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Can Open Data be leveraged to improve environmental policy design or implementation?

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ABSTRACT

The importance and benefits of using Open Data - which refers to the "*data that can be **freely used, modified,** and **shared** by **anyone** for **any purpose**[1]"* **–** is gradually starting to generate an interest in Belgium. This paper discusses the use of Open Data in the policy-making context and more precisely its use for the purpose of improving environmental policy design or implementation. A decision matrix has been developed in the paper to identify for which type of policies Open Data might be useful. The main result is that Open Data might be useful in the case of targeted policies as it can help to cope with the information asymmetry issue. Furthermore, the current roof insulation subsidy policy of the Brussels-Capital Region, which is a self-targeted subsidy policy, has been taken as concrete application to illustrate how the use of Open Data can enhance the effectiveness of an environmental policy. The results show that Open Data can be leveraged to redesign the current roof insulation subsidy by directly targeting the houses that are poorly insulated. With a similar total amount of subsidy granted annually over the 2009-2016 period by the Brussels-Capital Region, the subsidy policy redesigned using Open Data could have potentially benefited more houses in total over the period, allowed more annual energy savings and consequently more annual pollutants emissions reductions than the current roof insulation subsidy.

Keywords: *Open Data, Roof Insulation Subsidy, Air Pollution, Environmental Policy, Policy Effectiveness.*

[1] The Open Knowledge Foundation. (n.d.-a). The Open Definition. Retrieved 30 July 2017, from http://opendefinition.org/

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INTRODUCTION

Although the importance and benefits of using Open Data – which refers to the "*data that can be **freely used, modified,** and **shared** by **anyone** for **any purpose**[2]"* - have already been realised in some countries such as the UK or the USA, it is just starting gradually to generate an interest in Belgium. Several cities in Belgium are starting to organise various events to promote the use of Open Data and an Open Data strategy at the Federal level has also been implemented in Belgium.

In this paper, a focus will be made on the use of Open Data in the policy-making context. Due to the worldwide increasing concern for environmental issues, the main purpose of the paper will be to examine whether Open Data can be leveraged to improve environmental policy design or implementation. To tackle this question, a decision matrix will first be developed as a tool for the policymakers to identify for which type of policies Open Data might be useful. The redesign of one concrete environmental policy using Open Data will then be taken as a concrete application. Since air pollution - for which buildings (mainly due to the tertiary and residential heating) is one of the main sectors responsible- is an important current environmental issue to be addressed in Belgium and more specifically in the Brussels-Capital Region, the current roof insulation subsidy policy of the Region has been chosen for the application. It will be seen whether there is a room for improvement of the effectiveness of the current roof insulation subsidy policy using Open Data. For this purpose, a comparison in terms of energy savings and pollutants emissions reductions will be made between the current policy and the potential policy that will be redesigned using Open Data. It will therefore make it possible to see whether the conclusions of this comparison coincide with what the decision matrix predicts.

Concretely, the paper is organised as follows: Part I gives an overview of what Open Data is, its current availability in Belgium and its main limitations. Part II discusses the use of Open Data in the policy-making context by highlighting the issues faced by the policymaker when designing a policy and discussing how the use of Open Data can potentially tackle these issues. The decision matrix is also developed in this part. Part III discusses in detail the redesign of the current roof insulation subsidy policy of the Brussels-Capital Region using Open Data. Finally, the last part concludes the paper.

[2] The Open Knowledge Foundation. (n.d.-a). The Open Definition. Retrieved 30 July 2017, from http://opendefinition.org/

PART I: OPEN DATA - DEFINITION, USE AND LIMITATIONS

This first part is intended to provide a theoretical framework about Open Data. The first section will give an overview of what Open Data is concretely. The second section will discuss the availability of Open Data in Belgium and its current use through some examples. Finally, the third section will highlight the current limitations of Open Data.

1. Overview of Open Data

1.1. Origin and definition of Open Data

The United States are the precursors of Open Data with notably the "Freedom of Information Act" of 1966, which allows the population to have free access to administrative documents[3]. The emergence of the Internet in the 1990s also played a major role in the expansion of Open Data[4].

Several definitions of Open Data exist. For example, the Open Knowledge Foundation[5] defines Open Data as *"data that can be **freely used, modified,** and **shared** by **anyone** for **any purpose**"*[6] while the European Commission defines it as follows: "*Open Data refers to the idea that certain data should be **freely available** for **use** and **re-use***"[7].

More specifically, Open Data are distinguished from the so-called "Closed Data" by 4 aspects, namely:

- **Accessibility**: Open Data are accessible to everyone and not just to a part of the population.
- **Machine readability**: Open Data are in such a format (e.g. CSV, XML or JSON) that it can be easily readable by all computers.
- **Cost**: Open data are available for free.

[3] Tout savoir sur l'Open Data. (2016, March 7). Retrieved 30 July 2017, from https://www.opendatasoft.fr/2016/03/07/tout-savoir-sur-open-data/

[4] Boydens, I. (2014). *Open Data et eGovernment* (Research Note No. 33). Smals. Retrieved from https://www.smalsresearch.be/download/research_reports/research_note/OpenDataRN.pdf

[5] The Open Knowledge Foundation (OKF) is a British non-profit organisation that promotes Open Data.

[6] The Open Knowledge Foundation. (n.d.-a). The Open Definition. Retrieved 30 July 2017, from http://opendefinition.org/

[7] European Commission. (n.d.-c). Open Data. Retrieved 30 July 2017, from https://ec.europa.eu/digital-single-market/en/open-data

- **Rights**: Open Data can be reused, redistributed and republished as many times as desired[8].

1.2. The Licences

One of the four aspects explained above that is of particular importance is the "rights" aspect. Each database available on the Internet has a licence that defines the conditions under which the data can be reused.

In the specific case of Open Data, these are called "open licences". There exist various open licences, such as the CC-BY (Creative Commons Attribution) licence from Creative Commons, the ODC-BY (Open Data Commons Attribution) licence from the Open Knowledge, or the OGL (Open Government Licence) from the United Kingdom, for example[9].

The databases with the licences mentioned above guarantee a reuse of the data by the re-user provided that there is a *paternity mention*[10]. No *copyleft* is required here, which is not the case with open licences like the OdbL (Open Database Licence) one. The "paternity mention*"* implies that, once the database is reused, the owner must be cited by the re-user[11], while "copyleft" means that any database that is created based on the owner's must be exploited under the original licence[12].

However, it should be noted that there are also open licences that require no paternity mention or copyleft, such as the CC0 (Creative Commons Zero)[13].

[8] Chui, M., Farrell, D., & Jackson, K. (2014). *How government can promote Open Data and help unleash over $3 trillion in economic value*. Mckinsey. Retrieved from http://www.mckinsey.com/~/media/mckinsey/industries/public%20sector/our%20insights/how%20government%20can%20promote%20open%20data/how_govt_can_promote_open_data_and_help_unleash_over_$3_trillion_in_economic_value.ashx

[9] Statistics Belgium. (2015, October 22). Licence Open Data. Retrieved from http://statbel.fgov.be/fr/binaries/Licence%20open%20data_fr_FINAL_2_tcm326-272764.pdf

[10] Ibid.

[11] Open Data et licences, comment ça marche ? (2016, April 4). Retrieved 30 July 2017, from http://blog.synaltic.fr/2016/04/04/open-data-licences/

[12] What is copyleft? - Definition from WhatIs.com. (n.d.). Retrieved 30 July 2017, from http://whatis.techtarget.com/definition/copyleft

[13] CC0 1.0 universel. (n.d.). Retrieved 30 July 2017, from https://creativecommons.org/publicdomain/zero/1.0/deed.fr

1.3. The five stars of Open Data

Tim Berners-Lee, the inventor of the World Wide Web (or more commonly known as the Web), developed a 5-star model to gain insight into the level of database openness and incentivise the data providers to publish the most reusable data possible[14]. It should be noted that for a database to be a 3-star database for example, it must first fulfil the conditions of a 1-star and 2-star database. The stars are awarded as follows:

Table 1: Tim Berners-Lee's 5-star Open Data

★	The data are available on the Internet under an open licence regardless of the data format[15].
★★	The data are structured and machine-readable (Excel file for instance)[16].
★★★	The data are available in a non-proprietary format (i.e. a format such as the CSV, XML or TXT formats that do not require to be used under a specific software).
★★★★	URIs (Unique Resource Identifiers or websites) are used so that the users can easily refer to the data.
★★★★★	The data contain links from other data to give context to the initial data. This type of data is called "*linked open data*"[17,18].

Source: https://www.w3.org/DesignIssues/LinkedData.html

[14] Projet de note stratégique pour une stratégie fédérale Open Data. (n.d.). Belgique. Retrieved from http://digitalbelgium.be/wp-content/uploads/2017/07/compressed_FR-strategisch-dossier.pdf
[15] Berners-Lee, T. (2009, June). Linked Data. Retrieved 30 July 2017, from https://www.w3.org/DesignIssues/LinkedData.html
[16] Ibid.
[17] Projet de note stratégique pour une stratégie fédérale Open Data. (n.d.). Belgique. Retrieved from http://digitalbelgium.be/wp-content/uploads/2017/07/compressed_FR-strategisch-dossier.pdf
[18] 5-star Open Data. (n.d.). Retrieved 30 July 2017, from http://5stardata.info/en/

1.4. The notion of interoperability

The notion of interoperability is a key concept in Open Data. It refers to the ability of different systems to co-operate. In the specific case of Open Data, interoperability makes it possible to facilitate the combination of two (or more) datasets and therefore facilitate the development of value added ideas[19].

It should be noted that raising interoperability between different databases is done at four levels[20]:

- *At the legal level*: Databases must be under open licence.
- *At the technical level*: It should be possible to have easy access to these databases, which is generally the case thanks to the Internet.
- *At the syntactic level*: The serialisation[21] of the data must allow an easy merging of 2 (or more) databases. This is the case when serialisation is done using open standards such as JSON, XML or CSV.
- *At the semantic level*: Data must be "linked data"[22].

1.5. Reasons to promote Open Data

The public sector and, to a lesser extent, the private sector are the main Open Data providers. These data are usually published either continuously (real-time data) or discretely (statistical data)[23] and are related to numerous themes such as the environment, transport, education, etc.[24] With the opening of the data, data providers hope that the data will be reused through the creation, for instance, of added-value mobile phone apps for citizens, which will allow to make the cities "smarter"[25]. Some examples of the use of Open Data through mobile phone apps in Belgium will be seen in section 2.2.3.

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[19] The Open Knowledge Foundation. (n.d.-b). What is Open Data? Retrieved 30 July 2017, from http://opendatahandbook.org/guide/en/what-is-open-data/

[20] Colpaert, P. & al. (2017). *Open Transport Data for maximising reuse in multimodal route planners: a study in Flanders*. Retrieved from https://pietercolpaert.be/papers/iet-otd/paper.pdf

[21] Serialization = "*Serialization is the process of translating data structures or objects state into binary or textual form to transport the data over network or to store on some persistent storage"* definition from https://www.tutorialspoint.com/avro/avro_serialization.htm

[22] Colpaert, P. & al. (2017). *Open Transport Data for maximising reuse in multimodal route planners: a study in Flanders*. Retrieved from https://pietercolpaert.be/papers/iet-otd/paper.pdf

[23] Boydens, I. (2014). *Open Data et eGovernment* (Research Note No. 33). Smals. Retrieved from https://www.smalsresearch.be/download/research_reports/research_note/OpenDataRN.pdf

[24] Data.gov.be. (n.d.). Retrieved 30 July 2017, from http://data.gov.be/fr

[25] Boydens, I. (2014). *Open Data et eGovernment* (Research Note No. 33). Smals. Retrieved from https://www.smalsresearch.be/download/research_reports/research_note/OpenDataRN.pdf

To promote the creation of new apps and make the city a so-called "smart city", many cities around the world organise events where several teams composed of developers and citizens compete for the purpose of creating apps related to a specific theme using available Open Data. These events are called "hackathon", which comes from the combination of the words "hack" and "marathon"[26].

It should be noted that the governments could also make use of Open Data in order to try to make their policies more effective and efficient. Part 2 will focus on the use of Open Data in the policy-making context.

2. Open Data in Europe: a focus on Belgium

2.1. European Union Directives

At the European level, the reuse of Open Data can generate economic gains amounting to €40 billion per year[27]. As a result, the European Union has introduced the Directive 2013/37/EU amending the Directive 2003/98/EC (PSI (Public Sector Information) Directive), which obliges the EU Member States to make all public data reusable and to make more data available in a machine-readable format. This Directive was to be transposed by the Member States before July 2015[28,29].

Moreover, the so-called "INSPIRE (Infrastructure for Spatial Information in the European Community)" Directive has been put in place by the European Union with the aim to facilitate the sharing of environmental geospatial data between the Member States. Data were indeed collected differently depending on the Member State, which hampered the interoperability between the EU Member States. With the INSPIRE Directive, environmental data have been harmonised across the EU Member States and an infrastructure for sharing spatial data has been created. The directive should be fully implemented by 2021[30].

[26] Open Data Brussels Hackathon. (2017, April 6). Retrieved 30 July 2017, from https://www.bruxelles.be/open-data-brussels-hackathon

[27] European Commission. (2011). *Open Data - An engine for innovation, growth and transparent governance*. Bruxelles. Retrieved from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0882:FIN:EN:PDF

[28] European Parliament. Directive 2013/37/UE du Parlement européen et du Conseil du 26 juin 2013 modifiant la directive 2003/98/CE concernant la réutilisation des informations du secteur publicTexte présentant de l'intérêt pour l'EEE (2013). Retrieved from http://eur-lex.europa.eu/legal-content/FR/TXT/PDF/?uri=CELEX:32013L0037&from=FR

[29] Boydens, I. (2014). *Open Data et eGovernment* (Research Note No. 33). Smals. Retrieved from https://www.smalsresearch.be/download/research_reports/research_note/OpenDataRN.pdf

[30] European Commission. (n.d.-a). About INSPIRE. Retrieved 30 July 2017, from http://inspire.ec.europa.eu/about-inspire/563

2.2. Open Data in Belgium

2.2.1. Key Open Data figures

The European Union has put in place two main indicators, the *Open Data Readiness* and the *Portal Maturity*, in order to see to what extent a specific EU Member State opens its data (i.e. the *Open Data Maturity* of a given EU Member State). Each EU Member State gets a score based on these 2 indicators. It should be noted that both the indicators are composed of several sub-indicators for which the maximum scores are shown in Table 2. Appendix A gives the detailed components of each sub-indicator[31].

