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MULTI-SCALE APPROACH OF THE GREEN ROOFING POTENTIAL: APPLICATION TO THE PARIS AGGLOMERATION

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ABSTRACT

Green roofs are experiencing a significant development in France since the early 2000s. In 15 years, the market has increased from 100,000 m² implemented / year to over 1.3 million. If the motivations for the implementation of green roofs are often multiple, their participation in urban storm water management issues and in urban heat islands reduction are particularly often cited (Li and Babcock, 2014).

As shown for stormwater management (Versini et al., 2015a), a key element to achieve significant effects on the urban scale is the amount of roof area to be vegetated. It is therefore necessary to focus on the green roofing potential, i.e. the roof surface likely to be vegetated for a given urban area. In fact, this amount depends on many factors, relating to: (i) the physical characteristics of the buildings in the area (in particular, the existence of a flat roof which can accommodate green roofing), and (ii) the use and operating conditions of the buildings (more or less compatible with green roofing); but also: (iii) economic considerations on products used (in terms of installation and operation) and (iv) favorable or unfavorable regulatory realities (professional rules, planning regulations, incentive schemes...) (Chauveau and Gouvello, 2013).

This paper will present the results of researches that aim on characterizing and mapping the potential of urban greening roofs at three different spatial scales: the scale of a municipality representative of the urbanization of the metropolitan area (the city of Créteil), the scale of a county of the first ring (Seine-Saint-Denis) and the scale of the Paris agglomeration (431 municipalities). The approach chosen to characterize this green roofing potential incorporates the principles of a methodology developed to assess the emissions of pollutants from roofs at an urban scale (Sellami - Kaaniche et al., 2014). It is based on the combination of systematic land cover data for the three considered scales (provided by the IAU-IF: Institut d'Aménagement et d'Urbanisme d'Ile-de-France) crossed with urban development and history of the regional architecture and the use of a statistical approach based on a sample of buildings. The calculation and representation of the GRP is adapted on the studied territorial level. The results shows that the GRP differs significantly from a county to another and also within a same county.

INTRODUCTION

The development of green roofs (GR) is increasing in France for ten years. Around 100,000 m² were installed per year in the early 2000s, and now the market is around 1.3 million m² (data Adivet, 2013). GR have often been presented as offering benefits for the city in terms of aesthetic contribution, thermal regulation, biodiversity support, air quality improvement and storm water management. A significant number of studies were focused on this last topic over the past decade. They aimed to characterize and/or model the hydrological behavior of green roofs (eg: Villareal and



Bengtsson, 2005; Berndtsson et al., 2006; Baraglioli et al., 2008; Palla et al, 2009; Berthier et al, 2011; Gregoire and Clausen, 2011; Stovin et al, 2012; Gromaire et al, 2013).

In a dense urban area, the proportion of roofs can represent a significant fraction of the surface. In such environments, characterized by low land availability which limits the implementation of "traditionnal" BMPs, GR may play a role, since they do not need additional space. Few works were focused on this issue (Carter and Jackson, 2007; Palla et al., 2008; Versini et al, 2015b and 2015A.). Based on of real urban study basins located in the Hauts de Seine, Versini et al. (2015b) showed that GR could have a significant effect to reduce the network overflow frequency or runoff discharge from sewer systems when GR is significantly implemented. The ability of a given territory to host a large area of GR becomes an issue that should be investigated further. Indeed, this capacity is highly variable from one territory to another because of the diversity of urban characteristics and particularly its "built heritage".

This communication is intended as an original contribution to the analysis of this issue. Its purpose is to offer a simple definition of the potential for revegetation of an urban space and to present a method to estimate it. This method is defined and applied in the territory of Ile-de-France to three successive levels: municipality (city of Créteil), county (Seine-Saint-Denis) and the Parisian agglomeration (with more 400 municipalities of the Paris region). At each considered scale, some specific modes of representation and analysis are conducted.

The paper is organized in two parts. The first one presents the concepts and the adopted methodological approach. In the second one, the results obtained for each considered scale are presented through tables and maps, and discussed.

1. CONCEPTS AND METHODOLOGY

The potential for green roofing (GRP) of a given urban area is the cumulative area of the existing roofs, which are already vegetalized or technically able to be vegetalized in the future. The criterion adopted for considering a roof technically able to be vegetalized is its flatness. Indeed, it is assumed that: (i) current technologies allow to provide GR solution for any type of flat roof - hence with a seal - and (ii) the greening of inclined roofs is so marginal at urban scale that it can be neglected.

