing a novel software solution to man-

age GPP criteria revolving around eForms, a recently introduced standard that became mandatory for high-value contracts in the EU. eForms also provide us with a common layer to integrate with existing e-Procurement platforms, which are highly diverse across Europe.

The software solution presented in this thesis aims to integrate GPP elements directly into e-Procurement with the goal of making it more accessible, and lowering the barriers to its usage. To accomplish this, the tool provides the functionalities to easily identify the GPP criteria applicable directly from the eForm notice, and the mechanisms to apply such criteria into it. This emphasis on usability is critical to overcome resistance from public authorities and promote GPP adoption.

A key principle followed during the design was facilitating the integration with the existing e-Procurement environment. To do this, the solution involves a modular architecture comprised of a GPP Library, which provides the key functionalities, a GPP Service, which exposes such functionalities through a REST API, and a GPP UI, which provides a ready-to-use, user-friendly interface. Furthermore, the programming language and publication tools were selected specifically to match the current e-Procurement development tools provided by TED to further facilitate an integration into other e-Procurement systems.

Although it has a set of acknowledge limitations, the design and implementation of this software solution identifies a gap and advances the state of the art of practical GPP criteria integration into digital procurement in Europe.

5.2. Overall Limitations

Despite the positive impact that this tool can have in promoting Green Public Procurement in Europe, there are some limitations to be acknowledged.

- **Manual Maintenance of Domain Knowledge**: The key domain knowledge used to power the GPP Library is defined in an Excel file. This information needs to be provided by a GPP domain expert who can correctly interpret the information in the formal GPP criteria documents and translate it into the inputs for the domain knowledge sheets. These official GPP criteria documents are also subject to periodic updates (although not so regular), which may require monitoring to maintain the domain knowledge valid. Additionally, it requires a manual step involving a script to convert it from Excel to JSON, which can then be consumed by the GPP Library.
- **Software Maintenance**: Beyond the maintenance of the domain knowledge, the inherent nature of software requires constant maintenance. The technical stacks

evolve rapidly and continuously for all of the components. In particular, this involves the eForms SDK, which would require a full system revision in case of a major version upgrade.

- **Production (Non-)Readiness**: The GPP Library was thoroughly tested as a stand-alone component, however, it may still need exposure to edge-cases present in the real world to test its robustness. The GPP Service and the GPP UI, although functionally complete, have not undergone the necessary security and performance testing required to be considered production-ready. The lack of a dedicated server to host the application also contributes to this. Nevertheless, they can serve as advanced templates for the integration of the GPP Library.
- **Lack of Formal User Validation**: The software tools developed in this thesis were not formally studied with real-world public authorities. The assessment of the usability and effectiveness of the tools defined remains theoretical until a proper quantitative assessment of the application is performed.
- **Unknown Impact**: Even with the successful integration of GPP elements into the eForm notices, it is unclear what concrete benefits such inclusions would have on the environmental impact of the works, services, and goods procured through such contracts. This is a complex matter that could only be quantified through careful monitoring.

5.3. Future Work and Developments

During the development and analysis of the software tools, a set of actionable items have been identified that could improve and build upon the solution presented and help contribute to achieve its main goal: to facilitate the use of GPP criteria in European public procurement. These include:

- **Support for Different Languages**: The modifications being done for notices in this version of the software are only in english, using the appropriate `ENG` indicator. The language trigram is already configurable through most of the project, however, the domain knowledge would need to be translated into the desired languages. The recommendation is to focus on the language in which a formal user study may be carried out. Italian is of course the strongest contender.
- **Formal User Studies**: The lack of formal user studies has been mentioned throughout this thesis, as it is identified as crucial to properly quantitatively assessing the usability and effectiveness of the GPP tools provided in the real European public

procurement world. The feedback provided by public authorities would be essential for driving further improvements in the tools.

- **Integration of Evaluation Capabilities**: The original goal was to create an end-to-end tool covering the identification, integration, and evaluation of GPP criteria. Nevertheless, due to aforementioned reasons, the evaluation step fell out of scope of the current work. Developing a multi-criteria evaluation tool into the GPP UI would help complete the scope of the solution, allowing the management of GPP criteria to be centralized, and thus much more accessible to users.