Table 2: Breakdown of the Open Data Maturity Scoring - Score of Belgium

Open Data Readiness		
Sub-indicator	**Maximum Score**	**Score of Belgium**
Presence of Open Data Policy	330	200
Licensing Norms	70	15
Extent of coordination at national level	130	90
Use of the data	260	95
Impact of Open Data	300	50
Sub-Total	***1090***	***450***
Portal Maturity		
Sub-indicator	**Maximum Score**	**Score of Belgium**
Usability of the portal[32]	60	40
Re-usability of the data	140	100
Spread of data across domains[33]	50	50
Sub-Total	***250***	***190***
TOTAL	**1340**	**640**

Source: Open Data Maturity in Europe 2016

As can also be seen from Table 2, Belgium has a total score of 640 out of 1340. In order to get an idea of the performance of Belgium's Open Data Maturity, it is necessary to compare this

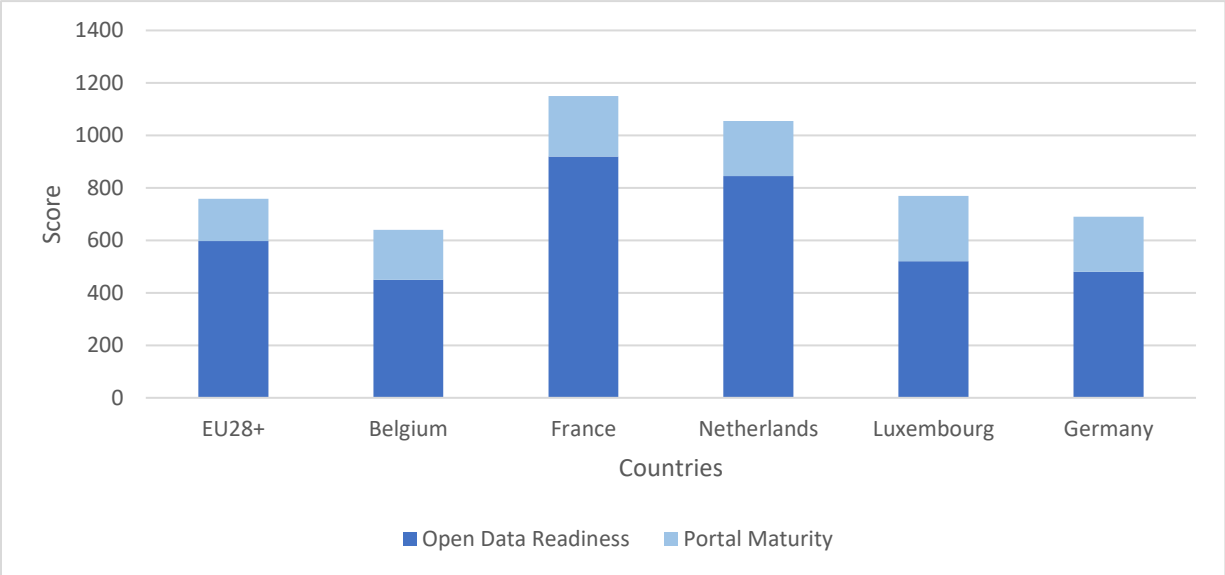
[31] Carrara, W., Nieuwenhuis, M., & Vollers, H. (2016). *Open Data Maturity in Europe 2016 - Insights into the European state of play*. Capgemini Consulting. Retrieved from https://www.europeandataportal.eu/sites/default/files/edp_landscaping_insight_report_n2_2016.pdf

[32] *A portal is a website where a country makes its data available for the citizens.*

[33] *A domain here represents a theme such as energy or environment for instance*.

score with that of other countries. The scores of Belgium's neighbouring countries as well as the EU28+[34] average score are shown in the following graph.

Figure 1: Open Data Maturity Scores of the EU28+ and the neighbouring countries of Belgium



Source: https://www.europeandataportal.eu/en/dashboard#tab-detailed

It can be observed on Figure 1 that Belgium has a low Open Data Maturity score[35] and is lagging behind the EU28+ average as well as its neighbouring countries. This is mainly due to its low Open Data Readiness score because Belgium does not use data enough and the data are not always under open licence[36].

Moreover, it can be highlighted that, based upon the two indicators, 4 groups amongst the EU28+ countries can be formed: *Beginners*, *Followers*, *Fast Trackers* and *Trend Setters.* Figure 2 shows that, unlike France and the Netherlands, which are Trend Setters, Belgium is a Follower. It indicates that despite an implementation of an Open Data Policy, there are still barriers to the reuse of the data available on the Belgian portal[37].

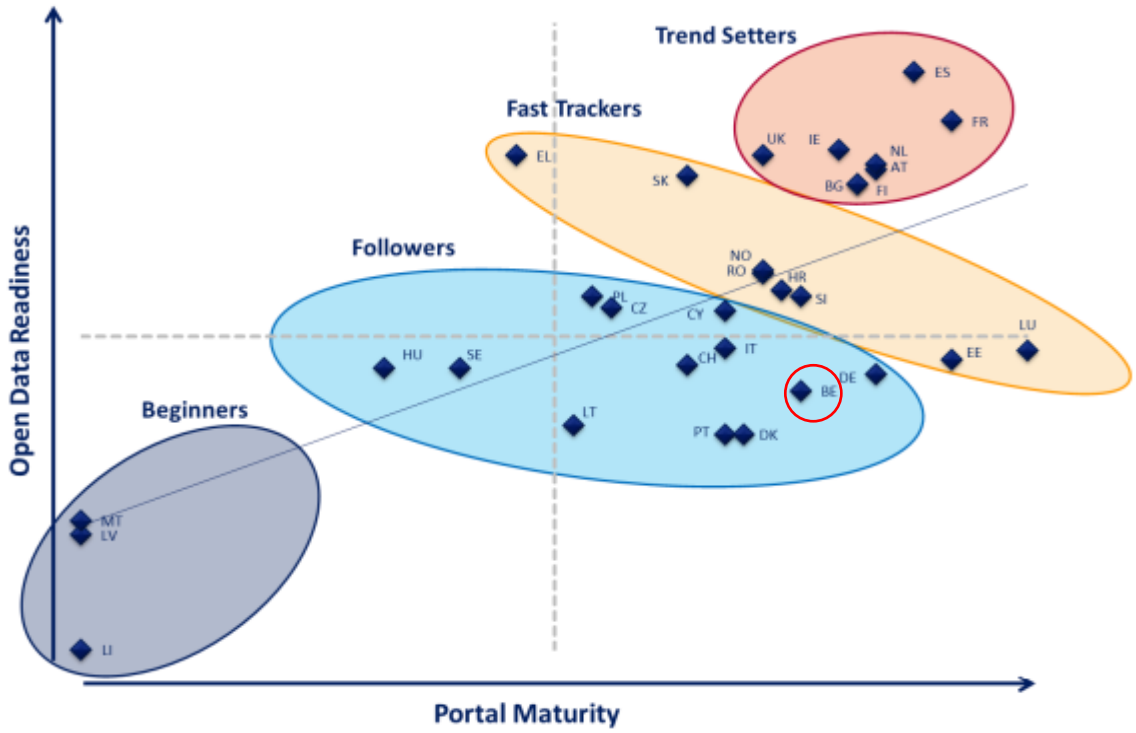
[34] The EU28+ is composed of the 28 EU Member States as well as of Switzerland, Liechtenstein and Norway (which are countries belonging to the European Free Trade Association).

[35] Open Data Readiness Score + Portal Maturity Score

[36] Projet de note stratégique pour une stratégie fédérale Open Data. (n.d.). Belgique. Retrieved from http://digitalbelgium.be/wp-content/uploads/2017/07/compressed_FR-strategisch-dossier.pdf

[37] Carrara, W., Nieuwenhuis, M., & Vollers, H. (2016). *Open Data Maturity in Europe 2016 - Insights into the European state of play*. Capgemini Consulting. Retrieved from https://www.europeandataportal.eu/sites/default/files/edp_landscaping_insight_report_n2_2016.pdf

Figure 2: Four groups of Open Data Maturity levels across the EU28+ countries



Source: Open Data Maturity in Europe 2016

2.2.2. Open Data Federal Strategy

According to Agoria[38] estimates, the opening of public data in Belgium could lead to potential gains of 875 to 900 million euros[39]. Therefore, given that Belgium's Open Data Maturity Score is low compared to its neighbouring countries and the EU28+ average, Belgium has implemented an Open Data strategy at the Federal level[40].

The following are the main points of the strategy:

- All the datasets must be "open by default" following the "comply or explain" principle. It means that the data must be automatically made open by the data provider, otherwise an explanation should be provided.

[38] Federation of Enterprises of the Technological Industry

[39] Agoria. (n.d.). Donner accès aux données publiques. Retrieved from https://www.agoria.be/upload/agoriav3/5Donner_acces_aux_donnees_publiques.pdf

[40] Projet de note stratégique pour une stratégie fédérale Open Data. (n.d.). Belgique. Retrieved from http://digitalbelgium.be/wp-content/uploads/2017/07/compressed_FR-strategisch-dossier.pdf

- The datasets must preferably be under the CC0 licence even if other open licences could also be used provided that it is justified by the data provider (the "comply or explain" principle).
- The data providers should provide machine-readable datasets and, as far as possible, 5-stars datasets.
- A federal portal[41] gathers the data available on all the regional portals in order to have an overview of all the open data available in Belgium and therefore encourage their reuse[42,43].

2.2.3. Examples of the use of Open Data in Belgium

Given its low score for the re-use of Open Data, Belgium is trying to put in place various projects that would make use of Open Data and would benefit citizens. Two examples of the current use of Open Data in Belgium will be explained below. The first one is related to the environment while the second is related to transport. It must also be emphasised that there is an increasing number of hackathons that are organised across the country with the aim of promoting the use of Open Data[44,45].

- **Environment - *Exp'Air project***

The Brussels Institute for Environmental Management[46] and Bral[47] are the initiators of the Exp'Air project. The aim of this project is to measure the individual exposure of the inhabitants of Brussels to urban air pollution and to raise public awareness regarding the air pollution issue[48]. The project will only measure the individual exposure to the "Black

[41] Data.gov.be. (n.d.). Retrieved 30 July 2017, from http://data.gov.be/fr

[42] Colpaert, P. (2015, July 24). Green light for the Belgian federal Open Data strategy. Retrieved 30 July 2017, from https://www.openknowledge.be/2015/07/24/green-light-for-the-belgian-federal-open-data-strategy/

[43] Projet de note stratégique pour une stratégie fédérale Open Data. (n.d.). Belgium. Retrieved from http://digitalbelgium.be/wp-content/uploads/2017/07/compressed_FR-strategisch-dossier.pdf

[44] Rawart, I. (2017, March 15). Retour sur le hackathon Citizens of Wallonia 2017. Retrieved 30 July 2017, from https://www.digitalwallonia.be/citizens-of-wallonia-hackathon-2017/

[45] Concertation Portails de données ouvertes. (2016, March 2). Retrieved from http://www.belgif.be/files/opendataportals_201603_fr.pdf

[46] Institut Bruxellois pour la Gestion de l'Environnement (IBGE)

[47] Urban movement that fights to have an environmentally-friendly city (Brussels).

[48] Institut Bruxellois pour la Gestion de l'Environnement. (n.d.). Le projet ExpAIR: évaluer l'EXPosition individuelle des Bruxellois à la pollution urbaine de l'AIR -. Retrieved from http://document.environnement.brussels/opac_css/elecfile/DEP%20Expair%20FR

Carbon", which is a particulate matter that has a diameter of 20 to 150 nanometres[49] and can be a good proxy for the other atmospheric pollutants[50].

For the moment, ground-based air pollution monitoring stations are used to measure the real-time exposure to air pollution in Brussels[51]. There are 12 stations in the Brussels-Capital Region whose location is given in Appendix B. However, two of them are currently out of use, which prompted some citizens to file a complaint against the Brussels government demanding, among others, the reopening of these stations. Indeed, according to them, these stations were closed because the atmospheric pollutants concentration exceeds the limits set by the European Union[52].

It should be highlighted that those air pollution monitoring stations do not provide measures on the pollutants concentration on a street-by-street basis. Therefore, the Exp'Air project tried to make citizens contribute to the collection of data[53]. Five people travelled the streets of the Brussels-Capital Region for 5 days with a portable aethalometer[54] and a GPS[55]. The data that were collected were used to create a map, which is not yet available but will look like Figure 3. However, the map will not be updated in real time and the Black Carbon concentration will not be available for all the streets[56].

[49] Les effets de Black Carbon sur la santé humaine. (2014, November 10). [Text]. Retrieved 30 July 2017, from http://www.environnement.brussels/etat-de-lenvironnement/synthese-2011-2012/environnement-et-sante/les-effets-de-black-carbon-sur-la

[50] Institut Bruxellois pour la Gestion de l'Environnement. (n.d.). Le projet ExpAIR: évaluer l'EXPosition individuelle des Bruxellois à la pollution urbaine de l'AIR -. Retrieved from http://document.environnement.brussels/opac_css/elecfile/DEP%20Expair%20FR

[51] Measurements. (n.d.). Retrieved 30 July 2017, from http://www.irceline.be/en/air-quality/measurements

[52] De Marcilly, C. (2017, February). Le gouvernement bruxellois dissimule-t-il aux citoyens qu'ils respirent un air pollué et nocif ? Retrieved 30 July 2017, from http://www.lalibre.be/actu/planete/le-gouvernement-bruxellois-dissimule-t-il-aux-citoyens-qu-ils-respirent-un-air-pollue-et-nocif-589de2c7cd703b9815237a2e

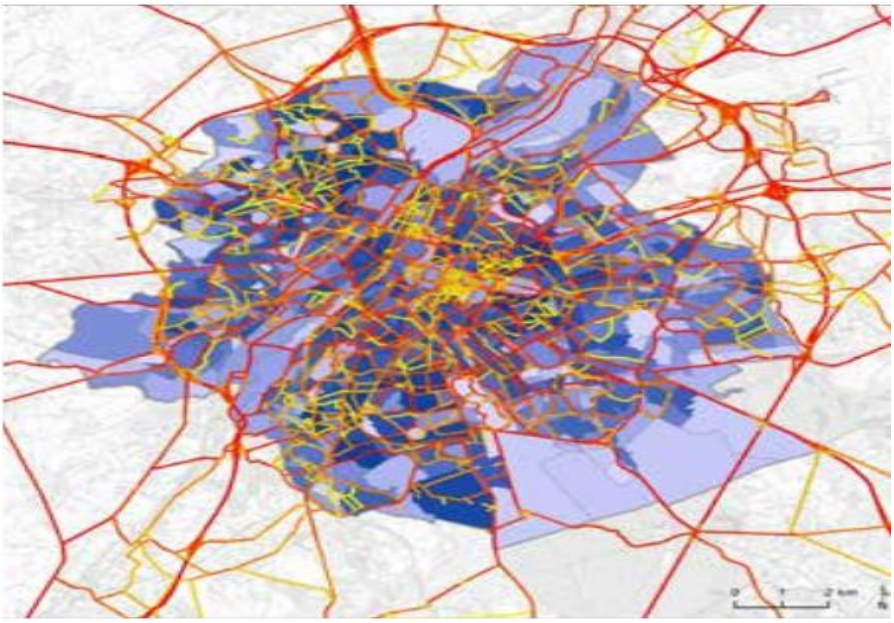
[53] Institut Bruxellois pour la Gestion de l'Environnement. (n.d.). Le projet ExpAIR: évaluer l'EXPosition individuelle des Bruxellois à la pollution urbaine de l'AIR -. Retrieved from http://document.environnement.brussels/opac_css/elecfile/DEP%20Expair%20FR

[54] Device that measures the pollutants concentration.

[55] Heene, Beaujean, Declerck, de Vos, Mendes, & Brasseur. (2016). *Evaluation de la qualité de l'air dans le pentagone de la région de Bruxelles-Capitale*. Brussels Institute for Environmental Management. Retrieved from http://bral.brussels/sites/default/files/bijlagen/BIM_Brasseur_Evaluation_QA_Pentagone_Rapport_BRAL_ExpAIR_03032016_0.pdf

[56] Mesurer la qualité de l'air : des technologies citoyennes pour agir tous ensemble ? (2016, November 28). Retrieved 30 July 2017, from http://bral.brussels/fr/artikel/mesurer-la-qualit-de-l-air-des-technologies-citoyennes-pour-agir-tous-ensemble

Figure 3: Ambient Air Quality in the Brussels-Capital Region Map



Source: Le projet ExpAIR- évaluer l'EXPosition individuelle des Bruxellois à la pollution urbaine de l'AIR

In the long run, Bral would like to make a larger part of the citizens contribute to the collection of the data (i.e. to promote "citizen science" or "crowdsourcing"). One of the ideas would be to provide citizens with "sensors" such as the "Smart Citizen Kit", which is an initiative from Barcelona[57]. These Smart Citizen Kits measure the ambient air quality and have an integrated GPS[58]. They would be worn every day by citizens to enable real-time data collection, which would therefore allow having real-time maps. Mobile apps can thus be created enabling the citizens to choose a route where they will be the least exposed to air pollution, for instance[59].

A project similar to the Exp'Air one was carried out by VITO[60] in several cities of Flanders and is named AirQMap[61].

