sustainability

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Sustainable Urban Drainage Systems in Spain: A Diagnosis

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Abstract: Sustainable urban drainage systems (SUDS) were almost unknown in Spain two decades ago; today, urban drainage in the country is transitioning towards a more sustainable and regenerative management in a global context where green policies are gaining prominence. This research establishes a diagnosis of SUDS in Spain and examines the extent to which the country is moving towards the new paradigm in three dimensions: (a) the governance and social perception of the community, (b) the regulative background, and (c) the implementation and the technical performance of SUDS. The diagnosis identifies barriers that hinder the change. Then, we define the challenges that Spain has to face to overcome obstacles that delay the transition. Barriers to the governance sphere are related to the lack of involvement, knowledge, and organisational responsibilities. Within the regulative framework, the absence of national standards hinders the general implementation at the national scale, although few regional and local authorities are taking steps in the right direction with their own regulations. From the technical perspective, SUDS performance within the Spanish context was determined, although some shortcomings are still to be investigated. Despite the slowdown caused by the hard recession periods and the more recent political instability, SUDS implementation in Spain is today a fact, and the country is close to reaching the stabilisation stage.

Keywords: SUDS; nature-based solutions; change management; technical performance; legislation; social perception; governance; regenerative policies

Citation: Andrés-Doménech, I.; Anta, J.; Perales-Momparler, S.; Rodriguez-Hernandez, J. Sustainable Urban Drainage Systems in Spain: A Diagnosis. *Sustainability* **2021**, *13*, 2791. https://doi.org/10.3390/su13052791

Received: 4 February 2021
Accepted: 1 March 2021
Published: 5 March 2021

1. Introduction

Urban drainage management has been experiencing a complex evolution in recent decades, from a conventional well-established framework to an emerging new paradigm. Conventional practice of urban drainage often considers stormwater as a waste, therefore focusing on its rapid conveyance into discharging water bodies causing negative environmental impacts. Uncontrolled urban growth and soil sealing worsen these effects [1], as they roughly alter the urban hydrological cycle. More rapid catchment kinetics and higher runoff volumes lead to heavier hydrological urban catchment responses. Therefore, runoff washes more contaminants downstream [2], and, consequently, polluted sewer overflows threaten the quality of the water natural capital and its ecological status [3].

New technologies emerged in the last 30–40 years to cope with the new challenges that urban drainage has to face. Sustainable urban drainage systems (SUDS) are an alternative and supplementary approach to traditional urban drainage practices. SUDS are an innovative strategy for stormwater management and urban planning, aiming at mimicking and restoring hydrological processes existing prior to urban development (infiltration, filtration, storage, evapotranspiration, etc.), by integrating runoff management devices into the urban landscape. Common SUDS techniques comprise green roofs, permeable pavements, filter strips, vegetated swales, infiltration trenches, soakaways, rain gardens, detention and retention basins, and constructed wetlands, among others. The innovation of SUDS when compared to the traditional approach is the placement of equal emphasis on water quantity (controlling the runoff rate and volume [4]), water quality (preventing diffuse pollution [5]), amenity (creating and sustaining better places for people [6]), and biodiversity (creating and sustaining better places for nature [7]), the four pillars of the SUDS philosophy [8]. This approach can help cities transitioning from the traditional approach to a more sustainable urban environment by incorporating SUDS for drainage management [9].

Transition frameworks applied to urban drainage management must provide coherent methodologies to enable cities to adapt their water systems from today's state into a better condition in the future [10]. Nevertheless, the complexity of the urban ecosystem arises as a major challenge to develop the paradigm switch from traditional drainage perspectives to a SUDS-based horizon [11]. As it is strongly dependent on the climate and the local urban environment, the connection with the place for the adoption of best practices, which are conducted with the aim of achieving a regenerative system, is of great importance [12]. Many authors have documented this transition process [13,14], showing that a structured pathway increases the probability of success. The governance context is also important; different studies on transitions in urban water management demonstrate that obstacles to the paradigm switch are largely socioinstitutional rather than technical [15,16]. Therefore, the more the governance context aligns with regenerative policies, the more forceful the transition steps will be.

In Europe, drainage issues in cities have been given increasing attention from policymakers since the Water Framework Directive [17] came into force. Two decades later, the European Union is promoting the European Green Deal, an action plan to boost the efficient use of resources by moving to a clean and circular economy in order to restore biodiversity and to cut pollution. The European Green Deal is an integral part of the Commission's strategy to implement the United Nation's 2030 Agenda and the Sustainable Development Goals (SDG) [18]. Within this context, nature-based solutions (NbS) are gaining prominence. NbS are defined as actions which are inspired by, supported by, or copied from nature; they aim at enhancing sustainable urbanisation, restoring degraded ecosystems, developing climate change adaptation and mitigation strategies, and improving risk management and resilience [19]. SUDS are specific technologies included in the broader NbS concept. Increasing their use is set as a European priority for a better drainage management in *the cities of the future* [20].

In recent decades, the European Union has shown a transition into this new paradigm [21] at very different speeds. The United Kingdom and, especially, Scotland, played a pioneer role for many years, while Denmark and Sweden are today the frontrunners countries in the transition process. Nevertheless, despite a recent take-off, the SUDS paradigm is still limited in Europe [21] and unequally distributed among countries. In the Mediterranean area, experiences are still scarce, with the need to create showcases to demonstrate the feasibility and suitability of new solutions in the long term [12]. Although significant advances have been achieved over the last decades, it is in the very recent years that southern European countries improved their knowledge and experience. Spain and Italy stand out in terms of their recent research efforts, showing that SUDS are drivers of innovation and transition towards a new stormwater paradigm in the Mediterranean [22].

This paper focuses on analysing and diagnosing the stage reached by Spain after two decades of efforts promoting the paradigm shift towards a more sustainable and regenerative urban drainage management. We describe three main levels of the transition process and examine to which extent Spain has transitioned within them. First, we tackle the governance and social perception of SUDS by the community as the dimension at the higher level that demands the change. Then, we analyse the normative and regulative background in which we must embody SUDS. Finally, we present the level of implementation and technical performance of SUDS reached in Spain. The correct steps and enablers, as well as the barriers hindering the process, are documented to finally determine the challenges that the country must face in the near future to strengthen the new approach for smarter integrated urban drainage management.