  The implementation can initially follow a simple methodology with a basic approach at evaluating the proposals made to a given contract notice. As we have previously discussed, compromises can be made in the accuracy of the tool in favor of facilitating the use, thus maximizing the impact.

- **Integration into e-Procurement Ecosystem**: There are a couple of ways of achieving this. A good initial approach would be to directly integrate the GPP Library or GPP Service into an existing e-Procurement platform to demonstrate its capabilities and get some exposure. Notice that this approach would require the cooperation of their development team. A successful integration would however, provide critical feedback and lay the foundations for a more wide-spread use.

  Another possible way is to seek an opportunity to promote this tool within the TED developer portal. This advertisement would likely lead to the adoption of the tool within new e-Procurement platforms based on the TED developer environment. The challenge here would be the lack of observability of the tool's performance. This would require contacting the TED team and may involve giving the necessary guarantees to the current capabilities of the tools and their future maintenance.

- **Expand GPP Domain Knowledge**: During the development of this thesis, the domain knowledge integration was mostly limited to the EU GPP Criteria for Furniture, with some limited integration of other categories of EU GPP Criteria. This was the case due to the time-intensive tasks of translating the official GPP criteria documents into the proper format.

  A useful future development would be to expand the GPP domain knowledge to include all of the EU GPP Criteria, as well as some national GPP criteria, which would require minimal changes in the business logic of the GPP Library (namely filtering by the country of the procurement).

- **Adaptation to eForms SDK v2**: A new major version of the eForms SDK is

expected within the next year. While the transition period might be slow, in order for the tool to remain relevant long-term, a revision of the eForms domain knowledge and the GPP Library logic will need to be performed. An early adoption would be ideal to maximize the possibilities of an integration into the full development environment.

Bibliography

[1] M. Aldenius and J. Khan. Strategic use of green public procurement in the bus sector: Challenges and opportunities. *Journal of Cleaner Production*, 164:250–257, 2017. ISSN 0959-6526. doi: https://doi.org/10.1016/j.jclepro.2017.06.196. URL https://www.sciencedirect.com/science/article/pii/S0959652617313665.

[2] A. Alliance. Agile essentials. https://agilealliance.org/agile101/, 2025. Accessed: 16 06 2025.

[3] S. Bobowski and J. Gola. E-procurement in the european union, 07 2017.

[4] F. Bof and G. Casella. Public e-procurement as a key-impact factor in the ue welfare context-the italian public e-markets: Research findings and e-solutions analysis. In *2015 38th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, pages 1434–1443, 2015. doi: 10.1109/MIPRO.2015.7160499.

[5] S. CheminyChesseto, P. Gudda, N. D.M.N, and MuneneMbuchi. E-procurement and procurement performance. *THE INTERNATIONAL JOURNAL OF BUSINESS & MANAGEMENT*, 2019.

[6] W. Cheng, A. Appolloni, A. D'Amato, and Q. Zhu. Green public procurement, missing concepts and future trends – a critical review. *Journal of Cleaner Production*, 176:770–784, 2018. ISSN 0959-6526. doi: https://doi.org/10.1016/j.jclepro.2017.12.027. URL https://www.sciencedirect.com/science/article/pii/S0959652617329578.

[7] E. Commission. Eu green public procurement criteria for indoor cleaning services, oct 2018.

[8] E. Commission. Eu green public procurement criteria for furniture, jul 2018. Corrigendum: This document corrects document SWD(2017) 283 final of 10.8.2017. Correction of several minor mistakes on page 8, 13, 14, 20, 27 and 39. Clarification in several places that all padding materials, not only latex and polyurethane foams, need to fulfil the same requirements on page 8, 9, 10, 11, 12, 22, 23, 24, 26.

[9] E. Commission. Common procurement vocabulary. https://single-market-economy.ec.europa.eu/single-market/public-procurement/digital-procurement/common-procurement-vocabulary_en, 2025. Accessed: 15 06 2025.