[57] Mesurer la qualité de l'air : des technologies citoyennes pour agir tous ensemble ? (2016, November 28). Retrieved 30 July 2017, from http://bral.brussels/fr/artikel/mesurer-la-qualit-de-l-air-des-technologies-citoyennes-pour-agir-tous-ensemble

[58] Smart Citizen : Citizen Science Platform for participatory processes of the people in the cities. (n.d.). Retrieved 30 July 2017, from https://smartcitizen.me/

[59] De Muelenaere, M. (2016, October). Bruxelles à la chasse aux axes pollués. *Le Soir*. Retrieved from http://celinefremault.be/wp-content/uploads/2016/10/Bruxelles-%C3%A0-la-chasse-aux-axes-pollu%C3%A9s.jpg

[60] VITO is an European independent research and technology innovation

[61] airQmap. (n.d.). Retrieved 30 July 2017, from http://www.airqmap.com/info.html

Apple's 'Differential Privacy' Is About Collecting Your Data---But Not Your Data. (n.d.). Retrieved 30 July 2017, from https://www.wired.com/2016/06/apples-differential-privacy-collecting-data/

- **Transport- *NextRide***

NextRide is a mobile app created by Belgian citizens that allows to inform the population of the real-time timetables of public transport (TEC & STIB) in Wallonia and Brussels as well as how long it will take to get to the closest stop[62].

The mobile app made use of the data made available by STIB and TEC. However, in order to have access to the real-time data, a contract must be signed between the re-user and the public transport company. This restriction makes it impossible to qualify these data as being Open Data but rather as being "shared data"[63]. In the future, NextRide plans to integrate the real-time data of the De Lijn as well as of the SNCB, which has just recently made its data available[64,65].

The mobile app also allows citizens to be informed in the event that public transport is crowded or delayed. This information will be transmitted in real time by the citizens themselves (= "crowdsourcing")[66].

3. The current limitations of Open Data

Although one of the limitations of Open Data is, in some countries, its lack of availability, Open Data is facing other key challenges that will be developed in this section.

3.1. Privacy issues

Open Data cannot contain personally identifiable Information (PII) - the name, the home address, the IP address, etc. - to ensure that the privacy of the population is not compromised. But the publication of these data could lead to the creation of new value-added apps. As a result, the data containing PII are anonymised (or "desidentified") in order to allow their publication[67].

[62] Open Belgium 2015. (n.d.). Retrieved 30 July 2017, from http://2015.openbelgium.be/

[63] Open Belgium 2017: the state of Open Transport Data. (2017, March 5). Retrieved 30 July 2017, from https://hello.irail.be/2017/03/05/state-of-open-transport-data/

[64] Nextride : les horaires de la SNCB intégrés à l'application dès 2017 | geeko. (n.d.). Retrieved 30 July 2017, from http://geeko.lesoir.be/2016/10/25/nextride-les-horaires-de-la-sncb-integres-a-lapplication-des-2017/

[65] La SNCB rend ses données horaires en temps réel accessibles. (2017, Aprill). Retrieved 30 July 2017, from http://www.belgianrail.be/fr/corporate/Presse/Presse-releases/05_04_2017.aspx

[66] Open Belgium 2015. (n.d.). Retrieved 30 July 2017, from http://2015.openbelgium.be/

[67] The Center for Open Data Enterprise. (2016). *Briefing Paper on Open Data and Privacy*. Retrieved from http://reports.opendataenterprise.org/BriefingPaperonOpenDataandPrivacy.pdf

However, even if the data have been anonymised, there is a remaining risk that these data reveal PII and therefore a risk that they can be re-identified. The combination of several datasets could indeed make it possible to identify individuals and thus be an obstacle to the protection of privacy. This phenomenon is called the "mosaic effect"[68].

To deal with this mosaic phenomenon, there are some techniques of anonymization that exist such as "differential privacy", which maximise the accuracy of the data while minimising as much as possible the risk of mosaic effect[69,70]. There are several tools used by the differential privacy technique such as the noise injection into the datasets, for instance. Another solution to tackle the mosaic effect would be to have "semi-open data". In this case, the data will be accessible only to a part of the population, namely the trusted researchers and the people concerned by the data. However, this would run counter to what Open Data promotes: a free access to data for everyone. Finally, restrictions could be included in open licences in order to prohibit possible attempts by the re-users to re-identify the data that are anonymised, which can therefore allow the data to be completely open[71].

3.2. Lack of co-operation between the data providers and users

As previously explained, the data providers – mainly the public sector – are publishing Open Data on the online portals in order to push the reuse of these data. Except during the hackathons, there is no coordination between the data providers and the data users. When the data providers make the data available, they do not know for which purpose the data will be used and, above all, they do not know whether the data will be used or not. However, although the access to these data is free for the users, this is not the case for the providers who face some costs (data collection, data processing, data updating, etc.)[72].

The focus is currently more on the Open Data supply rather than on its demand[73]. The data providers are indeed generally only focused on publishing as much data as possible,

[68] Ibid.

[69] The Center for Open Data Enterprise. (2016). *Briefing Paper on Open Data and Privacy*. Retrieved from http://reports.opendataenterprise.org/BriefingPaperonOpenDataandPrivacy.pdf

[70] airQmap. (n.d.). Retrieved 30 July 2017, from http://www.airqmap.com/info.html

Apple's 'Differential Privacy' Is About Collecting Your Data---But Not Your Data. (n.d.). Retrieved 30 July 2017, from https://www.wired.com/2016/06/apples-differential-privacy-collecting-data/

[71] The Center for Open Data Enterprise. (2016). *Briefing Paper on Open Data and Privacy*. Retrieved from http://reports.opendataenterprise.org/BriefingPaperonOpenDataandPrivacy.pdf

[72] L'open data. (n.d.). Retrieved 30 July 2017, from https://www.europeandataportal.eu/elearning/fr/#/id/co-01

[73] *Ibid.*

regardless of the quality of these data[74], ignoring the needs of data users. However, it should be noted that the availability of a large amount of Open Data is not sufficient because *"data itself has no value"*[75]. It would therefore be necessary to find ways to also focus on demand in order to identify the needs of data users and thus create value with the use of data. To do so, a co-operation between the data providers and the data users must be encouraged[76]. This would greatly reduce the costs that the data providers face as they will only need to publish and update the data that the data users need[77].

To put it simply, although a co-operation between data providers and data users could reduce the quantity of Open Data available, it could significantly improve the quality of these data.

3.3. Sustainability of Open Data

Ensuring that open data is "sustainable" (i.e. available for a long period of time) is another challenge faced by Open Data. The fact that the data is sustainable gives a guarantee to the data users, who spend time and money in order for instance to develop value-added apps, that the data will still be available in the coming years[78].

To assess the sustainability of Open Data, there are mainly two factors that could give an indication. On the one hand, the commitment of data providers to continue making data available and updating them. If the data comes from, for example, the government, it could be possible that Open Data is not a priority anymore for the newly elected government that succeeds the previous one, which can hamper the sustainability of Open Data. On the other hand, the use (and reuse) of data is also an important indicator of the sustainability of Open Data. The more the data are used and reused, the greater the chance that these data will continue to be available in the future as this shows that the data can be a source of value creation[79].

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[74] Boydens, I. (2014). *Open Data et eGovernment* (Research Note No. 33). Smals. Retrieved from https://www.smalsresearch.be/download/research_reports/research_note/OpenDataRN.pdf

[75] World Bank Group. (2015). *Open Data for Sustainable Development* (Policy Note ICT01). Retrieved from http://pubdocs.worldbank.org/en/999161440616941994/Open-Data-for-Sustainable-Development.pdf

[76] Vathana, A., & Pramil Audsin, D. (2013). *An Open Analysis on Open Data*. Retrieved from https://www.w3.org/2013/04/odw/odw13_submission_33.pdf

[77] Boydens, I. (2014). *Open Data et eGovernment* (Research Note No. 33). Smals. Retrieved from https://www.smalsresearch.be/download/research_reports/research_note/OpenDataRN.pdf

[78] Pourquoi se préoccuper de la durabilité ? (n.d.). Retrieved 30 July 2017, from https://www.europeandataportal.eu/elearning/fr/module7/#/id/co-01

[79] Ibid.

3.4. Complexity of using the data for the average citizens

The average citizens who are willing to use the Open Data available on the Internet may not be able to do so. Although the data are freely available to everyone, it is not always straightforward to be able to process and use them. It requires indeed some adequate skills and tools, which are not at everyone's disposal. This can therefore create an imbalance between the users since the opening of the data would benefit mainly the "qualified" users[80].

Although the data providers generally give enough information on the published data (description of data, etc.) - what is referred to as metadata - to facilitate the data understanding, this remains insufficient for the average citizens[81]. The data providers should, for example, list the tools (software) that could be used by the citizens to process the data, or the governments could organise trainings that would enable citizens to acquire the necessary skills.

[80] L'Open Data risque de ne pas profiter d'abord aux citoyens ». (2016, July 20). *La Croix*. Retrieved from http://www.la-croix.com/France/Politique/L-Open-Data-risque-profiter-abord-citoyens-2016-07-20-1200777032

[81] World Bank Group. (2015). *Open Data for Sustainable Development* (Policy Note ICT01). Retrieved from http://pubdocs.worldbank.org/en/999161440616941994/Open-Data-for-Sustainable-Development.pdf

PART II: OPEN DATA IN THE POLICY-MAKING CONTEXT

This second part will focus on the use of Open Data in the policy-making context. For this purpose, the first section of this part will highlight the main issues faced by the policymaker when designing a policy. The second section will give a theoretical framework through a decision matrix that can help the policymaker to identify in which specific cases Open Data can be used.

1. Issues faced in the design of a policy

One of the main concerns that a policymaker has when designing a policy is making sure that the policy achieves the desired objectives by reaching the targeted groups (= effectiveness) at the lowest possible cost (=efficiency)[82]. In other words, the policymaker must ensure that the policy is designed in an effective and efficient way. To do so, the policymaker should have as much information as possible about the individuals in order to distinguish clearly the targeted groups from the non-targeted ones[83]. However, a problem of information asymmetry can prevent a policy from being effective and efficient. Indeed, information asymmetry happens when an actor has more or better information than the other one[84]. In the case of policy-making, it is obvious that the policymaker has less information about the individuals than the individuals themselves, making it complicated for the policymaker to know whether the individuals who were affected by the policy were the ones who were initially targeted.

This lack of information actually leads to two potential errors: the ***exclusion error*** (called Type I error) and the ***inclusion error*** (called Type II error)[85]. The table below allows to understand in which cases these errors could occur:

Table 3: Type I and II errors

	Targeted Group	Non-Targeted Group
Affected by the policy	No error	Inclusion Error – *Type II*
Not affected by the policy	Exclusion Error – *Type I*	No error

Source: Poverty alleviation policy targeting: a review of experiences in developing countries

[82] Estache, A. (2016). *The economics of regulation*.

[83] Lavallee, E., Olivier, A., Pasquier-Doumer, L., & Robilliard, A.-S. (2010). *Poverty alleviation policy targeting: a review of experiences in developing countries*. Institut de recherche pour le développement. Retrieved from http://www.dial.ird.fr/content/download/49726/380998/version/1/file/2010-10.pdf

[84] Investopedia. (2003, November 19). Asymmetric Information. Retrieved 30 July 2017, from http://www.investopedia.com/terms/a/asymmetricinformation.asp

[85] Smolensky, E., Reilly, S., & Evenhouse, E. (1995). Should Public Assistance Be Targeted? *Journal of Post Keynesian Economics*, pp. 3–28.

As can be seen in Table 3, the ***exclusion error*** occurs when the designed policy does not affect the targeted group while the ***inclusion error*** arises when the designed policy affects the non-targeted group. In order to have a policy that is effective and efficient, the inclusion and exclusion errors must be minimised.

To illustrate the two possible errors that might occur, the policy which aims at helping the individuals living below the poverty line, which is carried out by the Public Center for Social Action[86] in Belgium, can be taken as example. It is very often a cash support but it might also be an in-kind support depending on the financial situation of the individuals[87]. In this example, the aim of the policy is to grant an aid only to the individuals in need (= "targeted group") while avoiding that the aid is granted to the ones who do not need it (= "non-targeted group"). This is to minimise the risk of excluding those who need this assistance while minimising the risk of including those who do not need it. In other words, the exclusion error (Type I) must be minimised while minimising the inclusion error (Type II).

It should be noted that it is difficult to minimise the exclusion and inclusion errors simultaneously. In the case of the example, having a **more restrictive** aid policy would make it possible to minimise the **inclusion error** but it would increase the risk that the individuals who actually need the aid do not benefit from it (i.e. increase the risk of an exclusion error). On the contrary, having a **less restrictive** aid policy would allow to minimise the **exclusion error** but it would increase the risk that the individuals who do not need the aid benefit from it (i.e. increase the risk of an inclusion error). Therefore, there is a trade-off between either minimising the exclusion error or the inclusion error[88]. Generally, the minimisation of the inclusion error is preferred since the fiscal capacity of the governments is limited[89].

One solution to the problem of information asymmetry, which prevents the policymaker from distinguishing the targeted from the non-targeted group, is to have a self-targeting (or self-selection) scheme. Self-targeting consists of letting the individuals disclose their information by requiring them to make an application in order to benefit from a policy for which they

[86] CPAS = Centre Public d'Action Social

[87] CPAS. (n.d.). Retrieved 30 July 2017, from http://www.cpasbru.irisnet.be/fr/

[88] Lavallee, E., Olivier, A., Pasquier-Doumer, L., & Robilliard, A.-S. (2010). *Poverty alleviation policy targeting: a review of experiences in developing countries*. Institut de recherche pour le développement. Retrieved from http://www.dial.ird.fr/content/download/49726/380998/version/1/file/2010-10.pdf

[89] Smolensky, E., Reilly, S., & Evenhouse, E. (1995). Should Public Assistance Be Targeted? *Journal of Post Keynesian Economics*, pp. 3–28.

think they are eligible[90]. In the example of the aid policy, the individuals must, with the self-targeting scheme, fill in an application by providing their personal information in order to potentially get an aid. On the basis of the information, it can be seen whether they meet the conditions to be targeted by the policy or not. This generally disincentives the individuals who are not in need (i.e. the non-targeted group) to make the application since the application process is often tedious[91]. Although the self-targeting seems to overcome the information asymmetry issue faced by the policy-maker, there are still some problems that can arise. First, the group targeted by a policy may not be aware that a policy has been designed for them (= lack of information) or may not know whether they are eligible or not for a specific policy (= lack of education). Moreover, in the case of aid policies, people may feel stigmatised and may therefore decide not to benefit from the aid policy. Finally, individuals who are not targeted by the policy may want to falsify their personal information in order to become eligible for the policy[92].

To put it simply, due to a lack of data which leads to information asymmetry, the policymaker experiences some issues to design a policy that is efficient and effective.

2. Open Data in the policy design process using a decision matrix

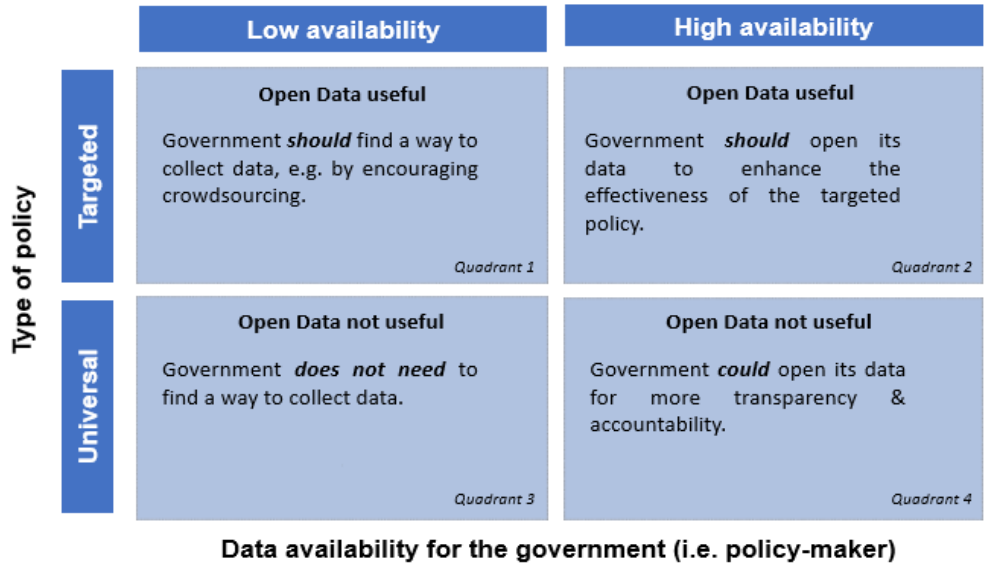
As it has been highlighted in the previous section, the policymaker faces a problem of information asymmetry, due mainly to a lack of data at its disposal, which prevents him to distinguish clearly the targeted group from the non-targeted one. One solution is to have a self-targeting scheme but, as it has been discussed previously, this solution has some drawbacks. That is the reason why instead of relying on a self-targeting scheme, the policy-maker (generally the government) could make use of the data that is potentially or already open to address the information asymmetry issue. In order to identify precisely the cases in which Open Data may be useful, the following two-dimensional decision matrix has been created.