2. Diagnosis Methodology

The diagnosis presented herein is based on identifying barriers that hinder the change towards a more sustainable and regenerative urban drainage in Spain. Often, physical constraints for change are identified as limits rather than barriers, whereas this last term is usually reserved for sociological and institutional obstacles [23]. The following three categories of barriers were addressed by Hoang and Fenner [24] to analyse systems interactions of stormwater management using SUDS and green infrastructure: physical barriers (limitations in implementation and performance), perception/information barriers (unaccommodating social opinion and prejudices), and organisational barriers (divergent responsibilities amongst involved actors). Brown and Farrelly [15] identified 12 different typologies of socioinstitutional barriers impeding the transition towards sustainable urban water management: an uncoordinated institutional framework; limited community engagement, empowerment and participation; limits of the regulatory framework; insufficient resources (capital and human); unclear, fragmented roles and responsibilities; poor organisational commitment; lack of information, knowledge, and understanding in applying integrated, adaptive forms of management; poor communication; no long-term vision, strategy; technocratic path dependencies; little or no monitoring and evaluation; and lack of political and public will.

The barrier typology and classification used herein to diagnose the challenges that Spain has to face to overcome obstacles that impede SUDS advancement towards the stabilisation stage are as follows (Table 1).

Table 1. Barriers typology and classification (adapted from [15,24]).

Barrier Dimension		Barrier Classification
(a)	Social and governance dimension	a.1. Low community engagement and participation. a.2. Isolated roles and responsibilities. a.3. Lack of technical information dissemination.
(b)	Regulatory framework dimension	b.1. Uncoordinated institutional framework. b.2. Limits of the regulatory framework. b.3. Lack of political and public will.
(c)	Technical dimension	c.1. Insufficient resources. c.2. Lack of monitoring and evaluation. c.3. Reluctance regarding long-term efficiency.

The analysis of the social/governance and technical dimensions was carried out by a systematic literature review. Keywords used were as follows: "Sustainable Urban Drainage Systems" OR "Sustainable Drainage Systems" OR "Low Impact Development" OR "Water Sensitive Urban Design" OR "Innovative Stormwater Management" OR "sustainable stormwater systems" AND "Spain". The search was performed on the Web of Science with the following specific settings: timespan = all years; selected databases = Web of Science Core Collection; region = Spain. The query returned 54 items. An analysis of the year of publication of these references shows a rapid overview on how SUDS research has evolved in the country: 1 reference in 2003, 1 in 2005, 12 between 2010 and 2015, and 40 since 2016, highlighting a strong take-off of the topic in the last 5 years. The literature review in this research was completed with other publications, mainly from Spanish non-indexed journals. It is worth mentioning the special issue "Consolidating sustainable drainage in Spain" published in 2019 by the journal *Revista de Obras Públicas*, a reference for civil engineering publications in Spanish. In addition, reports of R&D projects were analysed and reported.

The analysis of the regulative background was performed by direct analysis of laws, regulations, and guidelines of application in Spain. European directives and documents were accessed at the EUR-Lex and EU Publications sites of the Publications Office of the European Union. Spanish laws were accessed on the official State gazette site (Boletín Oficial del Estado), whereas regional and local documents were accessed on the respective public websites.

Finally, the political and economic contexts were added into the discussion, as they have both conditioned the evolution of SUDS technologies in Spain in recent years. Given these contexts and the identified barriers, the challenges for the near future were identified.

3. Social Perception and Governance for the Paradigm Switch

Over the last decades, barriers hindering SUDS implementation have been overcome at different speeds in different countries. Major efforts have been made in regard to the technical performance of SUDS. In parallel, the normative and regulative framework is growing, although great efforts are still needed. Nevertheless, social perception of SUDS and governance issues have not been paid enough attention to in recent years, at least in Spain, with very few experiences of community participation.

Conventional urban stormwater systems are mainly centralised, both from the technical and operational perspectives. Urban drainage with SUDS comprises a multidisciplinary group of stakeholders that aligns with the decentralised approach of the problem. Multiple actors associated with stormwater management can be classified according to different factors (origin, profession, interest, etc.) Specifically, the categorisation known as the quintuple helix stands out, since it is usually used as a formula for innovation in territorial management. According to this classification, four groups are distinguished into the fifth element, the environment: government, academia, industry, and civil society. For boosting sustainable stormwater management, the involvement of all stakeholders is needed, especially to consider their perceptions and to achieve common and consensual solutions [25].

Involving stakeholders in a collaborative framework to better design technical solutions was the purpose of the project "Collaborative transition towards sustainable urban drainage: making it happen at district scale" [26], the first well-known initiative of this type in Spain. With the aim of designing the drainage strategy in a neighbourhood in the city of Castellón (Valencian Community), collaborative sessions were conducted to establish the subject focus; identify and facilitate stakeholders; describe problems and issues; and finally, develop the long-term integrated vision. A collaborative, multi-actor approach for defining the optimal strategy for sustainable and adaptive stormwater management is needed and demanded by society to provide assistance in overcoming barriers for the transition to better urban environments [27]. A remarkable achievement was the formation and work undertaken by the collaborative group of actors involved in urban stormwater management formed by key local and regional actors, from technicians and politicians to neighbourhood citizens. The latter were key actors in the establishment of the baseline and shared their district knowledge in the identification of the best solution. The main goal defined during the sessions was bridging the gap between pilot to district-city implementation of SUDS. To do so, during three collaborative sessions, different objectives were progressively reached: identification of baseline conditions; listing of shortcomings; definition of the vision for the pilot city; cataloguing of potential SUDS typologies to be considered for the pilot district, locating SUDS implementation, discussion of results from multicriteria analysis of solutions, and identification of actions at the mid and long term. The group boosted dissemination of the benefits that SUDS bring, contributing to enhanced urban environments from the environmental and social points of view.

Within the context of the above-mentioned research project, a questionnaire was developed to better assess the needs at the local and regional levels [28]. Among the respondents (44), 56.8% were local administration, 11.4% were water companies, 9.1% were consultants, 2.3% were researchers, 2.3% were construction companies, 2.3% were national administration, and 6.8% were regional administration (9.5% corresponded to other profiles). Most of the respondents were municipal authorities and, in particular, technical profiles. For context, two questions opened the questionnaire: (a) Do you know what SUDS are? and (b) Do you think SUDS help in mitigating the climate change effects? Figure 1 shows the results of these two questions. The survey also asked for the main motivations for implementing SUDS. The main responses were runoff quality improvement, flood risk reduction, urban landscape improvement, infiltration and aquifers recharge, and natural environments creation and biodiversity enrichment.