The systematic identification of flat roofs for an entire city is a time consuming and expensive task. Although it was conducted by the city of Paris in order to define a GR policy (Apur, 2013), it is not possible to lead such a study on larger territories. Several methods of automatic recognition of roofs' flatness have also been developed, but they are not yet fully operational and remain costly.

1.1. General Principle

In this work, the methodology uses a different logic. It is inspired by the approach proposed by Emna Sellami-Kaaniche to evaluate pollutants flows from roofs on the urban scale and applied in the city of Créteil (Sellami-Kaaniche et al., 2014).

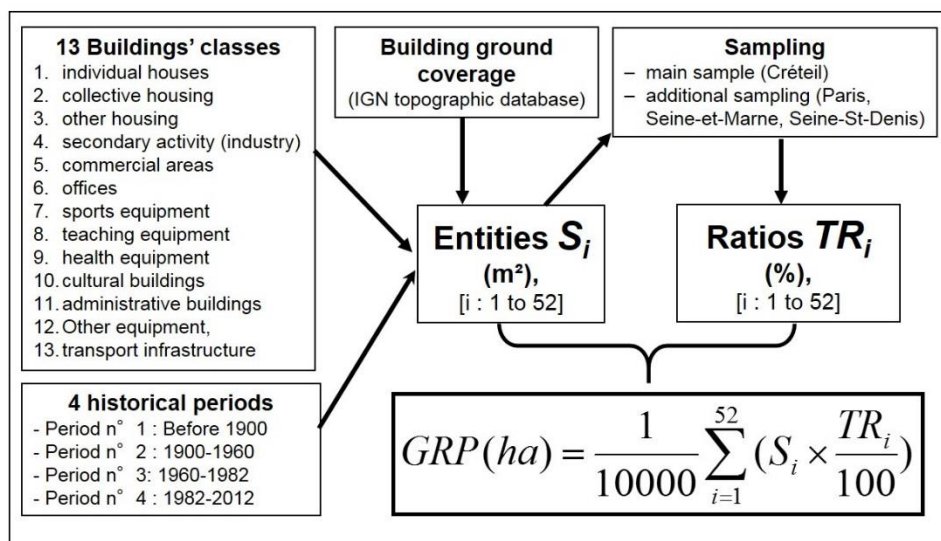


Figure 1: General principle of the method

This approach uses land use database of the IAU-IF (Institute of Urban Planning and Development of the Ile-de-France region) and the topographic database of IGN that are crossed with an historical analysis of the urban development. The key point here is the "entity" concept (as shown fig. 1).

The urban space is divided into 4 periods corresponding to the historical urban development of the Paris region: before 1900, 1900-1960, 1960-1982 and 1982-2012. The land use patterns corresponding to built-up areas are grouped into 13 distinct classes: individual homes, collective housing, other types of housing, secondary activity, offices, indoor sports, teaching equipment, health equipment, cultural facilities, administrative equipment, other equipment, commercial areas, and transports. This leads to a partition of up to 52 entities. For a given portion of territory, the value of an entity is provided by the total of ground surfaces of the buildings belonging to the same class and located on the area corresponding to the same historical period of urban development.

Each entity i has a unique flat roof ratio (TR_i , %), that represents the proportion of terraces (flat roofs) among the roofs included in this entity. These ratios have been determined on the basis of samplings selected for each entity on the city of Créteil (considered representative of the urbanization of the Paris area). They have been completed for entities insufficiently represented in this city by some additional samplings in Paris and several municipalities from the Seine-Saint-Denis and Seine-et-Marne counties. Table 1 shows all the 52 applicable TR_i ratios.