[90] Lavallee, E., Olivier, A., Pasquier-Doumer, L., & Robilliard, A.-S. (2010). *Poverty alleviation policy targeting: a review of experiences in developing countries*. Institut de recherche pour le développement. Retrieved from http://www.dial.ird.fr/content/download/49726/380998/version/1/file/2010-10.pdf

[91] https://www.povertyactionlab.org/sites/default/files/publications/Identifying%20the%20Poor%20Through%20Self-Targeting_0.pdf

[92] Lavallee, E., Olivier, A., Pasquier-Doumer, L., & Robilliard, A.-S. (2010). *Poverty alleviation policy targeting: a review of experiences in developing countries*. Institut de recherche pour le développement. Retrieved from http://www.dial.ird.fr/content/download/49726/380998/version/1/file/2010-10.pdf

Figure 4: Open Data-Policy decision matrix



The matrix is composed of two axes:

- The vertical axis represents the type of policy: the policy set up by the government may be a universal policy (i.e. a policy designed for all individuals without exception) or a targeted policy (i.e. a policy designed for a specific group of individuals).
- The horizontal axis represents the extent to which the government has data at its disposal (low availability or high availability) for the implementation of a policy.

On the basis of these two criteria, several cases are possible:

- **Universal Policy:**

In the case of a universal policy, the policy-maker does not face any information asymmetry issue since it must not distinguish the targeted group from the non-targeted group. The availability of the data is therefore not a problem for the policy-maker and the use of Open Data to overcome the information asymmetry is not required here. To be precise, two cases must be considered:

  - ***Low Data Availability – Quadrant 3:***

The third quadrant describes a situation where data availability is low but the policy is not targeted anyway. In this case, the government does not need to find a way to get data and, consequently, making use of Open Data is not necessary.

- ***High Data Availability – Quadrant 4:***

In the case that data availability is high, the openness of the data by the government – which is the main Open Data provider – is not required given that there is no need to overcome any information asymmetry issue in the design of a universal policy. However, the opening of the data could allow an increase in the accountability and transparency of the government[93]. For example, the government of the UK made the data related to government spending open with the project called "Where Does My Money Go?". For each region of the UK, the amount spent by the government is disclosed with, in each case, the associated decomposition (health, education, defence, etc.)[94,95]. The citizens can therefore know exactly where the taxes levied by the government are spent, which leads to an increase in its transparency and accountability and a potential increase in the citizens' confidence in the government[96].

- **Targeted Policy:**

In the case of a targeted policy, the policy-maker faces an information asymmetry problem, which hinders its ability to clearly distinguish the targeted group from the non-targeted group. In this case, the use of Open Data could be helpful. To this end, two cases can be distinguished:

- ***Low Data Availability – Quadrant 1:***

If the government does not have enough data at its disposal to be able to implement an effective policy, facing therefore a risk of information asymmetry, it must find a way to collect the necessary data. The government could, for instance, encourage the participation of the citizens and stakeholders in the data collection, what is commonly referred to as crowdsourcing[97]. The data collected would then be made open, which would allow not only the government but also the citizens and other stakeholders to use them.

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[93] Center for city solutions and applied research. (2017). *City Open Data Policies*. National League of Cities. Retrieved from http://www.nlc.org/sites/default/files/2017-03/CSAR%20Open%20Data%20Report%20FINAL.pdf

[94] Where Does My Money Go? - Showing you where your taxes get spent. (n.d.). Retrieved 30 July 2017, from http://app.wheredoesmymoneygo.org//

[95] Center for city solutions and applied research. (2017). *City Open Data Policies*. National League of Cities. Retrieved from http://www.nlc.org/sites/default/files/2017-03/CSAR%20Open%20Data%20Report%20FINAL.pdf

[96] Ibid.

[97] Ubaldi, B. (2013). *Open Government Data: Towards empirical analysis of open government data initiatives* (OECD Working Papers on Public Governance No. 22). OECD. Retrieved from https://demo-ipp.nuvole.org/system/files/OECD-open-gov-data_3.pdf

Regarding the areas in which the government could make use of the crowdsourced data, it strongly depends on the areas in which the citizens and stakeholders are willing to contribute in the collection of data. In the Brussels-Capital Region, for instance, a "Winter Plan" is put in place during the extremely cold periods of the year to temporarily shelter the homeless who request this help[98]. However, these individuals may not be aware of the possibility of being hosted and the low data availability makes it difficult for the Region to identify the exact location of these homeless people. In this case, using crowdsourced data could be helpful. The Region could indeed create a mobile app so that the citizens can provide real-time data about the location of an encountered homeless individual. Once collected, it would be preferable if these data were open in order to potentially push other organisations to develop ideas to help the homeless not only during cold periods but also throughout the year. Moreover, crowdsourced data can also be used by the Region in order to develop other smart projects such as a just-in-time waste collection[99]. Currently, the bins are emptied on a determined frequency but the issues are that some of them are not emptied while filled to the brim whereas others are emptied while not being filled which leads to a waste of time for garbage collectors. Therefore, one solution could be to install so-called intelligent bins, which would give a signal to the garbage collectors when bins need to be emptied[100]. However, this solution is costly and all the bins of the Region cannot be equipped with this system. An alternative solution would be to make citizens contribute to the data collection (i.e. they can indicate via a mobile app whenever they see a filled bin), which can help the garbage collectors to target the filled bins.

While crowdsourced data could be an alternative when there is a low availability of data, it should be emphasised that ensuring that these data are complete, accurate and reliable before using them could be the main pitfall of this data collection method[101].

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[98] Brussels homeless policy now in force year-round | Flanders Today. (n.d.). Retrieved 30 July 2017, from http://www.flanderstoday.eu/current-affairs/brussels-homeless-policy-now-force-year-round

[99] van Dijk, A. (2015). *Smart Cities: How rapid advances in technology are reshaping our economy and society*. Deloitte. Retrieved from https://www2.deloitte.com/content/dam/Deloitte/tr/Documents/public-sector/deloitte-nl-ps-smart-cities-report.pdf

[100] Libre.be (n.d.). Bruxelles-Ville débourse 150.000 € pour des poubelles intelligentes sur le piétonnier. Retrieved 30 July 2017, from http://www.lalibre.be/regions/bruxelles/bruxelles-ville-debourse-150-000-pour-des-poubelles-intelligentes-sur-le-pietonnier-5640fb313570bccfaeea7f57

[101] Ubaldi, B. (2013). *Open Government Data: Towards empirical analysis of open government data initiatives* (OECD Working Papers on Public Governance No. 22). OECD. Retrieved from https://demo-ipp.nuvole.org/system/files/OECD-open-gov-data_3.pdf

- ***High Data Availability – Quadrant 2:***

In the event that the government has a significant amount of data at its disposal, the opening of the data might initially appear unnecessary. However, by having a large amount of data, the government may face a risk of "data overload", which refers to a situation where there is so much data available that the government may not know exactly how to use them[102]. In this case, opening the data, if it is not already the case, could allow the government to rely on the help of the stakeholders who could contribute to the identification of the data (e.g. by combining these data with other datasets) that could potentially improve the targeting of a specific policy by alleviating the information asymmetry issue. This nevertheless requires some co-operation between the government and the various stakeholders.

To illustrate this possibility (i.e. the second quadrant of the matrix), Part III will provide a detailed analysis of how Open Data can be used in the case of an environmental policy in the Brussels-Capital Region.

[102] Information Overload, Why it Matters and How to Combat It. (n.d.). Retrieved 30 July 2017, from https://www.interaction-design.org/literature/article/information-overload-why-it-matters-and-how-to-combat-it

PART III: OPEN DATA IN THE REDESIGN OF AN ENVIRONMENTAL POLICY

Over the last few decades, there has been increasing concern for environmental issues, and especially for the issues of global warming and air pollution. The first section of this part will deal with the current environmental issues and highlight what has been done internationally and at the EU level to tackle pollution. A focus will be made on the situation in Belgium and more precisely in the Brussels Capital Region. The redesign of one policy (the roof insulation subsidy) implemented by the Brussels Capital Region and chosen for its potential will be discussed using Open data in the second section of this part.

1. Current environmental issues and regulation

1.1. The environmental issues

It should be noted that global warming and air pollution are two of the main worldwide environmental issues that are primarily caused by human activities. While global warming is mainly a consequence of GHG emissions, air pollution (or atmospheric pollution) is due to the emission of atmospheric pollutants.

1.1.1. Global warming

According to the Intergovernmental Panel on Climate Change (IPCC), the Earth's temperature has already increased by approximately 0.74°C since the Industrial Revolution of the XIXth century and it is likely that it will rise by 1.1-6.4°C by 2100 if the issue of climate change is not addressed properly [103].

The GHG, that are namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO), water vapour (H_2O) and ozone (O_3) are gases that are present in the atmosphere by nature. Without their presence, the Earth's temperature would be below zero. They indeed allow the Earth to go from an average temperature of -18°C to an average temperature of 15°C. This phenomenon is called "*the natural greenhouse effect*"[104].

[103] Institut Bruxellois pour la Gestion de l'Environnement. (2016). *Plan régional Air-Climat-Energie*. Retrieved from http://document.environnement.brussels/opac_css/elecfile/PLAN_AIR_CLIMAT_ENERGIE_FR_DEF.pdf

[104] L'effet de serre naturel. (n.d.). Retrieved 30 July 2017, from http://www.climatechallenge.be/fr/des-infos-en-mots-et-en-images/le-changement-climatique/leffet-de-serre/leffet-de-serre-naturel.aspx

However, these GHG may also originate from human activities such as transport or residential heating, which require the use of fossil fuels (i.e. coal, oil and gas)[105]. This phenomenon is called "*additional or anthropogenic greenhouse effect"*[106]. These anthropogenic GHG have increased sharply since the Industrial Revolution and are responsible for global warming[107]. And, amongst all the greenhouse gases, carbon dioxide (CO_2) is the one that is the most responsible for the anthropogenic greenhouse effect[108].

1.1.2. Air pollution

The World Health Organisation (WHO) estimated that in 2012, the exposure to air pollution was responsible for the premature death of about 6.5 million people all around the world. Among those, 3.5 million died as a result of indoor air pollution while 3 million died as a result of outdoor air pollution[109]. It is indeed important to mention that a human is exposed to *indoor* and *outdoor air pollution*. Indoor air pollution can be caused by the use of cleaning products or by moisture for instance, whereas outdoor air pollution is, for example, due to transport, industry or residential heating[110].

The main pollutants that contribute to the air pollution are: sulphur dioxide (SO_2), nitrogen oxides (NOx), particulate matter (PM)[111], ozone (O_3), ammonia (NH_3), non-methane volatile organic compounds (NMVOCs), carbon monoxide (CO) and methane (CH_4). Some of them, such as NH_4 or O_3, contribute not only to air pollution but also to global warming[112].

Each type of pollutant has a specific adverse effect on either the environment or human health or both. For instance, the negative effects of these pollutants on human health can range from respiratory problems to heart attacks[113]. The table in Appendix C gives a brief description and

[105]L'origine anthropique des gaz à effet de serre. (n.d.). Retrieved 30 July 2017, from http://www.climatechallenge.be/fr/des-infos-en-mots-et-en-images/le-changement-climatique/les-hommes-et-le-climat/origine-anthropique.aspx

[106] L'effet de serre additionnel. (n.d.). Retrieved 30 July 2017, from http://www.climatechallenge.be/fr/des-infos-en-mots-et-en-images/le-changement-climatique/les-hommes-et-le-climat/effet-de-serre-additionnel.aspx

[107] Intergovernmental Panel on Climate Change. (2014). *Changements climatiques 2014: rapport de synthèse*. Retrieved from http://www.climat.be/files/9114/1500/9514/141102_IPCC_AR5_SYR_key_messages_FR.pdf

[108] Que sont les gaz à effet de serre. (n.d.). Retrieved from https://ec.europa.eu/clima/sites/campaign/pdf/gases_fr.pdf

[109]Pollution de l'air : pourquoi l'OMS tire la sonnette d'alarme. (2016, September 27). Retrieved 30 July 2017, from http://www.liberation.fr/planete/2016/09/27/pollution-de-l-air-pourquoi-l-oms-tire-la-sonnette-d-alarme_1512090

[110] Institut Bruxellois pour la Gestion de l'Environnement. (2016). *Plan régional Air-Climat-Energie*. Retrieved from http://document.environnement.brussels/opac_css/elecfile/PLAN_AIR_CLIMAT_ENERGIE_FR_DEF.pdf

[111] $PM_{2.5}$ (PM_{10}) are particles that have diameter of at most 2.5 (10) micrometres.

[112] European Environment Agency. (2016a). *Air quality in Europe - 2016 report* (EEA Report No. 28). Retrieved from https://www.eea.europa.eu/publications/air-quality-in-europe-2016

[113] Ibid.

presents the sources of each pollutant as well as their respective effects on health and the environment.

1.2. Regulatory framework

As highlighted previously, there exist current environmental issues that should be tackled. According to the 2006 report made by a British economist, Nicholas Stern, if the environmental situation were to remain the same, the costs would amount to 5% to 20% of the world GDP while the costs of implementing a global climate policy would "only" amount to 1% of the world GDP. There is therefore a real need to intervene both at the international and the European level through regulation in order to tackle the global warming and air pollution issues[114].

1.2.1. Regulation on greenhouse gases

Under the United Nations Framework Convention on Climate Change (UNFCCC), the 2015 Paris Agreement put the international target to not exceed an increase in the Earth temperature of 2°C compared to pre-industrial levels, therefore pushing countries, amongst other things, to reduce their GHG emissions[115].

The 2020 climate & energy package of the European Commission goes in line with the international conventions. This plan aims at achieving the following 3 objectives by **2020**:

- A reduction of the GHG emissions of ***20%*** (compared to 1990 levels);
- An increase in the share of renewable energies in EU energy consumption to reach ***20%***;
- An improvement of the energy efficiency of ***20%***[116].

In the same way, the objectives set by the European Union to be achieved by **2030** are:

- A reduction of the GHG emissions of ***at least 40%*** (compared to 1990 levels);
- An increase in the share of renewable energies in EU energy consumption to reach ***at least 27%***;

[114] Institut Bruxellois pour la Gestion de l'Environnement. (2016). *Plan régional Air-Climat-Energie*. Retrieved from http://document.environnement.brussels/opac_css/elecfile/PLAN_AIR_CLIMAT_ENERGIE_FR_DEF.pdf

[115] European Commission. (2016). *Impact Assessment - The proposal for binding annual greenhouse gas emission reductions by Member States from 2021 to 2030*. Retrieved from http://ec.europa.eu/transparency/regdoc/rep/10102/2016/EN/SWD-2016-247-F1-EN-MAIN-PART-1.PDF

[116] Paquet sur le climat et l'énergie à l'horizon 2020. (2016, November 23).Retrieved 30 July 2017, from https://ec.europa.eu/clima/policies/strategies/2020_fr

- An improvement of the energy efficiency of ***at least 27%***[117]**.**

In order to achieve these objectives, the European Commission has put in place several directives that must be transposed into national law by the EU-Member States. The directives, by definition, set the objectives to be achieved by the Member States within a certain period while leaving the choice of the means to achieve them to the Member States[118].

The following are the main directives put in place by the EU in order to achieve the objectives included in the 2020 as well as in the 2030 climate and energy packages:

- The **Directive 2012/27/UE** related to the energy efficiency and that pushes the EU Member States to compute a national indicative target for energy efficiency,
- The **Directive 2010/31** related to the energy performance of the buildings,
- The **Directive 2009/28** on the promotion of the use of energy from renewable sources,
- The **Directive 2003/87** on the exchange of GHG allowances within the European Union, more commonly known as the EU Emissions Trading System (EU ETS). It covers approximately 45%[119] of the EU GHG emissions[120].