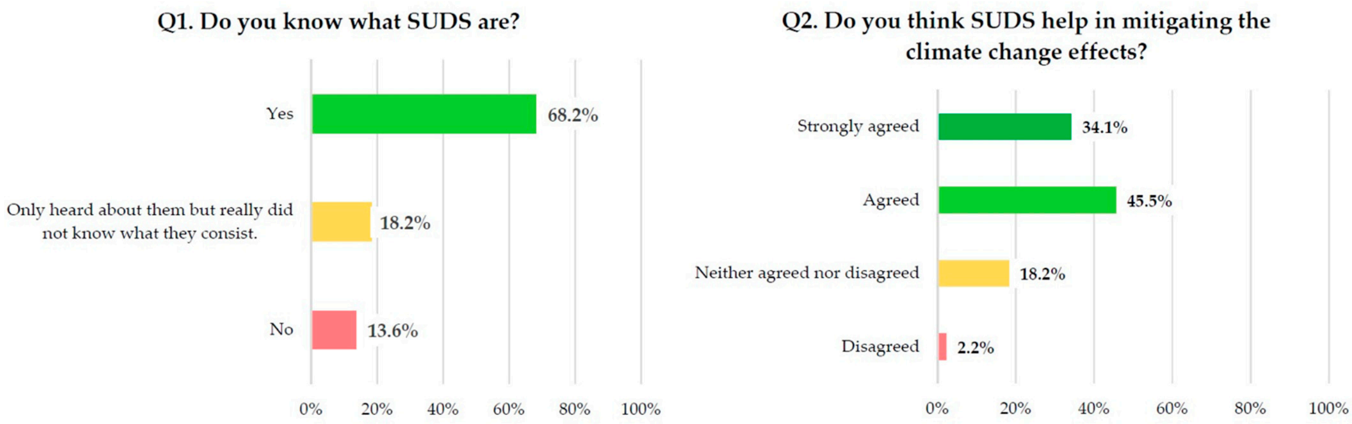

Figure 1. Results of the context questions within the survey developed in the project "Collaborative transition towards sustainable urban drainage: making it happen at district scale" [28].

This questionnaire also asked participants about the main barriers for SUDS implementations. Respondents identified as the main problems the uncertainty about costs and the lack of information regarding lifespan and maintenance needs of SUDS infrastructures.

The importance that neighbours can give to SUDS when exploring new ways to manage urban runoff was also highlighted by other authors in Spain [29]. The social experience developed in Cáceres (Extremadura) revealed the importance given by citizens to new solutions to face water management under uncertain climate change scenarios. This study also demonstrated that SUDS are perceived by citizens as "amenity providers", which empowers the non-hydraulic pillars of SUDS, amenity, and biodiversity. The result of such perceptions is that SUDS are evolving into a real alternative for urban runoff management, increasingly endorsed by all stakeholders and, no less important, understood by citizens [22].

The experience at Bon Pastor district in Barcelona city also reveals a high level of involvement during the design process [30]. As a result, citizens assumed sustainability as a major driver for future retrofitting actions. Nevertheless, this case also highlights one of the most important operational barriers at local scale: the responsibility of maintenance of SUDS. The usual isolation of services within local authorities (usually organised as silos, such water services, gardening, and urban planning) does not help to adopt coordinated strategies to manage and maintain SUDS infrastructures during their operational life.

The participation of all actors involved within the urban water cycle is needed to effectively promote the paradigm shift. It is necessary to consider their different perceptions and try to achieve integral and agreed solutions. The paradigm shift affects all levels, although the enablers of its integration may vary at different scales. Table 2 sums up factors involved to enhance the social perception of SUDS at different scale levels according to experiences developed in Spain [25].

Table 2. Factors to improve social perception of sustainable urban drainage systems (SUDS) (adapted from [25]).

Level	Factor
National	Collaborative networks involving governance actors. Conferences and workshops to share knowledge. Roadmap at the national scale.
Regional	Regional working groups to focus on the problem. Creation of supramunicipal alliances to boost replicability. Promotion of technical training.
Local	Integral management with effective relations between involved services. Development of strategic action plans for stormwater management. Educational activities to improve SUDS knowledge.
Neighbourhood	Involvement of the community and social actors. Sharing of SUDS pilot performance with citizens. Promotion of SUDS as enhanced solutions for amenity and biodiversity.

Knowledge networks are powerful tools that can be used to boost a paradigm switch and to encourage new forms of innovation. In 2004, Coventry University and the Urban Water Technology Centre at Abertay University (United Kingdom) launched a national network in the UK, SUDSnet, to help academia and the industry to communicate effectively about SUDS. Following the path of the British experience, the twin Spanish network RedSUDS was born in 2008 from a dissemination project developed by the GITECO group at the University of Cantabria. During the years of the economic crisis, RedSUDS decreased its activity. In 2016, in association with the Polytechnic University of Valencia and Green Blue Management, RedSUDS was re-launched with the objective of consolidating a group of professionals interested in SUDS to promote the change in Spain and to overcome the existing barriers.

RedSUDS organised a national meeting in 2017, "Challenges and future of SUDS in Spain". The event was a huge success with participation of more than 200 attendees from the administration, industry, university, and research centres. The Spanish National Government highlighted during the meeting the importance of a basic regulatory framework for the development of actions, as well as the importance of collaboration between administrations to go further together. The role of SUDS for urban retrofitting and regeneration processes was discussed. A high consensus was reached for its gradual implementation since the key for urban regeneration lies in the strong commitment to green infrastructure [25]. After the meeting, the National Government organised bilateral technical meetings with regional and local authorities and academia to collect feedback for SUDS implementation in Spain. These meetings put the topic on the agenda at the highest level. Nevertheless, the political instability in Spain since 2018 has hindered the process.

After the 2017 meeting, the network committed to meet every two years in order to maintain the focus group of SUDS in Spain. In 2019, the Universidade da Coruña joined the organising committee of the event. The 2019 meeting highlighted the gradual consolidation of SUDS in Spain, with the participation of representatives of the national, regional and local governments, as well as the industry and research centres. RedSUDS highlighted the quintuple helix model and put the environment at the top of the list of priorities, as demanded by society. To achieve the goals regarding regenerative development, the normative and regulative framework must ensure the right context to boost the green paradigm in urban drainage. The British experience of SUDSnet and its Spanish twin are excellent examples of how a network of professionals on a specific subject can effectively contribute to the management of the transition, but unfortunately, they are not enough.

4. Normative and Regulative Background

The Spanish regulatory and institutional framework for urban drainage is a complex issue, as in other many countries. This complexity is inherent with the distribution of powers between the national government, the different regional governments, and local authorities. In addition, the whole system is under the umbrella of the European legislation that sets the general rules. Therefore, the analysis of the Spanish legal framework on urban drainage must be fourfold: the European, national, regional, and local levels.