Table 1: Terraces' ratios by entity (TR_i , %)

Classe de bâtiments	Période n°1 (Avant 1900)	Période n°2 (1900-1960)	Période n°3 (1960-1982)	Période n°4 (1982-2012)

1. individual houses	11,5	3,5	7,0	7,8
2. collective housing	10,0	40,5	99,1	44,6
3. other housing	49,0	38,4	76,4	46,9
4. secondary activity (industry)	48,3	15,9	60,9	95,3
5. commercial areas	62,3	79,6	97,4	82,4
6. offices	22,0	93,0	99,5	33,1
7. sports equipment	39,2	52,2	40,1	37,1
8. teaching equipment	39,0	36,9	91,2	69,8
9. health equipment	53,5	66,8	84,0	95,7
10. cultural buildings	19,9	30,0	52,1	32,4
11. administrative buildings	38,0	27,1	87,9	53,5
12. other equipment	79,4	50,0	93,5	99,5
13. transport infrastructure	37,6	94,6	99,1	78,4

1.2. Calculation and mapping of GRP for the three scales

The method allows to calculate GRP for each of the entities located in any fraction of a given territory. Depending on the scale, it is necessary to conduct an adequate grouping of entities. The adopted methodology for the calculation and the mapping of the GRP depending on the studied scales is specified below.

At the municipal level (city of Créteil), the GRP calculation provides only a single value. Therefore, it is interesting to calculate the value of GRP for several sub-areas of the city. This can be done by dividing the communal space into sectors corresponding to an administrative reality. Créteil is divided into 5 sectors grouping 20 neighborhood councils' jurisdictions. It has been decided to represent on the same map the entities grouped in intervals of TR values and the GRP values of the five sectors. Créteil has also served as the basis for the validation of the method, since automated identification of flat roofs was conducted by the IAU-IF for this city.

When the scale is reduced, a more radical aggregation is necessary to achieve interpretable maps. For both county (40 municipalities) and agglomeration (431 municipalities) scales, the choice was to aggregate data inside each municipality.

At the County scale, two calculations have been conducted. First, the current GRP has been computed on the basis of buildings existing in 2012 (considered as the current situation). Second, a prospective calculation has been made. It is based on some already known future developments that are likely to change significantly the result. This is the case of the "Grand Paris" which will conduct to create railway and subway stations for new or existing lines in the surrounding counties of Paris as for the Seine-Saint-Denis. It has been estimated that such a new station may impact the urban development within 800 m. The contribution to GRP induced by the implementation of these stations has been re-calculated for each municipality. This calculation was made by considering the following assumptions: (i) the urban densification in new stations' areas will increase the buildings' footprint ratio and the corresponding new buildings will all have flat roofs; (ii) the footprint ratio of an affected area is likely to reach 0.30, without exceeding the double of the current situation ratio. The 0.30 value was established by analyzing the corresponding values for the 30 existing train stations (RER) of the County. It corresponds to the average value of the 6 highest values.

These two assumptions lead to the following calculation for each municipality:

$$GRP_P = GRP_C + \text{Min}(CSA * FRBSA, \text{Max}[CSA * (0.30 - FRBSA), 0])$$

where: GRP_P (ha) is the prospective GRP of the municipality;

GRP_C (ha) is the current GRP of the municipality;

CSA (ha) is the cumulated surface of the Stations' Areas of the municipality;

$FRBSA$ is the Footprint Ratio of the Buildings in the Stations' Areas of the municipality.

Finally, at the agglomeration scale, GRP is recalculated for each municipality and is mapped. Table 2 summarizes the approach to compute and represent GRP for every level.

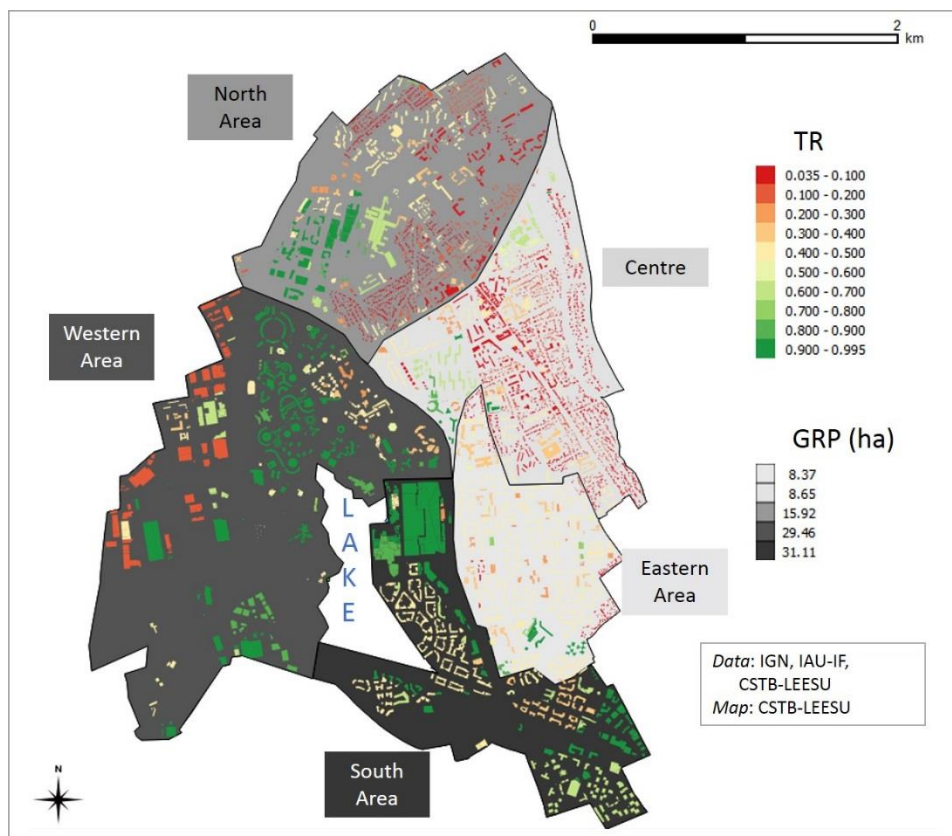
Table 2: GRP calculation and representation at every level