To these directives is added the **Decision 406/2009**, which is called "Effort Sharing Decision" and aims at setting GHG emissions targets based on the GDP/capita of the EU Member States for the sectors that are not concerned by the EU ETS such as buildings, transports, agriculture and waste[121] (called the non-ETS sectors).

1.2.2. Regulation on atmospheric pollutants

At the international level, the Convention on Long-range Transboundary Air Pollution (LRTAP) signed in 1979 marked the beginning of a willingness on the part of countries to reduce emissions of air pollutants. As a result, 8 protocols followed such as the Gothenburg

[117] 2030 climate & energy framework. (2016, November 23). Retrieved 30 July 2017, from https://ec.europa.eu/clima/policies/strategies/2030_en

[118] La directive de l'Union européenne. (n.d.). Retrieved 30 July 2017, from http://eur-lex.europa.eu/legal-content/FR/TXT/?uri=URISERV%3Al14527

[119] Paquet sur le climat et l'énergie à l'horizon 2020. (2016, November 23).Retrieved 30 July 2017, from https://ec.europa.eu/clima/policies/strategies/2020_fr

[120] Institut Bruxellois pour la Gestion de l'Environnement. (2016). *Plan régional Air-Climat-Energie*. Retrieved from http://document.environnement.brussels/opac_css/elecfile/PLAN_AIR_CLIMAT_ENERGIE_FR_DEF.pdf

[121] Effort Sharing Decision. (2016, November 23). Retrieved 30 July 2017, from https://ec.europa.eu/clima/policies/effort_en

Protocol for instance - which was adopted in 1999 and revised in 2012 - with the aim to set ceilings for the main air pollutants[122].

At the EU level, there are mainly two Directives related to air pollution:

- The first one, the **Directive 2016/2284/EU**, is about the atmospheric pollutants **emissions** and aims at setting national emission ceilings[123],
- The second one is related to the atmospheric pollutants **concentration** (i.e. the ambient air quality): the **Directive 2008/50/EC**, which sets standards on ambient air quality[124].

It is important to note that while the ambient air quality depends upon the atmospheric pollutants emissions, the relationship between both is not direct because of the meteorological conditions[125].

1.3. The current situation in Belgium: a focus on the Brussels Capital Region

Following the various objectives set by the European Union in its climate & energy package, Belgium must reduce its non-ETS GHG emissions by 15% by 2020 compared to 2005. Given that the environment is a regional competence, each region of Belgium must contribute to this reduction of GHG emissions. On that point, an agreement was signed in 2015 for a "burden-sharing" between the 3 different regions[126]:

- Reduction of the non-ETS GHG emissions by 15.7% in the Flemish Region,
- Reduction of the non-ETS GHG emissions by 14.7% in the Walloon Region,
- Reduction of the non-ETS GHG emissions by 8.8% in the Brussels-Capital Region.

[122] UNECE's Convention on Long-range Transboundary Air Pollution celebrates 30th Anniversary - Air Pollution - Environmental Policy - UNECE. (n.d.-a). Retrieved 30 July 2017, from http://www.unece.org/env/lrtap/30anniversary.html

[123] European Commission. (n.d.-d). Reduction of national emissions of atmospheric pollutants. Retrieved 30 July 2017, from http://ec.europa.eu/environment/air/pollutants/ceilings.htm

[124] European Commission. (n.d.-b). EU approves new rules for Member States to drastically cut air pollution. Retrieved 30 July 2017, from http://europa.eu/rapid/press-release_MEMO-16-4372_en.htm

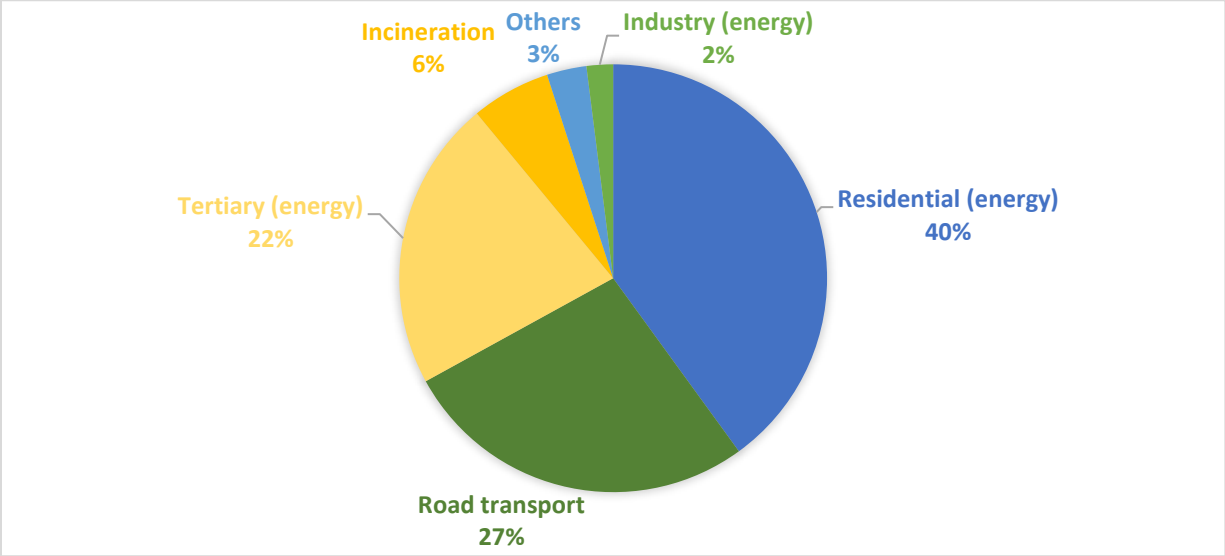
[125] Airparif - Pollution - Émissions ou concentrations ? (n.d.). Retrieved 30 July 2017, from https://www.airparif.asso.fr/pollution/emissions-ou-concentrations

[126] Marghem, M.-C., & Schauvliege, J. (2015, December). Accord politique sur le Burden Sharing intra-belge. Retrieved from http://www.climat.be/files/9914/5285/8927/burden_sharing_12-2015_FR.pdf

Concerning air pollution, the European Commission highlighted in June 2015 that Belgium does not seem to successfully meet the targets that are set in the EU ambient air quality directive, especially in the Brussels-Capital Region[127].

As a result, the Brussels Capital Region has put in place the so-called "Air-Climate-Energy plan" in June 2016 in order to reduce its GHG emissions by 30% by 2025 compared to 1990 and to improve the air quality in Brussels. This plan includes several measures that are related to road transport and buildings (mainly due to the tertiary and residential heating) to achieve these objectives. As can be seen in Figure 5, road transport and buildings are indeed the sectors that emit the most GHG (in CO_2 equivalents) in the Brussels-Capital Region[128].

Figure 5: GHG (in CO_2 equivalents) emissions in the Brussels Capital Region, by sector, in 2012



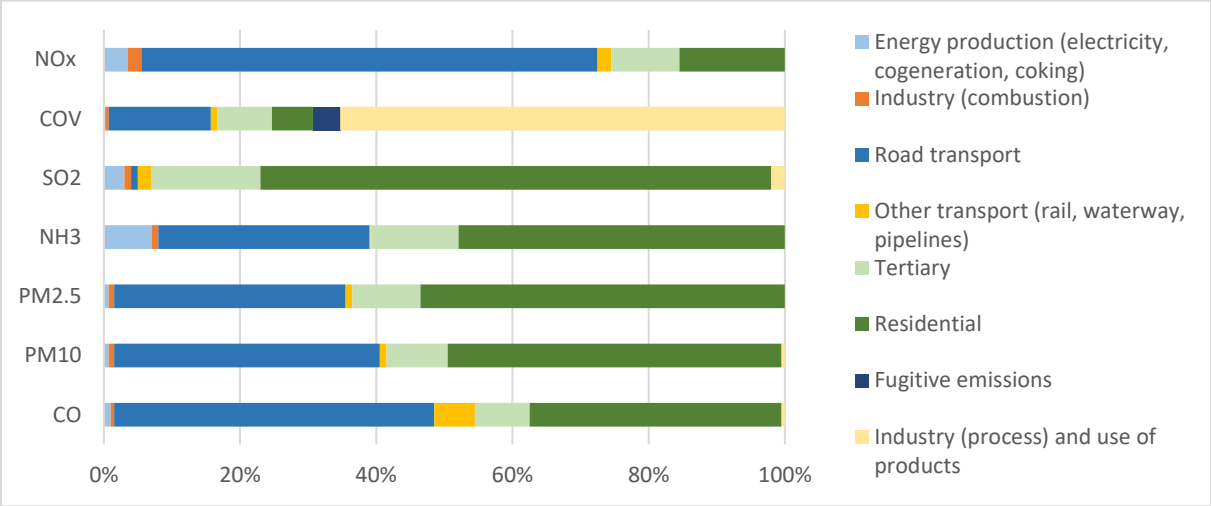
Source: Plan régional Air-Climat-Energie

It can also be seen in Figure 6 that the sources of the main atmospheric pollutants in the Brussels Capital Region are also road transport and buildings.

[127] European Commission. (2015, June). Commission refers Belgium and Bulgaria to Court and gives Sweden a final warning over poor air quality. Retrieved 30 July 2017, from http://europa.eu/rapid/press-release_IP-15-5197_en.htm

[128] Institut Bruxellois pour la Gestion de l'Environnement. (2016). *Plan régional Air-Climat-Energie*. Retrieved from http://document.environnement.brussels/opac_css/elecfile/PLAN_AIR_CLIMAT_ENERGIE_FR_DEF.pdf

Figure 6: Breakdown of the atmospheric pollutants emissions in the Brussels Capital Region, by sector, in 2013



Source: Plan régional Air-Climat-Energie

On the one hand, to address the emissions from road transport, one of the key measures of the plan is the introduction of low-emission zones in the Brussels-Capital Region. These areas may only be accessible to vehicles equipped with engines that comply with certain standards. This measure will come into force in 2018[129].

On the other hand, in order to address emissions from buildings, several measures have already been implemented to reduce the energy consumption in buildings. The energy subsidies, granted by the Brussels-Capital Region since 2004, are amongst one of the main measures. These subsidies are related to audits, heating and insulation[130]. As far as insulation is concerned, a good insulation would make it possible to avoid thermal losses. It should for instance be noted that about 15% to 20% of heat is lost by the roof[131]. The roof insulation is therefore an important issue that needs to be addressed. This particular subsidy policy will be analysed in more depth in the second section of this part and the redesign of this policy through the use of Open Data will be discussed.

2. Redesigning the current roof insulation subsidy policy

This section will focus on how Open Data can be used to improve the subsidy policy for roof insulation (i.e. redesigning the current policy). To do so, the first part will provide some information on the current roof insulation subsidy policy in the Brussels-Capital Region by

[129] http://celinefremault.be/fr/le-gouvernement-bruxellois-adopte-le-plan-air-climat-energie-pour-diminuer-de-30-les-gaz-a-effet-de-serre-dici-2025-et-ameliorer-la-qualite-de-lair

[130] http://www.environnement.brussels/thematiques/energie/primes-et-incitants/les-primes-energie-en-2017-la-continuite

[131] http://www.alcor-controles.fr/actualites-et-informations/renovation-energetique-deperditions-thermiques.html

detailing the procedure to get a subsidy and providing some key figures on this policy. The second part will focus on the redesign of the current roof insulation subsidy using Open Data and, for this purpose, a comparison between the current policy and the potential new policy (i.e. the redesigned policy using Open Data) will be made in terms of reduction of CO_2 and atmospheric pollutants emissions.

2.1. The current roof insulation subsidy policy in the Brussels-Capital Region

To encourage the population to undertake renovation work in order to improve the energy performance of their respective houses, the Brussels-Capital Region grants different types of subsidies. The latter are mainly related to audits (category A), insulation (category B) and heating (category C). As far as category B is concerned, they are granted for the insulation of roofs (B1), walls (B2), floors (B3) and windows (B4). The focus will be made on the roof insulation subsidies, which are more commonly called the "B1 subsidies"[132].

2.1.1. Procedure for granting roof insulation subsidy

2.1.1.1. Conditions to be fulfilled

The subsidies are granted both to individuals and professionals and on a ***voluntary basis*** (i.e. ***self-targeting***). In order to receive a subsidy, an application must be filed within a period of maximum 4 months after the renovation works are finished. Moreover, the subsidy is exclusively reserved for buildings older than 10 years[133]. Furthermore, in order to get the roof insulation subsidy, the insulating material must meet a condition relating to its thermal resistance (R). The latter is measured in square metres-kelvins per watt (m². K/W). The greater the coefficient of thermal resistance, the more the material is insulating[134]. In the case of the roof insulation subsidy, it is required that the material has a thermal resistance of at least 4 m². K/W[135].

[132]Institut Bruxellois pour la Gestion de l'Environnement. (2017, February). Primes 2017: Synthèse des incitants financiers à l'achat et à la rénovation des logements en Région de Bruxelles-Capitale.
[133] Ibid.
[134] La résistance thermique d'une couche de matériau (R). (n.d.-a). Retrieved 30 July 2017, from https://www.energieplus-lesite.be/index.php?id=16889#c20932567
[135]Isolation du toit. (2016, December 19).Retrieved 30 July 2017, from http://www.environnement.brussels/thematiques/energie/primes-et-incitants/les-primes-en-2017/primes-b-isolation-et-ventilation-0

2.1.1.2. The applicant categories

The amount of subsidy varies according to the category to which the applicant belongs. There are, indeed, three categories: A, B & C. The way in which these categories are allocated is different depending on whether the applicant is an individual or a professional[136].

- *For individuals:*

Individuals, by default, are part of category A. But, depending on the taxable income and on whether being isolated or in a couple, the households can belong to either category B or C (as shown in Table 4)[137].

Table 4: Allocation of categories according to taxable income (Y) and marital status

	Category A	Category B	Category C
Isolated	Y ≥ € 67,050.72	€ 33,525.36 ≤ Y ≤ € 67,050.72	Y ≤ € 33,525.36
Couple	Y ≥ € 82,050.72	€ 48,525.36 ≤ Y ≤ € 82,050.72	Y ≤ € 48,525.36

Source: Primes 2017 - Synthèse des incitants financiers à l'achat et à la rénovation des logements en Région de Bruxelles-Capitale.

It should be noted that, subject to certain conditions, the landlords might be considered to fall under category C[138].

- *For professionals:*

Legal entities are part of category A by default. Since 2016, communities such as nurseries, schools, retirement homes, universities (since 2017), etc. are entitled to receive a subsidy and are automatically belonging to category C[139].

[136]Quelle est ma catégorie de demandeur ? (2016, December 20). Retrieved 30 July 2017, from http://www.environnement.brussels/thematiques/energie/primes-et-incitants/les-primes-energie-en-2017-la-continuite/resume-des-0

[137] Institut Bruxellois pour la Gestion de l'Environnement. (2017, February). Primes 2017: Synthèse des incitants financiers à l'achat et à la rénovation des logements en Région de Bruxelles-Capitale.

[138]Quelle est ma catégorie de demandeur ? (2016, December 20). Retrieved 30 July 2017, from http://www.environnement.brussels/thematiques/energie/primes-et-incitants/les-primes-energie-en-2017-la-continuite/resume-des-0

[139]Les primes énergie en 2016. (2015, October 5). [Text]. Retrieved 30 July 2017, from http://www.environnement.brussels/thematiques/energie/primes-et-incitants/historique-des-primes/les-primes-energie-en-2016

2.1.1.3. The amounts of subsidy

The amount of the subsidies granted by the Brussels-Capital Region depends upon the categories in which the applicants belong. Some bonuses are also awarded if the applicant makes use of a natural insulating material or if the thermal resistance (R) largely exceeds the minimum thermal resistance required to be eligible for the subsidy[140]. The following table shows the possible scenarios:

Table 5: The amounts of subsidy depending on the categories

	Category A	Category B	Category C
Amount of the subsidy	€ 15/m²	€ 20/m²	€ 25/m²
Bonus	+ € 10/m² if R ≥ 9 m². K/W		
	+ € 10/m² if natural insulating material		

Source: Primes 2017 - Synthèse des incitants financiers à l'achat et à la rénovation des logements en Région de Bruxelles-Capitale.