4.1. The European Umbrella

Two decades ago, Directive 2000/60/CE [17] represented the most important improvement regarding environmental legislation related to water within the European Union. The Water Framework Directive (WFD) offers a general background for action in the field of water policy and, specifically, the principle that marks all further legislative development, including that of urban drainage. The WFD established the need to identify and assess pressures and impacts on the receiving water bodies. Stormwater; emergency overflows; and, specifically, urban drainage (including runoff) were identified as pollution sources [31]. Consequently, urban drainage, in terms of its broader definition, must be considered to preserve the good ecological status of receiving water bodies.

Since the WFD came into force, other European Directives related to urban drainage systems were developed. Some examples are water Directive 2006/7/CE [32] or groundwater pollution Directive 2006/118/CE [33]. Both directives affect to urban drainage management, recognising the impacts caused by stormwater discharges from combined or separate sewer systems.

In addition to the previous Directives, the earlier Urban Wastewater Treatment Directive (UWTD) 91/271/EC [34] requires that all flows reaching a combined network be treated. In addition, discharges to the receiving environment must be minimised, by limiting overflows in extreme situations such as unusually heavy rainfall.

Beyond the directives, there are European recommendations and strategies that regard important aspects for the implementation of the regulatory framework on urban drainage. "Guidelines on best practice to limit, mitigate or compensate soil sealing" [1] promote the use of permeable materials and surfaces, green infrastructure, and natural water harvesting systems to maintain some of the soil pristine functions. The EU Green Infrastructure strategy [35] highlights the great possibilities that green infrastructure offer for urban regeneration. In addition, it fosters stormwater and flood risk management through green infrastructure since it promotes the creation of multifunctional landscapes and spaces within the city.

Increasing urban runoff overloading caused by climate change and ongoing soil sealing in urban areas results in higher flooding risks and combined sewer overflow (CSO) and stormwater runoff pollution, enhancing ecological impacts on the aquatic systems [36]. Despite the improvements already made, significant investment is needed in urban drainage systems to maintain an acceptable functioning of the systems, as stated by the recent evaluation of the UWTD [37]. In this report, which was performed in parallel with the fitness of check evaluation of the WFD and the flood directive [38], urban runoff and CSO are considered as a main source of the deterioration of the ecological status of the water bodies. About 60% of surface water bodies do not achieve the "good" ecological status required by the WFD [39]. In addition, illicit intrusions into the sewage networks are recognised as an increasing problem, being even illegal as in Spain or Italy [40]. The optimal location of monitoring points within the system can help to identify pollution sources, as well as to quantify the impact of CSOs into the environment.

In late 2019, the European Commission launched the European Green Deal [18], an integral part of the strategy to implement the United Nation's 2030 Agenda and the SDG of United Nations. The Green Deal is an ambitious plan to tackling climate and environmental-related challenges. The plan specifically mentions the need to address water pollution from urban runoff and prevent and minimise flooding effects. This challenge related with urban drainage is at the top priorities of the European institutions.

4.2. The National Framework: From Top to Bottom

The Spanish national legislative framework on water-related issues began to be established in the early 19th century and was finally launched when the first Water Acts came into force in 1866 and 1879. The current situation began to develop during the mid-1980s, when the first Water Act of the recovered Democracy was approved. Spanish national legislation on water is composed of a set of different laws and regulations. The reference standard is the current Water Act [41]. This law presents the legal framework for the public hydraulic domain in regard to water quantity, uses, protection, and planning within the river basins that are directly managed by the central administration. However, this law does not have any specific aspects regarding stormwater management or urban drainage.

In 2012, a law modifying the regulations for the public hydraulic domain [42] came into force. This law supposes a strong milestone in urban drainage in Spain: the need for management for sewer systems overflows during rainy weather. All new urban development projects must not only consider the convenience of having combined or separate networks but must also adopt measures to limit stormwater conveyance into the sewer system and limit the production of first flushes to reduce the mobilisation of pollution during rainfall episodes. Although the modification of the regulations for the public domain did not explicitly name SUDS, they are implicit within measures to promote urban runoff control at the source and CSO reduction. In addition, this law calls the Ministry of Environment to dictate the technical standards to define the environmental objectives and technical guidelines to design specific measures and manage stormwater control systems. As we will later discuss, this issue is still a challenge for the country.

SUDS were finally considered in the national legislation in 2016 [43]. This new Royal Decree (638/2016) modified the regulations for the public hydraulic domain, the regulation of hydrological planning, and other regulations regarding the management of flood risks, ecological flows, hydrological reserves, and wastewater discharges. Specifically, the law states that new industrial estates and urban developments must introduce sustainable drainage systems, such as permeable surfaces, to reduce the risk of flooding. The law introduces the principle of hydrological invariance, and it establishes the situations where SUDS are compulsory within the country. In addition, the Instruction for Hydrological Planning [44] emphasises the need to consider and evaluate diffuse and point pollution sources. This text specifically considers pollution sources from stormwater overflows in urban areas, industrial estates, or roads.

This national framework provides the general rules for regional and local governments to develop their own regulations. The complexity of the territorial organisation of the country leads to different views and scopes in regard to facing the problem.

4.3. The Regional Governments: An Approach to Mid-Scale Solutions

Regarding urban drainage issues, regional governments have responsibilities related to urban planning, environment, water treatment, and water management on intra-region river basins (inter-region basins are responsibility of the national government). Regional governments suppose a link between the central government and the local authorities, which, in the end, are responsible for urban drainage management.

Table 3 shows regulations and guidelines developed in some regions of Spain. At the more ambitious level, areas such as Canarias or Región de Murcia have adopted a law requiring the compulsory usage of SUDS in new urban developments. The motivation that boosted Región de Murcia to adopt this obligation by law is related to the ongoing policies to restore the degraded environmental status of the “Mar Menor”, a coastal saltwater lagoon threatened by polluted agricultural and urban runoff overflows into the water body. SUDS have been recognised as a potential solution for the surrounding urban areas. At an intermediate level, regions such as Comunitat Valenciana, Comunidad de Madrid or Galicia have developed regulations promoting (but not compelling) the use of SUDS. The technical approach is detailed in the cases of Galicia or Madrid, whereas the documents of Comunitat Valenciana limit their scope to a mere recommendation. Finally, other regions have promoted the edition of guidelines (Catalunya and Euskadi) that identify SUDS as solutions for better stormwater management.

Table 3. Main regional regulations (R) and guidelines (G) in Spain related to SUDS.