Scale	Main features	Calculations and mapping
Municipality (Créteil) <i>Reference for the TR_i calculation</i>	- 89.845 inhabitants (2012) - 11,4 km ²	- GRP (ha) calculated gathering GRP values of the 39 existing entities - Mapping of TR by gathering entities, and GRP by sector (5 sectors for Créteil)
County (Seine-Saint-Denis)	- 40 municipalities - 1,54 millions of inhab. (2012) - 236 km ²	- For each one of the 40 communes 1) GRP _C : Current GRP 2) GRP _P : Prospective GRP - Maps of the County with GRP values.
Paris agglomeration	- 431 municipalities - 10,6 millions of inhab. (2012) - 2860 km ²	- GRP of the 431 municipalites - Map of the agglomeration with GRP values

2. RESULTS AND DISCUSSION

Municipal scale: the city of Créteil

The GRP computed for the city of Créteil is about 100 ha. This represents approximately 8% of the city area (11.4 km²) and more than 53% of the cumulative buildings footprints (178 ha). Regarding these figures, green roofing can affect the appearance of the city. However, this potential is characterized by a high spatial variability. Some differences appear significant as for the center and the eastern sector, where a quite low potential is noticed. Conversely both western and southern sectors are characterized by a GRP more than three times higher. The northern sector represents an intermediate situation with a GRP of 16.6 ha. The difference is partly explained by the number of apartment buildings in both western and southern areas contrasting with a majority of individual housing in central and eastern sectors. In the southern sector, it is worth noting the high contribution to the potential provided by the Créteil Soleil shopping center located east of the lake. This terrace is currently used as a car park: the actualization of this potential therefore depends on the building of a superstructure.



Map 1: RT dissemination and GRP by sector for the city of Créteil

Créteil allows to assess the accuracy of the method in terms of spatial resolution. Table 3 provides comparative GRP calculation by using: (i) the presented method and (ii) a numerical method implemented by the IAU-IF and combining satellite and geographic data.

Table 3: Comparative calculation of GRP (our method vs IAU-IF method)