2.1.2. Key figures on the current roof insulation subsidy policy

Although the energy subsidy scheme was introduced in 2004 in the Brussels-Capital Region, the Brussels Institute for Environmental Management[141] provided data about the roof insulation subsidy only for the period going from 2009 to 2016.

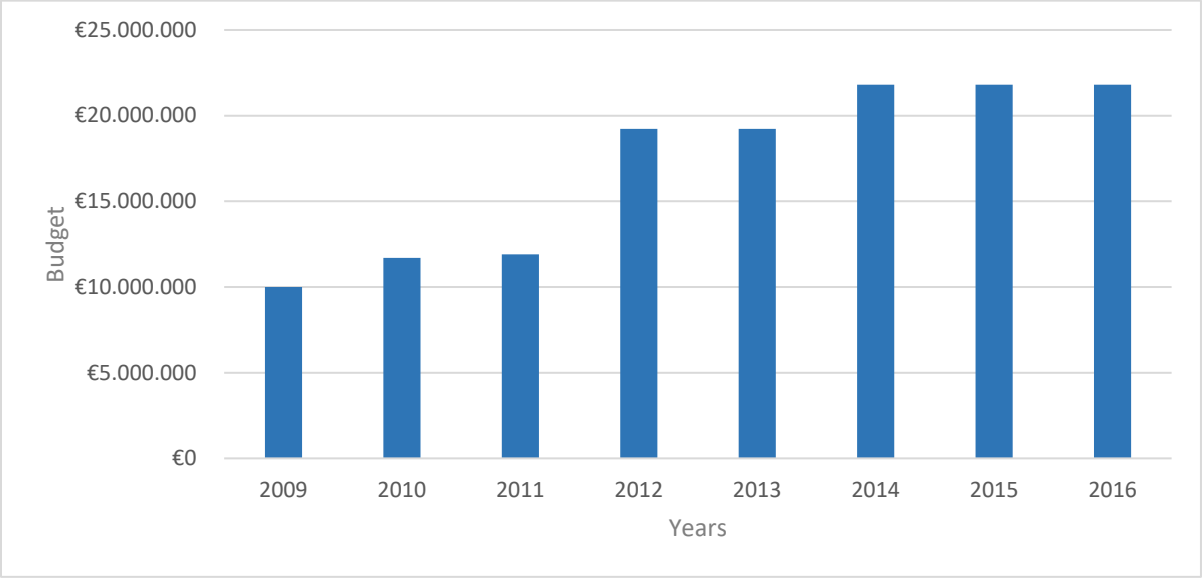
The budget allocated by the Brussels-Capital Region to energy subsidies is drawn up on an annual basis. Although the subsidy budget is allocated to three categories, namely audit, heating and insulation, there is no fixed amount dedicated to a specific category or subcategory. This means that, for instance, anyone can benefit from the roof insulation subsidy as long as the total budget for the subsidies as a whole is not exceeded.

As can be seen in Figure 7, the budget allocated to energy subsidies has more than doubled between 2009 and 2016, which proves that there is a desire on the part of the Brussels-Capital Region to incentivise the citizens to reduce their air pollutants and greenhouse gases emissions linked to energy consumption.

[140] Institut Bruxellois pour la Gestion de l'Environnement. (2017, February). Primes 2017: Synthèse des incitants financiers à l'achat et à la rénovation des logements en Région de Bruxelles-Capitale.

[141] Institut Bruxellois pour la Gestion de l'Environnement (IBGE)

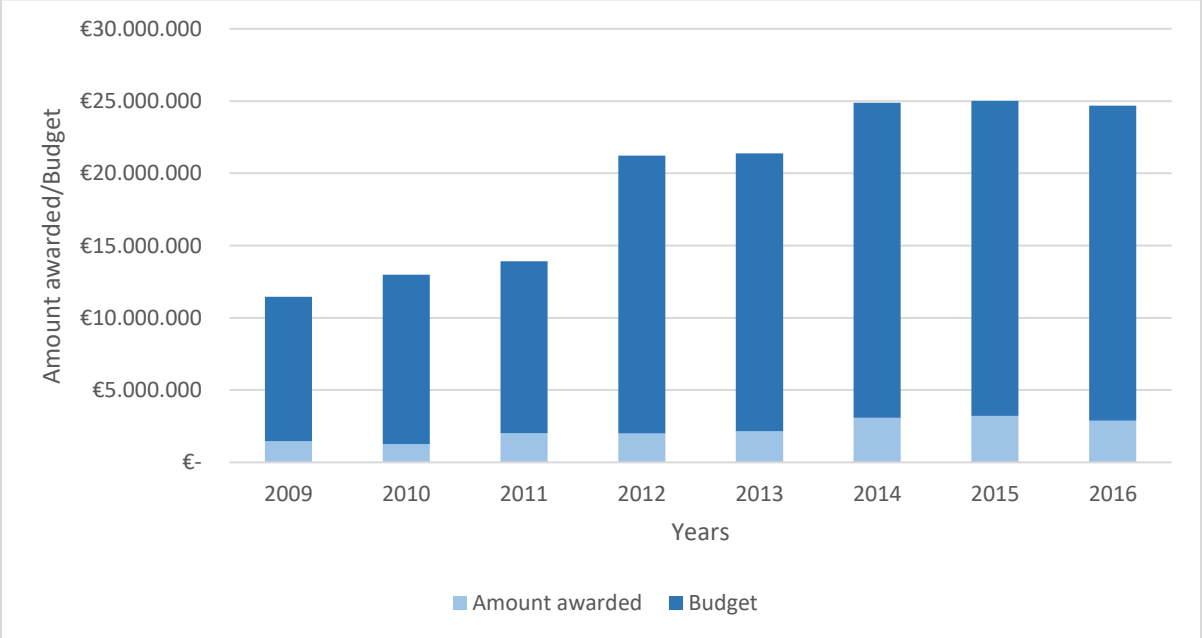
Figure 7: The budget allocated by the Brussels-Capital Region to energy subsidies, 2009-2016



Source: The Brussels Institute for Environmental Management

Figure 8 gives an overview of the annual share of the roof insulation subsidy in the total annual budget. On average, 13% of the total budget allocated annually to energy subsidies is devoted only to the roof insulation subsidy.

Figure 8: The annual share of the roof insulation subsidy in the total budget of the Brussels-Capital Region, 2009-2016

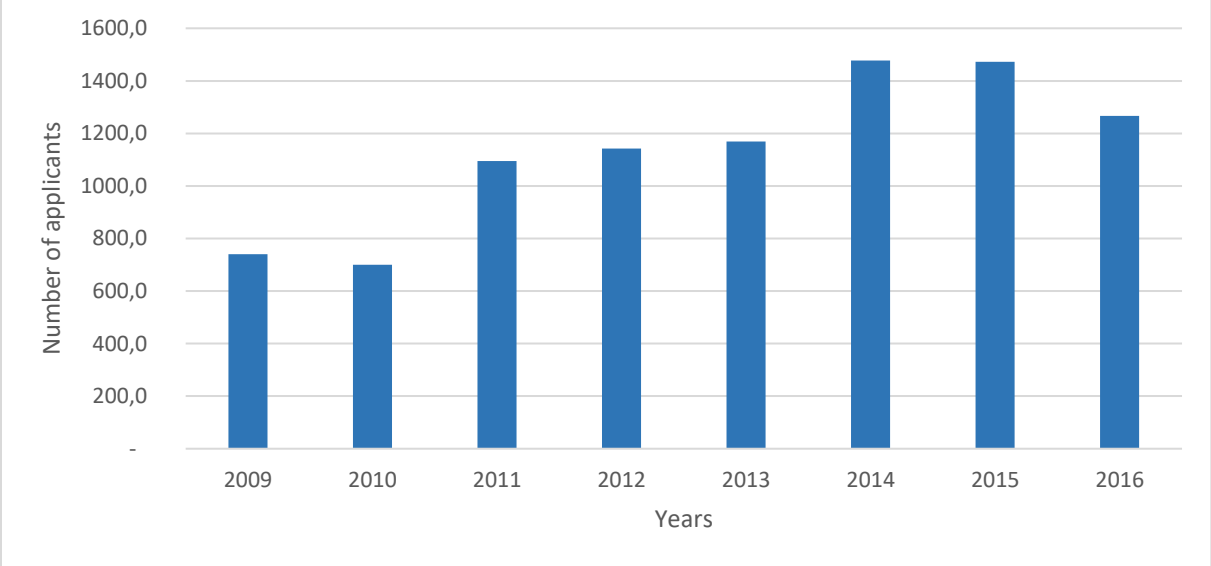


Source: The Brussels Institute for Environmental Management

As can be seen in Figure 9, between 2009 and 2016, the number of applicants who received a roof insulation subsidy has doubled to reach 1288 applicants in 2016. Moreover, it should be

noted that, although the energy subsidy scheme was made available by the Brussels-Capital Region to communities since 2016, it has not been a success. In fact, only 33 communities benefited from the energy subsidies, 7 of which received a roof insulation subsidy[142]

Figure 9: Number of applicants who benefited from a roof insulation subsidy in the Brussels-Capital Region, 2009-2016



Source: The Brussels Institute for Environmental Management

2.2. Redesign of the current roof insulation subsidy using Open Data

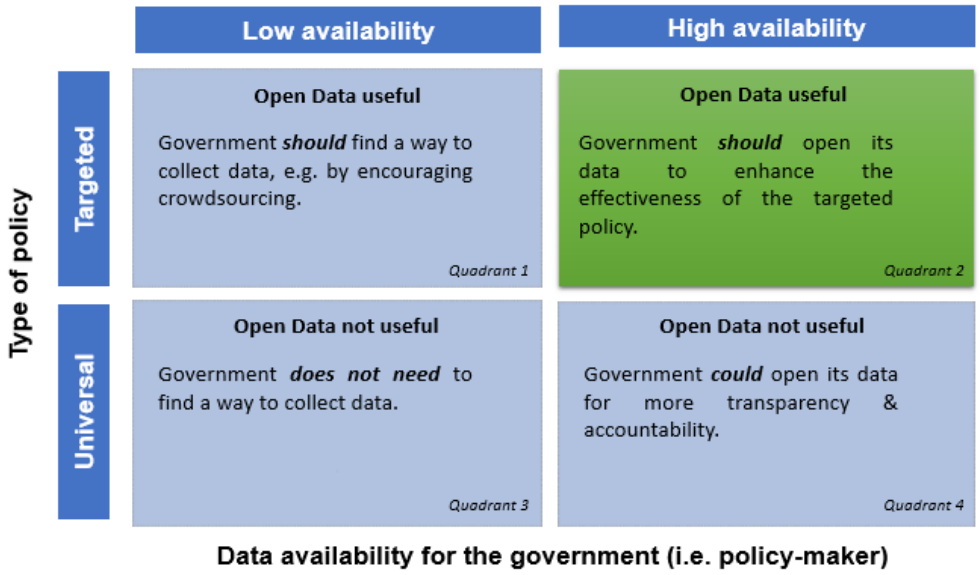
The fact that the granting of the roof insulation subsidies (and energy subsidies in general) is currently made on a ***self-targeting basis*** may lead to some issues, as discussed in Part II. On the one hand, a possible mistargeting could arise with the current policy. It may be, indeed, that those who apply for roof insulation subsidies are not those who really need it. On the other hand, there may be a lack of information that could explain the fact that people are not informed of the possibility of receiving subsidies. The Brussels-Capital region realised this lack of information and decided, in May 2017, to launch an advertising campaign to raise public awareness about the possibility of receiving roof insulation subsidies (and energy subsidies in general). But, to be able to tackle these two main issues and improve the roof insulation subsidy policy in force, the use of Open Data could be the solution. The redesign of the current policy will be discussed throughout this section.

[142]DH.be. (n.d.). Bruxelles: Les primes énergie s'ouvrent aux universités. Retrieved 30 July 2017, from http://www.dhnet.be/regions/bruxelles/bruxelles-les-primes-energie-s-ouvrent-aux-universites-589a28abcd702bc3190ce112

2.2.1. The need for Open Data in the context of the roof insulation subsidy

In order to know whether Open Data can be useful in the case of this environmental policy (i.e. the roof insulation subsidy) in the Brussels-Capital Region, the decision matrix developed in Part II can be used.

Figure 10: Open Data-Policy matrix in the context of the roof insulation subsidy policy



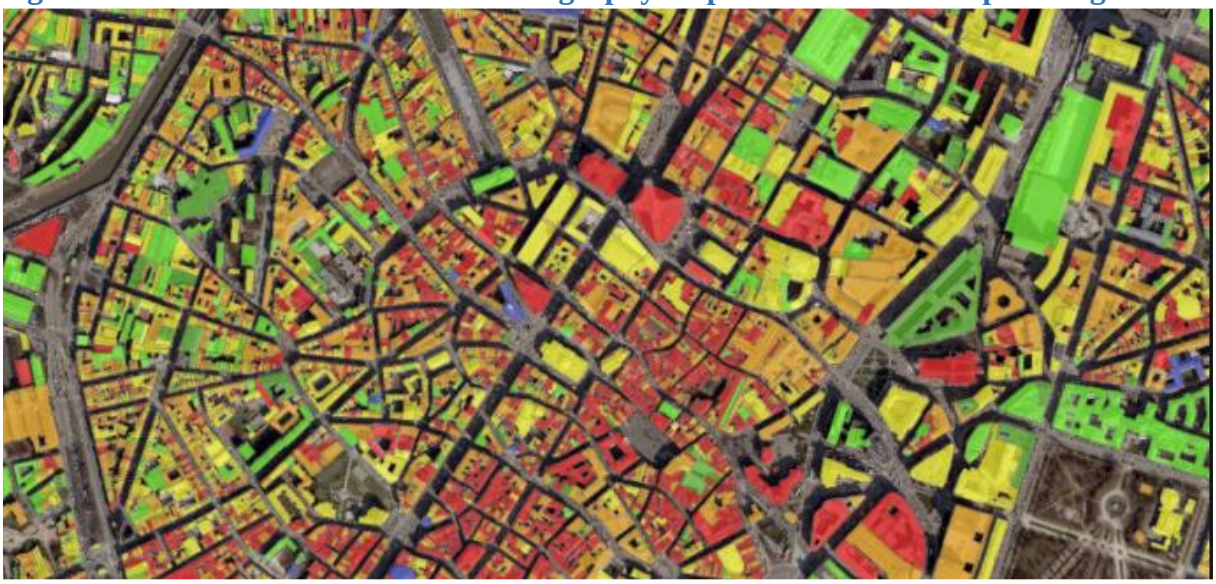
The roof insulation subsidy policy can be seen as a so-called "targeted policy" since it targets a specific group: the houses with poorly insulated roofs. Moreover, as it will be seen throughout this part, the policy-maker – which is, in this case, the Brussels Capital Region through the Brussels Institute for Environmental Management – has enough data at its disposal. It can thus be concluded that the roof insulation subsidy policy refers to the quadrant 2 of the matrix and, therefore, that Open Data could be useful.

2.2.2. Potential new procedure for granting roof insulation subsidy

The decision to grant a roof insulation subsidy could be made with a ***targeted subsidy policy*** rather than with a ***self-targeted subsidy policy,*** as currently in force. As it has been seen in section 2.2.1. with the decision matrix, the use of open data could indeed enable the Brussels-Capital Region to cope with the information asymmetry issue and be able to target houses that are poorly insulated by granting them a subsidy. In order to determine the extent to which a house is well or poorly insulated, an aerial infrared thermography of the building roofs of the Brussels-Capital Region is available on the website of the Brussels Institute for

Environmental Management[143]. This aerial thermography was carried out by Eurosense Belfotop BVBA[144] on the 29th and the 30th of December 2008 at the request of the Brussels Institute for Environmental Management[145]. An aerial infrared thermography is a technique that allows to estimate the heat losses emitted by the roofs via an aircraft with an on-board thermal camera[146]. Figure 11 gives an overview of the map that is available on the website.

Figure 11: Overview of the aerial thermography map of the Brussels-Capital Region



Source : http://geoportal.ibgebim.be/webgis/thermographie.phtml

As can be seen in Figure 11, the roofs of the houses can have different colours. There are in fact 6 possible colours in total. Each of these gives an indication about the level of thermal losses emitted by the roofs. As shown in Table 6, the colours go from blue to red in an ascending order. A blue roof indeed indicates that the thermal losses are not perceptible, meaning that the building roof may be well insulated while a red roof indicates that the thermal losses are very high, which could suggest that the building roof is not insulated at all.