[10] E. Commission. lxml - xml and html with python. https://lxml.de/, 2025. Accessed: 16 06 2025.

[11] E. Commission, D.-G. for Environment, and I. . G. for Sustainability. *Buying green! – A handbook on green public procurement*. Publications Office, 2016. doi: doi/10.2779/837689.

[12] Commission of the European Communities. Public procurement for a better environment. Technical Report COM(2008) 400 final, Commission of the European Communities, Brussels, jul 2008. URL https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0400:FIN:EN:pdf. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions.

[13] Consip. Le procedure di acquisto sul mepa. https://www.youtube.com/watch?v=h1Jh3Mh1jbM, May 2024. Accessed: June 16, 2025.

[14] A. Cordella and F. Iannacci. Information systems in the public sector: The e-government enactment framework. *The Journal of Strategic Information Systems*, 19(1):52–66, 2010. ISSN 0963-8687. doi: https://doi.org/10.1016/j.jsis.2010.01.001. URL https://www.sciencedirect.com/science/article/pii/S0963868710000028.

[15] M. Corporation. Xpath. https://developer.mozilla.org/en-US/docs/Web/XML/XPath, 2025. Accessed: 15 06 2025.

[16] M. R. De Giacomo, F. Testa, F. Iraldo, and M. Formentini. Does green public procurement lead to life cycle costing (lcc) adoption? *Journal of Purchasing and Supply Management*, 25(3):100500, 2019. ISSN 1478-4092. doi: https://doi.org/10.1016/j.pursup.2018.05.001. URL https://www.sciencedirect.com/science/article/pii/S1478409218301328.

[17] M. de Hacienda. Plataforma de contratación del sector público. https://contrataciondelestado.es, 2025. Accessed: 16 06 2025.

[18] M. dell'Economia e delle Finanze. Acquisti in rete. https://www.acquistinretepa.it, 2025. Accessed: 16 06 2025.

[19] T. M. development team. Matplotlib: Visualization with python. https://matplotlib.org/, 2025. Accessed: 16 06 2025.

[20] European Commission. Strategic procurement. https://single-market-economy.ec.europa.eu/single-market/public-procurement/strategic-procurement_en. Accessed: 13 June 2025.

[21] European Commission. DIRECTIVE 2014/24/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 February 2014 on public procurement and repealing Directive 2004/18/EC. Official Journal of the European Union, 2014.

[22] European Commission. COMMISSION IMPLEMENTING REGULATION (EU) 2019/1780 of 23 September 2019 establishing standard forms for the publication of notices in the field of public procurement and repealing Implementing Regulation (EU) 2015/1986 ('eForms'). Official Journal of the European Union, L 272/7, September 2019. Applies from 14 November 2022.

[23] European Commission. Commission implementing regulation (eu) 2022/2303 amending implementing regulation (eu) 2019/1780 establishing standard forms for the publication of notices in the field of public procurement. Official Journal of the European Union, L 305/12, November 2022. Text with EEA relevance. Done at Brussels, 24 November 2022. Published 25 November 2022. This regulation amends Implementing Regulation (EU) 2019/1780 and repeals Implementing Regulation (EU) 2015/1986.

[24] European Parliament and the Council of the European Union. Regulation (EC) No 66/2010 of 25 November 2009 on the EU Ecolabel (Text with EEA relevance), 2010. Published 30 January 2010.

[25] D. for Administration and F. M. D. of Norway. The criteria guide. https://kriterieveiviseren.anskaffelser.no/, 2025. Accessed: 16 06 2025.

[26] E. C. D.-G. for Environment. Green public procurement. https://green-forum.ec.europa.eu/green-public-procurement_en, 2025. Accessed: 16 06 2025.

[27] P. S. Foundation. Json. https://docs.python.org/3/library/json.html, 2025. Accessed: 20 06 2025.

[28] T. A. S. Foundation. Json. https://maven.apache.org/, 2025. Accessed: 20 06 2025.

[29] T. L. Foundation. Open api initiative. https://www.openapis.org/, 2025. Accessed: 21 06 2025.