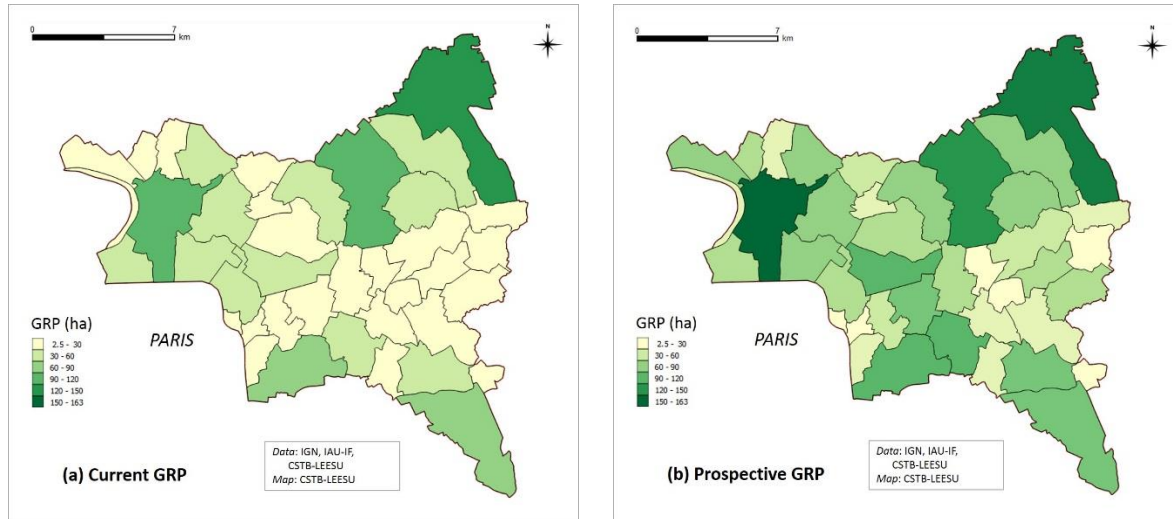
	1. Our method GRP (ha)	2. IAU-IF method GRP (ha)	Difference (GRP1-GRP2)/GRP2 (%)
Centre	8.65	8.724	0.82
Est	8.37	9.38	-10.79
Nord	15.92	17.34	-8.16
Ouest	29.46	35.49	-16.98
Sud	31.11	25.38	22.57
Total	84.87	96.31	-11.88

This table shows a quite good matching between both methods at the municipality scale. It seems logical since the TR ratios were calculated on the whole city. At the sectors' level, computed GRP remain convincing with some similar values obtained for the three main areas (center and east, north, west and south).

Scale of County: the Seine-Saint-Denis

The current GRP of the Seine-Saint-Denis County is about 13 km². It represents more than 5.5% of County total area (236 km²). According to the prospective scenario described in the previous section, this potential is likely to increase, and might reach 21.5 km², i.e. almost 10% of the territory. This result shows that the “Grand Paris” project, which will lead to a significant densification of the built environment in this County, is a tremendous opportunity to noticeably increase the presence of vegetation in the city by the implementation of green roofs.

Maps 2 (a) and (b) represent the current GRP and the prospective GRP for all the municipalities of the Seine-Saint-Denis County.



Maps 2: GRP of the municipalities of Seine-Saint-Denis County: (a) Current GRP; (b) Prospective GRP

The current situation reflects a significant GRP variation from one municipality to another. There is no simple explanatory factor (as a "center-periphery" effect for instance). The relative importance of GRP in the north-western part of the County is due to the concentration of both collective housing and industrial buildings characterized by some quite large (roof) areas.

The prospective map shows that the future railway stations are likely to strengthen significantly the GRP of many municipalities from north-west towards respectively north-east and south. Some municipalities located in the holes of the future rail transport network and on the limit of the county keep their situation unchanged, leading to a widening gap. It should however be noticed that these municipalities have mostly large green spaces regarding their total surface.

Paris agglomeration

Table 4 summarizes the results of GRP for all the Paris agglomeration and at each County level.

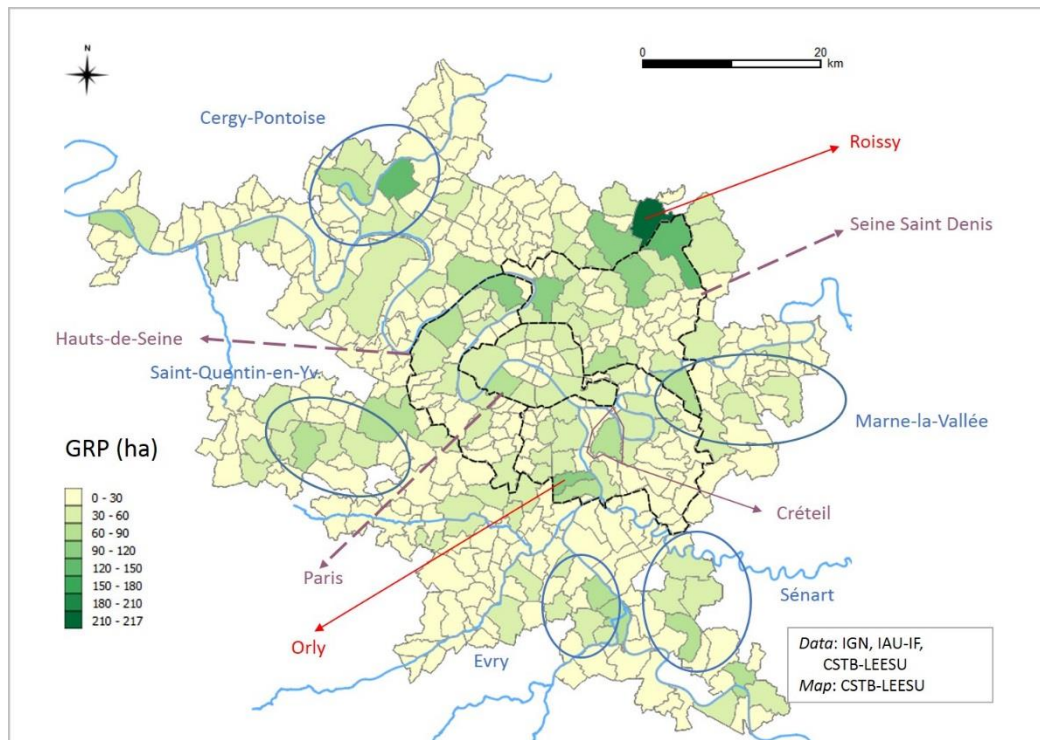
Table 4: GRP of the Counties of Paris agglomeration