[143] Thermographie aérienne. (n.d.). Retrieved 30 July 2017, from http://geoportal.ibgebim.be/webgis/thermographie.phtml
[144] Eurosense Belfotop BVBA is a company specialized in geo information services.
[145] Thermographie aérienne. (n.d.). Retrieved 30 July 2017, from http://geoportal.ibgebim.be/webgis/thermographie.phtml
[146] Eurosense Belfotop BVBA. (2012). *Thermographie aérienne infrarouge de la ville du Luxembourg*.

Table 6: Thermal losses legend of the aerial thermography of the Brussels-Capital Region

	Non-perceptible thermal losses
	Very low thermal losses
	Low thermal losses
	Average thermal losses
	High thermal losses
	Very high thermal losses

Although the aerial thermography map is useful to get a glimpse of the heat losses emitted by the buildings roofs, it is important to be cautious about the interpretation of the map. It must indeed be ensured that the building in question was heated in the period in which the aerial thermography was carried out[147]. The aerial thermography of the Brussels-Capital Region was carried out on the 29th and the 30th of December 2008 between 10 pm and 4 am. It was thus made during the winter, which means that the houses were probably heated. However, as this period also coincides with the Christmas holidays, it may be possible that the houses were not inhabited at the moment of the thermography (i.e. the heaters were not working). Furthermore, in the event that the roofs are covered with gravels, solar panels or vegetation, this may distort the interpretation of the map since aerial thermography will measure the thermal loss of the components above the roof and not of the roof itself[148].

2.2.3. Data and methodology

In order to be able to carry out the comparison between the self-targeted subsidy policy and the targeted subsidy policy in terms of energy savings, reduction of CO_2 and atmospheric pollutants emissions (section 2.2.4), different datasets have been collected. Section 2.2.3.1. will give a description of those datasets, section 2.2.3.2. will determine whether those are open data or not and section 2.2.3.3. will explain the methodology adopted to obtain the results.

[147] Interprétation de la carte. (2014, October 24). [Text]. Retrieved 30 July 2017, from http://www.environnement.brussels/thematiques/energie/economiser-votre-energie/pour-vous-aider/thermographie-aerienne/interpretation

[148] Eurosense Belfotop BVBA. (2012). *Thermographie aérienne infrarouge de la ville du Luxembourg*.

2.2.3.1. Description of the data

A total of three sets of data were collected from different institutions.

The first database was provided by the Brussels Institute for Environmental Management[149]. This dataset contains all the mailing addresses of the buildings of the Brussels-Capital Region that received a roof insulation subsidy from 2009 to 2016. The postal addresses are mostly in French although some addresses are in Dutch. In addition, at each mailing address is associated the amount of subsidy granted, the insulated roof area (in m²) and the thermal resistance (R) of the insulating material used (i.e. the thermal resistance after the renovation works). However, the data on the insulated roof area and the thermal resistance R are only available for the building that received a subsidy from 2012. This database will be called "**Subsidy Dataset"**.

The second database was provided by Eurosense Belfotop BVBA[150]. This contains the mailing addresses of buildings in the Brussels-Capital Region with a relative **average** heat loss value associated to each address. It should be noted that within the same roof there might be different thermal losses values. Therefore, in order to have only one value per roof, the average of the relative values of the heat losses was calculated, and this is what appears in the dataset provided. As can be seen from Table 7, based on the relative heat loss value, the thermal losses legend has been established, which enables the creation of the 2008 aerial thermography map. However, the dataset provided by Eurosense Belfotop BVBA contains "only" 74.4% of the building mailing addresses of the Region. This database will be referred to as **"Thermography Dataset"**.

Table 7: Thermal losses legend of the aerial thermography of the Brussels-Capital Region based on the relative heat loss value

	Relative average heat loss value	Interpretation
	2,063.896104 – 2,336.432558	Non-perceptible thermal losses
	2,336.432559 – 2,395.369532	Very low thermal losses
	2,395.369533 – 2,423.593407	Low thermal losses
	2,423.593408 – 2,445.678024	Average thermal losses
	2,445.678025 – 2,471.819372	High thermal losses
	2,471.819373 – 2,613.200000	Very high thermal losses

[149] Institut Bruxellois pour la Gestion de l'Environnement (IBGE)

[150] Eurosense Belfotop BVBA is a company specialized in geo information services.

Finally, a third database was available on the Computer Center for the Brussels-Capital Region[151] website[152]. This database contains the buildings' postal addresses of the Brussels-Capital Region in French and Dutch with the associated building floor area measured in m² (footprint of the building). This database will be named **"Area Dataset"**.

The following table summarises the description of the 3 datasets:

Table 8: Summary of the description of the datasets collected

	Subsidy Dataset	Thermography Dataset	Area Dataset
Provider	Brussels Institute for Environmental Management	Eurosense Belfotop BVBA	Computer Center for the Brussels Region
Content	-Mailing addresses of the applicants -Amount of subsidy received -Insulated roof area (since 2012) -Post-thermal resistance R (since 2012)	- 74.4% of the building mailing addresses - Relative average heat loss values	- Buildings postal addresses in French & Dutch - Floor area (in m²)
Period	2009-2016	2008	2017

2.2.3.2. Characterisation of the datasets

In order to be able to assess whether the 3 datasets collected can be considered as Open Data or not, the 4 criteria explained in the first section of Part I will be used. These criteria are namely: accessibility, machine readability, cost and rights.

- **Subsidy Dataset:**

- ***Accessibility:*** The dataset is not accessible to everyone but only to those who submit a request to the Brussels Institute for Environmental Management (provider), justifying the purpose for which the data will be used.
- ***Machine readability:*** The dataset is available in Excel format, which is easily readable by the computer.
- ***Cost:*** The dataset is available for free.
- ***Rights:*** The dataset can only be used for a specific purpose (the paper, here) and cannot be transmitted. In other words, the dataset is not under an open licence. A confidentiality

[151] Centre d'Informatique pour la Région Bruxelloise (CIRB)

[152] CIRB-CIBG-BRIC. (n.d.). Retrieved 30 July 2017, from http://cirb.brussels/fr/nos-solutions/urbis-solutions/telechargement

agreement must be signed between the user and the provider (The Brussels Institute for Environmental Management) in order to have access to the dataset (see appendix D).

On the basis of these four criteria, the **Subsidy Dataset** cannot be considered as being open. And it is unlikely that the dataset will be open in the future since it contains the amount of subsidy received for each building of the Brussels-Capital Region, which may be perceived as confidential data.

- **Thermography Dataset:**

- ***Accessibility:*** The aerial thermography map itself is available to everyone[153], while it is not the case for the dataset that was used to make the map.
- ***Machine readability:*** The dataset is available in Excel format, which is easily readable by the computer.
- ***Cost:*** The dataset is available for free.
- ***Rights:*** The dataset can only be used for a specific purpose (the paper, here) and cannot be transmitted. In other words, the dataset is not under an open licence. A confidentiality agreement must be signed between the user and the provider (Eurosense Belfotop BVBA) in order to have access to the dataset (see appendix E).

The 4 criteria seem to indicate that the **Thermography Dataset** is not open. However, given that the aerial thermography map is already available on the Internet, the dataset relating thereto could potentially be open in the near future.

- **Area Dataset:**

- ***Accessibility:*** The dataset is available to everyone on the Internet[154].
- ***Machine readability:*** The data is in .dbf format. This format is readable with a software such as Microsoft Excel.
- ***Cost:*** The dataset is available for free.
- ***Rights:*** The data can be reused and republished as many times as desired. This dataset is indeed under an open licence and compatible with the ODC-BY licence, which allows a re-use of the data provided that there is a paternity mention.

Based on the 4 criteria, the **Area Dataset** is considered as being open.

[153] Thermographie aérienne. (n.d.). Retrieved 30 July 2017, from http://geoportal.ibgebim.be/webgis/thermographie.phtml

[154] CIRB-CIBG-BRIC. (n.d.). Retrieved 30 July 2017, from http://cirb.brussels/fr/nos-solutions/urbis-solutions/telechargement

- **Summary of the datasets openness:**

The following table summarises the type of data (open data; potential open data; closed data) for each dataset based on the 4 criteria.

Table 9: Summary of the datasets openness based on the 4 criteria

	Subsidy Dataset	Thermography Dataset	Area Dataset
Accessibility	-	+/-	+
Machine readability	+	+	+
Cost[155]	+	+	+
Rights	-	-	+
Type of Data	**Closed Data**	**Potential Open Data**	**Open Data**

2.2.3.3. Methodology

In order to perform a data analysis in section 2.2.4 that will allow to make a comparison between the ***self-targeted subsidy policy*** and the ***targeted subsidy policy*** in terms of energy savings, reduction of CO_2 and atmospheric pollutants emissions, some data manipulations and assumptions must be made.

- **Datasets manipulation:**

The various manipulations and combinations of the different datasets were carried out with Microsoft Access software and more precisely using the SQL[156] computer language, which is a language that allows to work with databases. It should be noted that the different datasets were combined thanks to the houses addresses, which are components that are common to the 3 datasets.

First, in the Thermography Dataset, each address has been associated with a relative average heat loss value and, based on these values, a colour has been assigned. However, to facilitate the data analysis, each colour has been assigned to a class number that ranges from 1 to 6 as shown in the following table.

[155] (+) = free ; (-) = costly
[156] Structured Query Language

Table 10: Attribution of the classes based on the colours

	Relative average heat loss value	Interpretation	Class
	2,063.896104 – 2,336.432558	Non-perceptible thermal losses	1
	2,336.432559 – 2,395.369532	Very low thermal losses	2
	2,395.369533 – 2,423.593407	Low thermal losses	3
	2,423.593408 – 2,445.678024	Average thermal losses	4
	2,445.678025 – 2,471.819372	High thermal losses	5
	2,471.819373 – 2,613.200000	Very high thermal losses	6

Then, in order to have the associated floor area for each postal address that is part of the Thermography Dataset without having to refer to the Area Dataset, a combination between the two datasets has been realised. As a result, the associated class number and floor area of each house appeared in the same dataset (i.e. Thermography Dataset).

Finally, in order to know in which class the houses that requested a roof insulation subsidy belong as well as their respective floor area, the Subsidy Dataset and the Thermography Dataset were combined. However, before linking these two datasets, it was necessary to translate the Dutch postal addresses of the Subsidy Dataset in French. This translation was made possible thanks to the combination of the Subsidy Dataset with the Area Dataset given the fact that the Area Dataset contains all the postal addresses of the Brussels-Capital Region in French and Dutch.

- **Underlying assumptions:**

In order to carry out the data analysis of section 2.2.4, it is necessary to have the value of the 3 following variables:

- Area: Insulated roof area
- R_pre: Pre-thermal resistance (i.e. thermal resistance of the initial roof)
- R_post: Post-thermal resistance (i.e. thermal resistance of the roof after renovation)

First, regarding the insulated roof area, this information is available for houses that have applied for a subsidy from 2012, as indicated in section 2.2.3.1. For these houses, no assumption has been made and the available information will be used in the data analysis. For the other houses (i.e. those that have applied for a subsidy before 2012 and those that have not yet benefited from a subsidy), the floor area has been used as proxy for the roof area, although

the latter is usually larger than the floor area given that a large part of the roofs of houses in the Brussels-Capital Region are sloping roofs. The assumption that they isolate the entire surface of their roof has also been made for these houses.

Then, for the pre-thermal resistance (measured in m². K/W), no data was available. Therefore, for each class, a range of R_pre values have been created taking into account the fact that the greater the coefficient of thermal resistance, the more the material is insulating. The R_pre values were then assigned randomly within a class. The smallest value 0.10 was chosen arbitrarily while the largest value 3.99 was chosen taking into account that some of the houses of class 1 that applied for a subsidy have a R_post of 4, meaning that the R_pre of class 1 houses must be lower than 4. Then, based on the smallest and the largest value, 6 ranges have been created with the same length, as can be seen in Table 11.

Finally, with respect to post-thermal resistance (measured in m². K/W) this information was only available, as for the insulated roof area, for houses that have applied for a subsidy from 2012 and this value ranges from 4 to 10. Therefore, for the houses for which this information was not available, because they have applied for a subsidy before 2012 or because they simply did not apply for a subsidy, a value between 4 and 10 was randomly assigned.

Table 11: Pre and post thermal resistance associated to each class

	Class	R_Pre (in m². K/W)	R_Post (in m². K/W)
	1	3.35 – 3.99	4 – 10
	2	2.70 – 3.34	4 – 10
	3	2.05 – 2.69	4 – 10
	4	1.4 – 2.04	4 – 10
	5	0.75 – 1.39	4 – 10
	6	0.10 – 0.74	4 – 10

- **Resulting databases:**

The two following databases result from the various manipulations and assumptions taken:

Subsidy Dataset
Building postal address
Relative average heat loss value
Class
Amount Received
Year
R_pre
R_post
Area

Thermography Dataset
Building postal address
Relative average heat loss value
Class
R_pre
R_post
Area

- **Formulas used:**

In order to measure the energy savings, CO2 and air pollutants emissions reduction values resulting from roof insulation through the granted subsidies and therefore be able to compare the ***self-targeted subsidy policy*** with the ***targeted subsidy policy***, the following formulas were used.

- *Energy savings:*

Given that the heat loss per year (assuming that the houses are heated every day) is given by the formula (1)[157,158], the energy savings which are computed by subtracting the heat loss after roof insulating from the heat loss before roof insulation, can be computed based on formula (2)[159].

$$H = \frac{A \,.\, U \,.\, (t_i - t_o) \,.\, 8{,}760}{1{,}000} \qquad (1)$$

[157]Heat Loss from Buildings. (n.d.-a). Retrieved 30 July 2017, from http://www.engineeringtoolbox.com/heat-loss-buildings-d_113.html

[158] Cantillon, E. (2016). *Environmental Economics- Group Assignment 2: Energy Efficiency in the Brussels Capital Region*.

[159] Ibid.

Consequently,

$$\Delta H = H_{pre} - H_{post} = \frac{A \,.\, (U_{pre} - U_{post}) \,.\, (t_i - t_o) \,.\, 8{,}760}{1{,}000} \quad (2)$$

Where:

- H = heat loss (kWh/year)
- ΔH = energy savings per year (kWh/year)
- A = insulated roof area (m²)
- $U_{pre;\ post} = \frac{1}{R_{pre\ ;\ post}}$ = overall heat transmission coefficient (W/m²K)
- t_i = inside air temperature (°C) – *assumed to be 19 °C*[160]
- t_o = outside air temperature (°C) – *assumed to be 10.7 °C*[161]
- $(t_i - t_o)$ = difference between the inside and outside temperature (K[162])
- 8,760 = number of hours in one year (h/year)
- $\frac{1}{1{,}000}$ = to have the result expressed in kilos

- *CO_2 emissions reduction:*

The CO_2 content of natural gas is 53.02 kg per 1,000,000 BTU (British Thermal Unit). Knowing that 1 BTU is equivalent to 1.055.06 joules (J) and that 1 kWh is equivalent to 3,600,000 J, the following formula gives the CO_2 emissions reduction in kg per year assuming that all the houses in the Brussels-Capital Region are heated with natural gas[163,164]:

$$CO_2\ emissions\ reduction\ (in\ kg) = \Delta H \,.\, \frac{53.05}{1{,}000{,}000} \,.\, \frac{1}{1{,}055.06} \,.\, 3{,}600{,}000 \quad (3)$$

[160] Quelle est la température idéale de votre maison ou appartement ? (2010, December 9). [text]. Retrieved 30 July 2017, from http://temperatureideale.fr/temperature-ideale-piece-maison-appartement#

[161] Climat - Statistiques & Analyses. (n.d.). Retrieved 30 July 2017, from http://statbel.fgov.be/fr/statistiques/chiffres/environnement/climat/

[162] $\Delta K = \Delta °C$

[163] Cantillon, E. (2016). *Environmental Economics- Group Assignment 2: Energy Efficiency in the Brussels Capital Region*.