Year	Region	Climate [1]	Type	Scope and SUDS Implications	Reference
2005	Euskadi	Cf	G	Manual for urban planning with sustainability criteria. SUDS are key elements for a better urban drainage management.	[45]
2009	Galicia	Cf Cs	R	Technical guidelines for hydraulic infrastructures. Sets criteria for integrating SUDS and technical details.	[46]
2010	Euskadi	Cf	G	Guidelines for the sustainable development of urbanisation projects. Promotes rainwater harvesting and the use of SUDS for infiltration.	[47]
2011	Catalunya	BS Cs Cf Df	G	Guidelines for rainwater harvesting.	[48]
2014	Comunitat Valenciana	BS Cs	R	Law for territorial planning, urban planning, and landscape. Green infrastructure is promoted in urban and developable areas.	[49]
2015	Comunitat Valenciana	BS Cs	R	Territorial action plan on flood risk prevention in the Valencian Region. The regulative documents promote the use of SUDS for urban drainage management.	[50]
2015	Canarias	Cs BW	R	Regulation of hydrological planning in "El Hierro". SUDS are compulsory in new urban developments.	[51]
2015	Región de Murcia	BS BW	R	Modification of law for territorial and urban planning (2015). Eco-efficiency criteria for climate effects mitigation and re-naturalisation: use of SUDS.	[52]
2016 [2]	Comunidad de Madrid	BS Cs	R	Regulations for sewer systems. Includes technical recommendations for SUDS implementation.	[53]
2019	Región de Murcia	BS BW	R	Law for the adoption of urgent measures for environmental sustainability of the "Mar Menor". Prioritisation of SUDS for stormwater runoff control into the sea.	[54]

[1] Climate types according to the second-order Köppen classification [55]; BS = arid steppe; BW = arid desert; Cs = temperate with dry period in summer; Cf = temperate without dry period; Df = cold with temperate/fresh summer. [2] Regulations updated in 2020.

4.4. The Local Level: Regulations and Direct Legislation

The European, national, and regional regulatory framework must finally be detailed in the local legislation on urban drainage. In Spain, municipalities have full competences in urban sewage and stormwater management. In recent years, many local authorities have started to incorporate SUDS into their own legislation to align with the supra-municipal regulatory background. Table 4 compiles the main regulations and guidelines developed in some of the main cities of Spain (>100,000 inhabitants).

Table 4. Main local regulations (R) and guidelines (G) in Spain incorporating SUDS.

Year	City	Type	Scope and SUDS Implications	Reference
2004	Girona	R	Regulations for sewage and drainage systems. Requires rainwater harvesting. Promotes infiltration and retention to control hydrological impact of urbanisation.	[56]
2006	Madrid	R	Water management and efficient use ordinance. Sets minimum threshold of permeable pavements in public spaces.	[57]
2007	Madrid	G	Guidelines for sustainable green areas. Promotes rainwater harvesting, infiltration, and the use of permeable pavements.	[58]
2012	Santander	R	Incorporation of environmental prescriptions into the general urban development plan. New prescriptions include obligation of using SUDS like permeable pavements or infiltration techniques.	[59]
2015	Valencia	R	Regulations for sewage and drainage systems. Promotes the use of SUDS in new developments.	[60]
2015	Barcelona	R	Technical criteria for the sewage network. Promotes the use of SUDS in new developments.	[61]
2018	Madrid	G	Technical manual for SUDS design in green and public spaces. Establishes quantity and quality standards for SUDS design.	[62]
2019	Castellón	G	Technical manual for SUDS design. Promotes drainage management through SUDS, both in public and private spaces. Establishes quantity and quality standards for SUDS design.	[63]
2019	Sevilla	R	Technical instructions for sewage systems. Regarding drainage management, the document fixes a maximum flowrate to be released downstream. Promotes the use of SUDS to achieve this objective.	[64]
2020	Barcelona	G	Technical guidelines for SUDS design	[65]

The main cities in Spain are adopting local rules for SUDS implementation. The degree of obligation is still very uneven, from strong limitations for stormwater management like in Sevilla to just recommendations as in the case of Valencia. Nevertheless, all these cities are putting considerable effort into updating their regulative framework to include specific regulations for SUDS implementation.

Society demands a change to a greener drainage, and the regulatory framework must ensure the legal conditions to promote the transition. Spain has taken the experiences of many other countries that began the change before, but a lot of work still has to be conducted to overcome the institutional barriers regarding the implementation and performance of SUDS in the country.

5. Implementation and Technical Performance of SUDS

5.1. Implementation of SUDS in Spain

In 2002, the University of Exeter led the Daywater EU funded project (adaptive decision support system for the integration of stormwater source control into sustainable urban water management strategies) [66,67], which presented a review of the use of best management practices (BMPs) in Europe. The report concluded that "the use of BMPs in Southern European countries, such as Greece, Italy, Spain and Portugal, is limited. However, interest in their use appears to be growing". Focusing on Spain, the report highlighted that rainfall patterns of Mediterranean areas, more irregular and torrential than those in Northern Europe, were a concern for SUDS development in southern Europe. Nevertheless, interest in SUDS in Spain was taking off at that time, and experience after almost two decades proves that even under Mediterranean rainfall conditions, SUDS are an efficient solution to improve urban drainage management.

One of the first experiences in Spain documented in the literature was developed 22 years ago. It consisted of a system of vegetated swales and detention basins for the drainage management of a 300,000 m^2 industrial area [68]. At that time, SUDS were almost unknown in Spain; nevertheless, the developer of the industrial estate was a French company, and because of their influence, SUDS were demanded for implementing stormwater management in the area. Since then, SUDS have been progressively introduced in Spain. Table 5 sums up some of the most relevant implementations in the country. Figure 2 shows some of the most recent examples of SUDS implemented in Madrid, Ribarroja, Sevilla, and Benicàssim.

Table 5. SUDS in Spain. SUDS techniques: permeable pavement (PP), green roof (GR), filter drain (FD), infiltration tank (IT), vegetated swale (VS), bioretention systems (BS), infiltration basin (IB), detention basin (DB), and sand filter (SF).