County	Number of municip.	Total Area (km ²)		Roofs area (ha)		GRP (ha)		GRP/Total Area (%)
		Total	Moyenne/commune	Total	Moyenne/commune	Total	Moyen/commune	
75	20	105.42	5.27	1073	53.66	649	32.47	6.16
92	36	175.57	4.88	1347	37.40	938	26.04	5.34
93	40	236.86	5.92	2025	50.63	1320	33.01	5.57
94	47	244.83	5.21	1464	31.15	1153	24.54	4.71
F-77*	52	420.55	8.09	1623	31.21	1155	22.21	2.75
F-78*	89	678.59	7.62	2089	23.47	1470	16.52	2.17
F-91*	82	562.84	6.86	2001	24.41	1446	17.63	2.57
F-95*	65	434.81	6.69	1631	25.09	1470	22.61	3.38
Total Agglo.	431	2859.47	6.63	13253	30.75	9522	22.09	3.33

(*: These Counties are partially included in the Paris Agglomeration)

It is noteworthy that the GRP represents 3.33% of the total surface of the agglomeration, but this proportion differs from a County to another. Three Counties have a greater proportion than 5%: Paris town (75), Hauts-de-Seine (92) and Seine-Saint-Denis (93). It is consequently important to follow a deepening analysis for these territories.

At a more detailed level, it appears that the situation varies noticeably from one municipality to another (see map 3).



Map 3: GRP of the Municipalities of Paris agglomeration

This map shows a very uneven distribution of values. Three-quarters of the municipalities of the metropolitan area (320) have a GRP less than 30 ha when only 7 of them exceed 100 ha. Moving away from the capital, one can notice that the GRP generally tends to decline. This can be explained by the gradual "de-densification" of the urban spaces. However, there are several notable exceptions to this trend. On the one hand, GRP is important near the international airports (Roissy and Orly). On the other hand, one can note of the GRP increase within the 5 "new towns" created in the late 1960s' and now included in the scope of the Paris agglomeration (Marne-la-Vallée, Cergy-Pontoise, Saint Quentin-en-Yvelines, Evry and Senart). These areas are characterized both by a local re-densification and a greater proportion buildings with flat roofs, corresponding to their construction era.

CONCLUSION

The storm water management within cities in a climate change context creates pressure on the availability of space to implement mitigation techniques solutions, such as alternative techniques. Because they do not occupy additional space, green roofs are a particularly useful tool in this context. However, this work has shown that the physical characteristics of urban space influence sensitively the possibility of installing green roofs.

The ability to revegetate the roofs is not limited solely to physical characteristics of urban space. It is also based on the consideration of legal, economic and the identification of direct and



indirect levers-players (Belmeziti, 2012). These aspects have to be analyzed in order to develop public policies to move from assessment of GRP to RGRP (Reachable Green Roof Potential). The identification of territories with a high GRP is nevertheless a key-step in this process. Depending on the local operational issues of stormwater management (network overflow, or spill into the environment, that are likely to intensify with climate change), a deep analysis of RGRP in these territories has to be led. As such, the GRP calculation approach is a tool to support future developments of management at the source of rainwater.

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