[30] P. Gitau. Knowledge-based learning vs performance-based development. https://www.linkedin.com/pulse/knowledge-based-learning-vs-performance-based-ambassador-paul-gitau-qldsf, Jan. 2024. LinkedIn article. Accessed: 16 June 2025.

[31] GitHub. Github copilot. https://github.com/features/copilot, 2025.

[32] GitHub. Openpyxl. https://openpyxl.readthedocs.io, 2025. Accessed: 20 06 2025.

[33] J. Grandia. Finding the missing link: examining the mediating role of sustainable public procurement behaviour. *Journal of Cleaner Production*, 124:183–190, 2016. ISSN 0959-6526. doi: https://doi.org/10.1016/j.jclepro.2016.02.102. URL https://www.sciencedirect.com/science/article/pii/S0959652616300142.

[34] J. Grandia. *Public Procurement in Europe*, pages 363–380. Palgrave Macmillan UK, London, 2018. ISBN 978-1-137-55269-3. doi: 10.1057/978-1-137-55269-3_19. URL https://doi.org/10.1057/978-1-137-55269-3_19.

[35] GreenSpeed. Multi Forte - 5 l. https://www.greenspeed.eu/en-gb/catalog/product/01.03/4002879/multi-forte-5-l/. Accessed: 14 June 2025.

[36] L. Gupta. Rest. https://restfulapi.net/, 2025. Accessed: 20 06 2025.

[37] S. Halsbenning and M. Niemann. The european procurement dilemma-first steps to introduce data-driven policy-making in public procurement. In *2019 IEEE 21st Conference on Business Informatics (CBI)*, volume 01, pages 303–311, 2019. doi: 10.1109/CBI.2019.00041.

[38] K. Harris and S. Divakarla. Supply chain risk to reward: Responsible procurement and the role of ecolabels. *Procedia Engineering*, 180:1603–1611, 2017. ISSN 1877-7058. doi: https://doi.org/10.1016/j.proeng.2017.04.323. URL https://www.sciencedirect.com/science/article/pii/S1877705817318301. International High-Performance Built Environment Conference – A Sustainable Built Environment Conference 2016 Series (SBE16), iHBE 2016.

[39] M. Igarashi, L. de Boer, and O. Michelsen. Investigating the anatomy of supplier selection in green public procurement. *Journal of Cleaner Production*, 108:442–450, 2015. ISSN 0959-6526. doi: https://doi.org/10.1016/j.jclepro.2015.08.010. URL https://www.sciencedirect.com/science/article/pii/S0959652615010999.

[40] M. P. Inc. React. https://react.dev/, 2025. Accessed: 21 06 2025.

[41] V. Z. Inc. Vite. https://vite.dev/, 2025. Accessed: 21 06 2025.

[42] I. B. P. Manuaba and E. Rudiastini. Api rest web service and backend system of lecturer's assessment information system on politeknik negeri bali. *Journal of physics. Conference series*, 953(1):12069–, 2018. ISSN 1742-6588.

[43] R. Namas. How to submit an electronic public tender in spain. quick and easy. https://www.youtube.com/watch?v=hp3Q8g-WigU&ab_channel=RobertoNamas, May 2024. Accessed: June 16, 2025.

[44] B. Neto. Analysis of sustainability criteria from european public procurement schemes for foodservices. *Science of The Total Environment*, 704:135300, 2020. ISSN 0048-9697. doi: https://doi.org/10.1016/j.scitotenv.2019.135300. URL https://www.sciencedirect.com/science/article/pii/S0048969719352921.

[45] N. Obwegeser and S. D. Müller. Innovation and public procurement: Terminology, concepts, and applications. *Technovation*, 74-75:1–17, 2018. ISSN 0166-4972. doi: https://doi.org/10.1016/j.technovation.2018.02.015. URL https://www.sciencedirect.com/science/article/pii/S0166497218301299.

[46] O. of Government Procurement of Ireland. Gpp criteria search. https://gppcriteria.gov.ie/, 2025. Accessed: 16 06 2025.