Year	Location	SUDS Types	Description	Reference
1998	Sant Boi (Barcelona)	VS, DB	Industrial area (30 ha)	[68]
2003	Parque Gomeznarro (Madrid)	PP	Pedestrian impervious pavement replacement	[69]
2005	Sports Centre (Gijón)	PP	22,000 m^2 parking area (new development)	[70]
2005	Torre Baró (Barcelona)	PP, FD, DB	First implementation of SUDS in Barcelona at district scale	[71]
2007	Parque Cristina Enea (San Sebastián)	FD, IT	Urban park (9.50 ha)	[62]
2008	Las Llamas Park (Santander)	PP	1100 m^2 experimental parking area	[70]
2009	Parc Joan Reventós (Barcelona)	FD, DB, IT, IB	Urban park (2.80 ha)	[70]
2011	Benaguasil and Xàtiva (Valencia)	GR, PP, IB, DB, VS	Pilot showcases developed to gather data under Mediterranean climate	[12,70,72]
2012	Fene (A Coruña)	SF	Highway runoff (0.94 ha)	[73]
2014	Avenida Gasteiz (Vitoria)	PP, FD	Urban retrofitting	[74]
2015	BBVA headquarters (Madrid)	GR, PP, FD, IT	Green area of the building complex.	[62]
2015	Parque La Marjal (Alicante)	DB	Flooding prevention in an urban park	[75]
2016	Alfonso XIII street (Madrid)	BS, IB, DB, FD	Urban park (0.20 ha)	[62]
2016	Valdebebas (Madrid)	PP, IT	New residential development including green areas (1065 ha)	[76]
2017	Wanda Metropolitano Stadium (Madrid)	PP	108,000 m^2 parking area (new development)	[77]
2017	Parque Logístico Valencia (Ribarroja del Turia)	BS, VS, IB	Private industrial area	[78]

Table 5. *Cont.*

Year	Location	SUDS Types	Description	Reference
2018	Avenida El Greco (Sevilla)	PP, FD, BS	Urban retrofitting	[79]
2018	Parque Central (Valencia)	FD, IT	Urban park (8.60 ha)	[80]
2018	Torre en Conill and Mas Camarena residentials (Bétera)	FD, IT	Flooding prevention in a residential area	[81]
2018	Torre de S. Vicent street (Benicàssim)	PP	Urban retrofitting with reuse of ceramic material	[82]
2018	La Atalayuela (Madrid)	PP, FD, BS	Urban park (9.40 ha)	[83]

(a) (b) (c) (d)

Figure 2. (**a**) Infiltration–detention basin in Alfonso XIII park (Madrid); (**b**) infiltration trench in Ribarroja; (**c**) bioretention systems and permeable pavement in Sevilla; (**d**) ceramic permeable pavement in Benicàssim.

After two decades of SUDS implementation in Spain, sustainable drainage solutions are becoming more familiar to municipal practitioners and politicians. To achieve this take-off, research on SUDS is of paramount importance; demonstrations of good performances from the quantity and quality perspectives are crucial to promote this change with solid steps.

5.2. Research on SUDS Technical Performance

After some experiences in the 1990s with alternative stormwater drainage techniques in Santander and Barcelona, SUDS research in Spain focused on permeable pavements. Initial research projects on SUDS and, specifically, on permeable pavements, have been developed since 2003 in the University of Cantabria. GITECO Research Group, with the collaboration of Coventry University (UK), designed different test equipment and methodologies that have become a reference over the years [69].

The research developed in the experimental car park at Las Llamas Park (Santander) was an important milestone [84]. A total of 45 parking lots were built with different permeable materials and configurations to analyse their performance regarding water quantity and quality. The results show the ability of permeable pavements to enhance urban drainage management; these results were, at that time, of great importance to overcome barriers questioning SUDS performance. Quantitative analysis showed that surface materials are influential on the overall response of permeable pavement.

Clogging is always an issue for research on permeable pavements. This phenomenon directly affects the loss of infiltration capacity of this type of SUDS. Many studies have been conducted in recent years regarding this topic. Sañudo-Fontaneda et al. characterised clogging on interlocking concrete block pavements, proving that the surface slope of the pavement influences the clogging process: the flatter the surface, the less influence of clogging [85]. Further research on clogging considered porous concrete and porous asphalt surfaces [86]. The results show less reduction in infiltration capacities for porous concrete surfaces rather than for porous asphalt under the clogging scenarios analysed.

After 10 years of operation of the car park lots at Las Llamas Park, an end-of-life analysis of the infrastructure was conducted [87]. The research concluded that parking spaces constructed with porous concrete or porous asphalt were fully blocked after nine years of operation without any maintenance, in part due to mistakes during construction and ageing of the construction materials used. Nevertheless, those constructed with interlocking concrete blocks showed high infiltration rates after the same period and under the same (non)maintenance conditions. These results highlighted the paramount importance of construction materials selection, quality control during execution, and maintenance activities to preserve permeable pavements hydraulic properties.

The influence of initial moisture conditions of the permeable pavements can also be determinant for the hydraulic response. With porous concrete surfaces, the initial infiltration rates tested in unsaturated conditions were near to ten time higher than those corresponding to saturated moisture conditions [88]. These results show that the long-term hydraulic efficiency of permeable pavements might be different depending on the rainfall conditions and on the consequent dry–wet periods. When a permeable pavement response under two different climatic conditions is analysed, only varying the frequency of rainfall events, the same conclusions arise [89]. A long dry period before a rainfall episode increases the hydraulic infiltration and retention capacity of the permeable pavement.

Regarding the use of innovative construction materials, recent studies for replacing cement with other alternative materials in continuous cement-based porous surfaces have shown that replacing up to 5% of cement with metakaolin increases permeability [90]. Nevertheless, an increase in this proportion seems to be counterproductive; hence, much research is needed to accurately characterise these possibilities of cement replacement.

A great challenge for SUDS research in Spain was to demonstrate that, even under Mediterranean rainfall conditions, SUDS can improve urban drainage management. Overcoming this technical barrier was the main objective of the AQUAVAL project, developed between 2010 and 2013. Seven SUDS pilots (permeable pavement, green roof, infiltration basin, detention basin, vegetated swale, rainwater harvesting tank, and bioretention area) were constructed in Xàtiva and Benaguasil (Valencia region) and monitored for more than a year [12,22,72]. The results show great performances from the quantity and quality perspectives. For instance, permeable pavements reduced runoff production over 90%.

Some necessary design adjustments generated valuable lessons learned for the future to improve construction and maintenance of SUDS in the Mediterranean region.

Innovative solutions for permeable pavements made of reused low commercial ceramic material demonstrate that SUDS are technologies well aligned with the circular economy principles [82], again showing excellent performance: 86% average reduction of runoff production, 70%–100% peak flow reduction, and up to 90% retention of the chemical oxygen demand (COD). The Life-CERSUDS project has been recognised by the European Union as an example of an innovative strategy that improves urban resilience to climate change by promoting water infiltration and reuse.

Southern Spain also needs overcome the climate barrier for SUDS implementation. Research developed at the University of Granada compared the response of different types of permeable pavements under real rainfall conditions [91]. Hydrological efficiencies over 80% were reported for volume management, whereas the highest performance was achieved for peak flow reduction (over 95%). Moreover, significant increases in water residence times were proven (70%).