[47] G. of Netherlands. Mvi criteria tool. https://www.mvicriteria.nl/en, 2025. Accessed: 16 06 2025.

[48] T. . E. P. P. U. P. O. of the EU. eforms sdk repository. https://github.com/OP-TED/eForms-SDK, 2025. Accessed: 15 06 2025.

[49] T. . E. P. P. U. P. O. of the EU. Ted eu public procurement github organization. https://github.com/OP-TED, 2025. Accessed: 15 06 2025.

[50] opensource.org. Open source initiative. https://opensource.org/license/mit, 2025. Accessed: 16 06 2025.

[51] A. Pachamanov, K. Nikolova, K. Hristov, and K. Georgiev. Rehabilitation of street lighting systems according to eu green public procurement criteria. In *2021 Sixth Junior Conference on Lighting (Lighting)*, pages 1–4, 2021. doi: 10.1109/Lighting49406.2021.9599048.

[52] E. Prałat. Public e-procurement tools in european union. *Nierówności Społeczne a Wzrost Gospodarczy*, 58(2):189–196, 2019. ISSN 1898-5084. doi: 10.15584/nsawg.2019.2.14.

[53] Publications Office of the European Union. Tenders Electronic Daily - Supplement to the Official Journal of the EU. https://ted.europa.eu/en/, . Accessed: 14 June 2025.

[54] Publications Office of the European Union. TED Developer Docs. https://docs.ted.europa.eu/, . Accessed: 14 June 2025.

[55] A. Rainville. Standards in green public procurement – a framework to enhance innovation. *Journal of Cleaner Production*, 167:1029–1037, 2017. ISSN 0959-6526. doi: https://doi.org/10.1016/j.jclepro.2016.10.088. URL https://www.sciencedirect.com/science/article/pii/S0959652616316997.

[56] M. Remondino, V. Cantino, and M. Pironti. E-procurement as a driver for strategic management: A discrete-event model. In *2010 Fourth UKSim European Symposium on Computer Modeling and Simulation*, pages 188–193, 2010. doi: 10.1109/EMS.2010.39.

[57] A. Sapir, T. Schraepen, and S. Tagliapietra. Green public procurement: A neglected tool in the european green deal toolbox? *Inter economics*, 57(3):175–178, 2022. ISSN 1613-964X.

[58] P. Sustainability. Simapro: Lca software for informed changemakers. https://simapro.com/, 2025. Accessed: 16 06 2025.

[59] S. D. Sönnichsen and J. Clement. Review of green and sustainable public procurement: Towards circular public procurement. *Journal of Cleaner Production*, 245:118901, 2020. ISSN 0959-6526. doi: https://doi.org/10.1016/j.jclepro.2019.118901. URL https://www.sciencedirect.com/science/article/pii/S0959652619337710.

[60] V. Tanzu. Spring. https://spring.io, 2025. Accessed: 20 06 2025.

[61] U. Trejo. Gpp tool project. https://github.com/users/uritrejo/projects/1, 2025.

[62] U. Trejo. eforms gpp library repository. https://github.com/uritrejo/eforms-gpp-library, 2025.

[63] U. Trejo. eforms gpp service repository. https://github.com/uritrejo/eforms-gpp-service, 2025.

[64] U. Trejo. eforms gpp ui repository. https://github.com/uritrejo/eforms-gpp-ui, 2025.

[65] R. Vidal and N. Sánchez-Pantoja. Method based on life cycle assessment and topsis to integrate environmental award criteria into green public procurement. *Sustainable Cities and Society*, 44:465–474, 2019. ISSN 2210-6707. doi: https://doi.org/10.1016/j.scs.2018.10.011. URL https://www.sciencedirect.com/science/article/pii/S2210670718310795.

[66] Y. Yang and T. Morotomi. When can green public procurement really stimulate eco-innovation? considering the role of intellectual capital. *Journal of Cleaner Production*, 492:144841, 2025. ISSN 0959-6526. doi: https://doi.org/10.1016/j.jclepro.2025.144841. URL https://www.sciencedirect.com/science/article/pii/S095965262500191X.

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