Beyond permeable pavements, green roofs have shown good performance in Spain. After one year of monitoring, Andrés-Doménech et al. reported hydrological efficiencies between 53% and 100% in Xàtiva and Benaguasil (Valencia) [22,92]. Such values indicate that green roofs are effective at source, even under Mediterranean conditions. Indeed, retrofitting half of the conventional roofs of a densely urbanised area into green roofs would lead to a reduction of 75% of the runoff production at the city scale for the more frequent rainfall episodes [92]. Additionally, green walls have recently been studied and monitored [93], with researchers showing how alternative substrates like coconut fibre mixed with rice husk can reduce common impacts caused by usual growing media based on moss.

Other types of SUDS have also been the subject of attention, but to a lower extent. The performances of a concrete conventional ditch, a vegetated swale, and a filter drain in linear drainage in a car park in Oviedo were compared [94]. Total suspended solids (TSS) were reduced by 76% in the filter drain and by 56% in the vegetated swale. Turbidity was reduced by 59% and 54%, respectively. Detailed analysis of polluted runoff suggests that SUDS mainly based on retention (rain gardens, bioretention areas, detention basins, or wetlands) are appropriate to manage first-flush events [2] and remove about 90% of sediment loads [95].

Although good performance indicators have been shown within many monitored SUDS infrastructures, monitoring programs are still scarce as they usually depend on funding related to research projects that do not last more than 2–3 years. More ambitious monitoring plans are required to assess the long-term performance of SUDS and to quantify their end of life in order to better define the proper maintenance and conservation strategies.

6. Challenges for the Near Future

Besides social, governance, regulatory, and technical barriers, the paradigm switch towards a sustainable and regenerative urban drainage is also conditioned by the political and economic contexts. Figure 3 shows the general situation from these two perspectives and how SUDS deployment in the country has been unfolding. The figure also shows SUDS achievements in Spain over the last three decades. This analysis shows how the general context of the country has directly affected SUDS evolution in Spain.

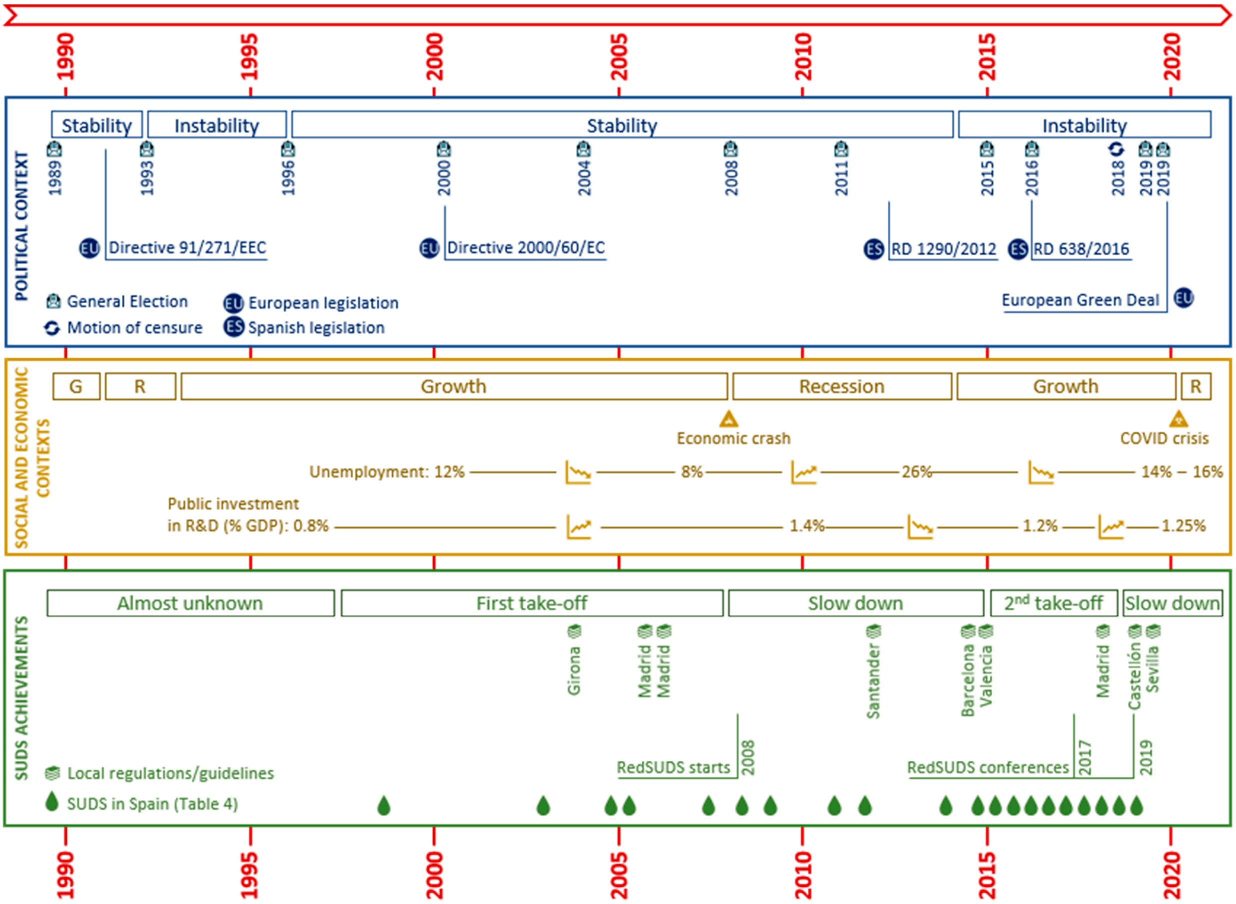

Figure 3. The evolution of SUDS in Spain in the framework of the political and socioeconomic contexts (1990–2020).

Almost until the late 1990s, SUDS were not known in Spain. Some isolated experiences (Barcelona and Santander) were developed during this period, and research on SUDS began, especially in relation to permeable pavements, with knowledge imported from the UK. During the following decade, SUDS experienced their first take-off in Spain. Large and ambitious R&D projects, with national and European funds, were developed during these years, overcoming mainly technical barriers. During this decade, SUDS techniques were also recognised as key elements needed for integrated stormwater management in separate and combined sewerage systems at the national level [96]. In 2008, the economic crash strongly hit Spain, and the consequences on investments were dramatic. Public resources in R&D decreased for the first time in 15 years and did not reach the same level until 2020. In addition, investments on public works also suffered strong cuts at the national, regional, and local levels. Consequently, SUDS implementation slowed down during the 2008–2014 recession.

After 2015, an apparent economic positive context has coexisted with an instable political period, with four general elections in the national government in a five-year period. As a result, the 2015–2018 period represented a second take-off for SUDS, with the consolidation of research, the implementation of the RedSUDS network at the national level, and the most determined implication of the national authorities in SUDS-related issues. In fact, one of the few technical guides promoted at the national level regarding sustainable water management in built environments was published in 2015 [97], although its scope and impact have been limited. The political changes since 2018 stopped any further initiative at the national level. Although RD1290/2012 called on the Ministry of Environment to dictate the technical standards to define the environmental objectives and technical guidelines to design and manage stormwater control systems measures, the country is still developing these standards to provide a uniform roadmap to tackle urban drainage challenges at the national scale. Fortunately, within the same context, some local guidelines and regulations have been developed; indeed, the local level is, at present, the most pro-active towards SUDS implementation in Spain.

Considering that in 2008, the economic crash and the following recession were responsible for the first slowdown period, and ten years later, since 2018, the high political instability caused the second slowdown period. The main required conditions to face these challenges in the near future are economic prosperity and political stability. Both are difficult to ensure nowadays considering the pandemic situation.

The evolution of SUDS in Spain is taking advantage of many lessons learned from other, more SUDS-advanced countries, especially on the technical level. Nevertheless, some governance best practices showing good results abroad are still reluctant to be adopted here. A paradigmatic example is the imperviousness fee in Germany, as part of an integral strategy to advance urban green infrastructure [98]. As a common practice, the wastewater fee is estimated based on the drinking water demand, which has been largely recognised as unfair. The change has been taking place decisively since the 2000s to effectively consider the runoff amount released per property [99]. Furthermore, in this sense, in the UK, the development of a large regulatory framework and the publication of technical guidance arise as strategical drivers for change [100]. As mentioned above, today, one of the main barriers impeding the transition at the national level is the lack of national standards developing the general technical criteria for design. From the technical perspective, SUDS performance within the Spanish context has been proven, although some shortcomings are still to be investigated (i.e., end of life and long-term performance). Thus, some technical challenges must be also tackled before achieving the stabilisation stage. Nevertheless, SUDS in Spain, after two decades since the first take-off, are a fact. The national regulative framework faces difficulties, but regional and local governments are taking steps in the right direction.

Table 6 presents the main challenges and their drivers for SUDS implementation in Spain, according to the barriers categorised within the three analysed dimensions herein: social/governance, regulative, and technical barriers. As other authors [15,16] have already recognised, the most challenging barriers to overcome are within the governance and regulative spheres rather than within the technical field. Indeed, the latter are mainly impeded by the lack of economic resources. Nevertheless, social and regulative barriers are related to human behaviours and attitudes and are more difficult to change, especially in a well-established discipline such as urban drainage management.

Table 6. Challenges and enablers of SUDS implementation in Spain, according to barriers presented in Table 1.

Dimension	Barriers	Challenges	Enablers
Social/Governance	a.1. Low community engagement and participation.	Increasing citizenship public participation.	Community involvement; proactive authorities.
	a.2. Isolated roles and responsibilities.	Need for protocols and coordination between municipal services.	Maintenance of SUDS as an opportunity for municipal services coordination.
	a.3. Lack of technical information dissemination.	Increasing awareness about multiple benefits of SUDS; promotion of a citizen science approach.	Green sensitivity and SUDS training; RedSUDS network; educational activities.

Table 6. *Cont.*

Dimension	Barriers	Challenges	Enablers
Regulative	b.1. Uncoordinated institutional framework.	Development of the national reference standards.	Municipalities boosting the change.
	b.2. Limits of the regulatory framework.	Development of the national legislative framework.	The international context: Agenda 2030 of UN and EU fitness evaluation of the Urban Wastewater Treatment Directive, Water Framework Directive, and EU Green Deal.
	b.3. Lack of political and public will.	Imperviousness fees.	Incentives for private owners.
Technical	c.1. Insufficient resources.	Strategic R&D focused on innovation and development of technological services for industry and society.	Innovation boosts by facilitating partnerships among the water utilities, policymakers, and researchers from public and private institutions. Increasing public and private resources for R&D.
	c.2. Lack of monitoring and evaluation.	SUDS long-term monitoring plans.	Funding and definition of a national strategy for combined sewer overflows (CSO) and SUDS monitoring.
	c.3. Reluctance regarding long-term efficiency and implementation.	Characterisation of the long-term performance of SUDS; urban water system hybrid approach combining grey and green infrastructure.	Research on SUDS long-term performance and end of life. Research on potential cost-effectiveness of SUDS in reducing CSOs.

7. Conclusions

In the early 1990s, sustainable urban drainage systems were technologies almost unknown in Spain. Today, SUDS have found their way in urban drainage strategies in the country due to the fact that many barriers have been overcome, especially on the technical level. Considerably strong efforts were made initially in research focusing on permeable pavements. Further work on other SUDS techniques has been conducted, meaning that performances from the quantity and quality perspectives are well documented at the national scale. Nevertheless, further efforts are needed, especially to establish long-term monitoring plans to analyse the end-of-life conditions of SUDS and the actions to define and establish best practices regarding maintenance, their implementation in existing dense urbanised urban areas, and the assessment of cost benefits in reducing CSO. The regulatory framework has shown considerable developments at the local level, driven by the promising results achieved at the technical level. Many cities are developing their own guidance and regulations on SUDS, but the lack of a national framework and, especially, the still unpublished national standards, impede the development of a coordinated strategy at the national scale. The challenge to overcome this situation must be driven from the highest level of governance by increasing awareness, community engagement, and coordination of the different actors involved within the transition process. Although political and economic contexts often play against change, the pillars of the transition are established and are strong. The opportunities that arise after any crisis must be seized. Over the next decade, SUDS in Spain must reach the stabilisation stage—we have the knowledge; we must maintain the will.

Author Contributions: I.A.-D. conceptualised the paper; the four authors gathered and analysed resources and data; I.A.-D. and S.P.-M. wrote the original draft of the governance section; I.A.-D. and J.A. wrote the original draft of the legislation section; I.A.-D. and J.R.-H. wrote the original draft of the technical section; the four authors discussed and wrote the challenges section; the four authors reviewed the complete paper. I.A.-D. edited the final version of the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research is developed within the framework of the Spanish Plan Estatal de Investigación Científica y Técnica y de Innovación 2017–2020, project HOFIDRAIN (Holistic characterization of filtering sections for smart and sustainable management of urban drainage systems at city scale) through the sub-projects ENGODRAIN (grant number RTI2018-094217-B-C31), MELODRAIN (grant number RTI2018-094217-B-C32) and POREDRAIN (grant number RTI2018-094217-B-C33) funded by Ministerio de Ciencia e Innovación, Agencia Estatal de Investigación (AEI) and the European Regional Development Fund (ERDF). The APC was funded by the ENGODRAIN (RTI2018-094217-B-C31) project.

Conflicts of Interest: The authors declare no conflict of interest.

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