[164] U.S. Energy Information Administration (EIA). (n.d.-a). Retrieved 30 July 2017, from https://www.eia.gov/oiaf/1605/coefficients.html

- *Atmospheric pollutants reduction:*

    - *NOx emissions reduction:*

The NOx content of natural gas is 0.5 g per 1,000,000,000 J. Knowing that 1 kWh is equivalent to 3,600,000 J and assuming that all the houses in the Brussels-Capital Region are heated with natural gas, the following formula gives the NOx emissions reduction in g per year[165,166]:

$$NOx\ emissions\ reduction\ (in\ g) = \Delta H\ .\ \frac{0.5}{1{,}000{,}000{,}000}\ .3{,}600{,}000 \quad (4)$$

    - *SO_2 emissions reduction:*

The SO_2 content of natural gas is 38 g per 1,000,000,000 J. Knowing that 1 kWh is equivalent to 3,600,000 J and assuming that all the houses in the Brussels-Capital Region are heated with natural gas, the following formula gives the SO_2 emissions reduction in g per year[167,168]:

$$SO_2\ emissions\ reduction\ (in\ g) = \Delta H\ .\ \frac{38}{1{,}000{,}000{,}000}\ .3{,}600{,}000 \quad (5)$$

    - *CO emissions reduction:*

The CO content of natural gas is 14 g per 1,000,000,000 J. Knowing that 1 kWh is equivalent to 3,600,000 J and assuming that all the houses in the Brussels-Capital Region are heated with natural gas, the following formula gives the CO emissions reduction in g per year[169,170]:

$$CO\ emissions\ reduction\ (in\ g) = \Delta H\ .\ \frac{14}{1{,}000{,}000{,}000}\ .3{,}600{,}000 \quad (6)$$

[165] Cantillon, E. (2016). *Environmental Economics- Group Assignment 2: Energy Efficiency in the Brussels Capital Region*.
[166] European Environment Agency. (2016b). *Small combustion*. Retrieved from https://www.eea.europa.eu/publications/emep-eea-guidebook-2016/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-4-small-combustion-2016/view
[167] European Environment Agency. (2016b). *Small combustion*. Retrieved from https://www.eea.europa.eu/publications/emep-eea-guidebook-2016/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-4-small-combustion-2016/view
[168] Cantillon, E. (2016). *Environmental Economics- Group Assignment 2: Energy Efficiency in the Brussels Capital Region*.
[169] European Environment Agency. (2016b). *Small combustion*. Retrieved from https://www.eea.europa.eu/publications/emep-eea-guidebook-2016/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-4-small-combustion-2016/view
[170] Cantillon, E. (2016). *Environmental Economics- Group Assignment 2: Energy Efficiency in the Brussels Capital Region*.

2.2.4. Results and interpretation

This section will present the results obtained with a self-targeted subsidy policy and with a targeted subsidy policy and compare both policies in terms of energy savings, CO_2 emissions and some atmospheric pollutants emissions reduction.

- **Results:**

Table 13 shows the annual energy savings, the annual CO_2 and atmospheric pollutants emissions reduction, the annual amount of subsidy awarded and the annual number of applicants in the case of a self-targeted policy for the 2009-2016 period.

Table 14 presents the potential annual CO_2 and atmospheric pollutants emissions reduction, the potential annual amount of subsidy awarded and the potential annual number of houses targeted in the case of a policy that targets only the houses with the highest roof thermal losses (i.e. classes 5 and 6) for the 2009-2016 period.

It should be noted that since the actual amount of subsidy per m² depends on several criteria as seen in Table 5, an average annual subsidy amount per m² was computed by dividing the total amount awarded with the current policy (i.e. self-targeted subsidy policy) by the total insulated roof area as can be seen in the following table.

Table 12: Average subsidy per year (€/m²)

Year	Amount Awarded – *Self Targeted Policy* (€)	Total Area (m²)	Average subsidy per year (€/m²)
2009	1,461,938.77	95,020.0	15.39[171]
2010	1,271,627.89	259,256.5	4.90[171]
2011	2,010,919.22	140,228.9	14.34[171]
2012	1,983,723.75	98,902.0	20.06
2013	2,142,796.43	104,874.6	20.43
2014	3,080,354.25	150,527.6	20.46
2015	3,218,767.67	158,684.3	20.28
2016	2,874,940.63	135,947.3	21.15
TOTAL	**18,045,068.61**	**1,143,441.2**	

Therefore, based on this annual average subsidy, a number of class 5 and 6 houses have been targeted annually in a way that the potential annual amount of subsidy awarded with the ***targeted subsidy policy*** is as close as possible to the annual amount of subsidy awarded with the ***self-targeted subsidy policy*** in order to compare these two policies.

[171] The fact that these values are low is explained by the fact that the data about the actual insulated roof area is only available from year 2012. For houses that have benefited from a roof insulation subsidy and whose actual isolated area is unknown (which is the case here) and for houses that have not yet benefited from a subsidy, the assumption that they isolate the **entire** surface of their roof is made. This explains why the values are low for these 3 years.

Table 13: Results obtained with the self-targeted subsidy policy

SELF-TARGETING							
Year	**Amount awarded (€)**	**Energy Savings (kWh)**	**CO_2 emissions reduction (kg)**	**SO_2 emissions reduction (g)**	**NOx emissions reduction (g)**	**CO emissions reduction (g)**	**Number of applicants**
2009	1,461,938.77	4,681,749.70	847,459.44	8,427.15	640,463.36	235,960.18	740
2010	1,271,627.89	7,044,786.41	1,275,200.76	12,680.62	963,726.78	355,057.24	700
2011	2,010,919.22	7,208,924.64	1,304,911.97	12,976.06	986,180.89	363,329.80	1,095
2012	1,983,723.75	5,052,019.36	914,483.21	9,093.63	691,116.25	254,621.78	1,142
2013	2,142,796.43	5,812,919.00	1,052,216.25	10,463.25	795,207.32	292,971.12	1,169
2014	3,080,354.25	7,430,282.31	1,344,980.68	13,374.51	1,016,462.62	374,486.23	1,477
2015	3,218,767.67	7,179,191.21	1,299,529.82	12,922.54	982,113.36	361,831.24	1,472
2016	2,874,940.63	6,584,709.31	1,191,920.63	11,852.48	900,788.23	331,869.35	1,267
TOTAL	**18,045,068.61**	**50,994,581.95**	**9,230,702.77**	**91,790.25**	**6,976,058.81**	**2,570,126.93**	**9,062**

Table 14: Results obtained with the targeted subsidy policy

TARGETING							
Year	**Amount awarded (€)**	**Energy Saving (kWh)**	**CO_2 emissions reduction (kg)**	**SO_2 emissions reduction (g)**	**NOx emissions reduction (g)**	**CO emissions reduction (g)**	**Number of houses targeted**
2009	1,460,874.39	10,786,892.53	1,952,572.12	19,416.41	1,475,646.90	543,659.38	747
2010	1,259,914.88	27,251,304.68	4,932,851.37	49,052.35	3,727,978.48	1,373,465.76	2,106
2011	2,010,630.55	13,881,389.57	2,512,717.55	24,986.50	1,898,974.09	699,622.03	1,183
2012	1,982,832.89	10,660,823.29	1,929,751.89	19,189.48	1,458,400.63	537,305.49	839
2013	2,140,947.69	10,777,879.64	1,950,940.66	19,400.18	1,474,413.94	543,205.13	881
2014	3,080,024.89	16,834,190.04	3,047,214.01	30,301.54	2,302,917.20	848,443.18	1,285
2015	3,215,251.44	16,889,988.25	3,057,314.23	30,401.98	2,310,550.39	851,255.41	1,302
2016	2,874,164.72	15,652,171.19	2,833,252.76	28,173.91	2,141,217.02	788,869.43	1,005
TOTAL	**18,024,641.43**	**122,734,639.21**	**22,216,614.60**	**220,922.35**	**16,790,098.64**	**6,185,825.82**	**9,348**

- **Interpretation:**

By comparing the self-targeted subsidy policy with the targeted subsidy policy, it can be seen that each year, with a similar total amount of subsidy granted, there could be more energy savings and consequently more CO_2, SO_2, NOx, CO emissions reductions with the targeted subsidy policy than with the self-targeted subsidy policy. Moreover, it can also be seen that, over the period 2009-2016, there could have been more houses benefiting from a roof insulation subsidy (i.e. B1 subsidy) with the targeted subsidy policy (9,348) than with the self-targeted subsidy policy (9,062).

The results from tables 15, 16 and 17 allow to get an idea of the percentage of annual CO_2, SO_2 and NOx[172] emissions reduction with the self-targeted subsidy policy and with the targeted subsidy policy compared to the total emissions emitted by heating (residential and tertiary) without any roof insulation subsidy. As the emissions reductions are greater with the targeted subsidy policy than with the self-targeted subsidy policy, it can be seen that the potential (i.e. with a targeted subsidy policy) percentage of emissions reduction is greater than the current (i.e. with a self-targeted subsidy policy) percentage of emissions reduction of the three pollutants, although these percentages are low, especially for the reduction of SO_2 emissions.

However, it should be noted that these results are valid only under the different assumptions that have been made. It has indeed been assumed that all the houses of the Brussels-Capital Region are heated every day with natural gas and that the entire roof area of houses is isolated when the houses benefit from the subsidy. Assumptions about the R_pre and R_post, the inside and outside air temperature and the amount of subsidy per m² have also been made. As can be seen in Appendix F, a sensitivity analysis has been performed to determine how the results (i.e. the energy savings and the total emissions reductions during the 2009-2016 period) are impacted by a change in the assumptions concerning the inside and outside air temperature. Moreover, as shown in Appendix G, a sensitivity analysis has been conducted to get a glimpse of the energy savings and emissions reductions that can be achieved annually when isolating 1m² of the roof of any house belonging to one of the classes determined by the R_pre, and having a certain R_post.

[172] The emissions from heating data were only available for CO_2 (2009-2012), SO_2 (2009-2013) and NOx (2009-2013)

In addition to the assumptions mentioned above, the implicit assumption that all the houses that are targeted by the roof insulation subsidy policy (i.e. class 5 and 6 houses) will undertake the renovation work to isolate their respective roofs has been made while it might not necessarily be the case in reality. Indeed, although the poorly insulated houses, once targeted, will be informed by the Brussels-Capital Region about the annual energy savings they can make annually – which lead to a reduction of the annual energy bills - by isolating their roof and the possibility to benefit from a subsidy for this purpose, some houses may still decide not to carry out the renovation work. This can mainly be explained by the fact that there are anomalies in the human behaviour that prevent them from making rational choices[173]. For instance, there is often a gap between what people say and what they actually do, which is referred as "knowledge-action gap": people may for instance seem to be concerned about climate change and the importance of reducing their energy consumption but, paradoxically, they are not taking any action for this purpose. Moreover, people may be reluctant to make an investment today (e.g. roof insulation renovation work) because the resulting benefits would only be perceived in the long run (e.g. reduction of the energy bills through energy savings), to which people generally attach less importance. Furthermore, people may also be strongly influenced by the behaviour of others[174]. As an illustration, following an awareness campaign that pushed the citizens to use their fans instead of their air conditioning during a summer in San Marcos (California) 10 years ago, different groups of citizens received different types of messages. Although there were messages that highlighted the potential energy savings that citizens could make or the importance to make efforts to save the planet, the message that effectively led to citizens' action was the one that informed them that their neighbours switched off their air conditioning to use their fans[175]. Consequently, if the houses targeted by the roof insulation subsidy policy are not informed that their respective neighbours have well-insulated roofs or have already benefited from a roof insulation subsidy, there may be less chance that the targeted houses will undertake the renovation work. In addition, people tend to be more receptive to messages expressed in terms of loss rather than messages expressed in terms of gain. For instance, a message such as "with your current insulation, you are losing 300 € annually" will be more persuasive than a message like "you can potentially earn 300€ annually by properly insulating your house".

[173] Frederiks, E. R., Stenner, K., & Hobman, E. V. (2015). Household energy use: Applying behavioural economics to understand consumer decision-making and behaviour. *Renewable and Sustainable Energy Reviews*, *41*, 1385–1394. https://doi.org/10.1016/j.rser.2014.09.026

[174] Ibid.

[175] Laskey, A. (n.d.). *How behavioral science can lower your energy bill*. Retrieved from https://www.ted.com/talks/alex_laskey_how_behavioral_science_can_lower_your_energy_bill

Finally, when the recommendation comes from a reliable source, there is more chance that a citizen will take this recommendation into consideration[176]. For example, it has been concluded that there were more electricity savings in New York in 1978 when the recommendation came from the Public Commission Service (more reliable source) than when the same recommendation came from an electricity provider (less reliable source)[177].

The Brussels-Capital Region must therefore take into account these behavioural anomalies when targeting the poorly insulated houses. In this regard, the Region could send personalized mails to the targeted houses by making sure that the message is expressed in terms of loss, that the targeted houses are informed in the event that the houses in their neighbourhood or in the same municipality already benefited from a roof insulation subsidy or are properly insulated and that it is well emphasised that the sender of the mail is the Brussels-Capital Region. This is in fact inspired by what a company called Opower does in the United States in partnership with utility companies. They indeed deliver personalized messages to help citizens reduce their energy consumption taking into account these behavioural anomalies. These messages mainly contain comparisons between the consumption of a specific house and its neighbourhood[178] and led to a reduction of the energy bill of more than $1 billion in the United States between 2007 and 2015[179].

To put it simply, under the assumptions made, the targeted subsidy policy - which was possible thanks to the use of Open Data - seems to be more effective and efficient than the self-targeted one. Indeed, with a similar total amount of subsidy granted annually by the Brussels-Capital Region, there are more energy savings and pollutants emissions reductions with a targeted subsidy policy rather than with a self-targeted one. Therefore, redesigning the current roof insulation subsidy using Open Data could enhance its effectiveness, as predicted by the decision matrix, as it allows to target directly the poorly insulated houses. However, it should be noted that the Region should not only focus on targeting those houses, but it should also find a way to encourage them to undertake the renovation work.

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Table 15: Current and potential percentage reduction of CO_2 emissions

Year	*Current* CO_2 emissions from heating[180] (kg)	*Current* CO_2 emissions *reduction*[181] (kg)	CO_2 emissions from heating *without B1 subsidy*[182] (kg)	*Potential* CO_2 emissions *reduction*[183] (kg)	*Potential* CO_2 emissions from heating[184] (kg)	*Current* % of CO_2 reduction[185]	*Potential* % of CO_2 reduction
2009	2,428,571,428.57	847,459.44	2,429,418,888.01	1,952,572.12	2,427,466,315.89	***0.0349%***	***0.0804%***
2010	2,714,285,714.29	1,275,200.76	2,715,560,915.05	4,932,851.37	2,710,628,063.68	***0.0470%***	***0.1820%***
2011	1,857,142,857.14	1,304,911.97	1,858,447,769.11	2,512,717.55	1,855,935,051.56	***0.0703%***	***0.1354%***
2012	2,357,142,857.14	914,483.21	2,358,057,340.35	1,929,751.89	2,356,127,588.46	***0.0388%***	***0.0819%***

Table 16: Current and potential percentage reduction of NOx emissions

Year	*Current* NOx emissions from heating[186] (g)	*Current* NOx emissions *reduction* (g)	NOx emissions from heating *without B1 subsidy* (g)	*Potential* NOx emissions reduction (g)	*Potential* NOx emissions from heating (g)	*Current* % of NOx reduction	*Potential* % of NOx reduction
2009	1,157,894,736.84	640,463.36	1,158,535,200.20	1,475,646.90	1,157,059,553.30	***0.0553%***	***0.1275%***
2010	1,852,631,578.95	963,726.78	1,853,595,305.73	3,727,978.48	1,849,867,327.25	***0.0520%***	***0.2015%***
2011	1,326,315,789.47	986,180.89	1,327,301,970.36	1,898,974.09	1,325,402,996.27	***0.0744%***	***0.1433%***
2012	1,326,315,789.47	691,116.25	1,327,006,905.72	1,458,400.63	1,325,548,505.09	***0.0521%***	***0.1100%***
2013	1,326,315,789.47	795,207.32	1,327,110,996.79	1,474,413.94	1,325,636,582.85	***0.0600%***	***0.1112%***

[180] Residential & Tertiary – *Source: Plan régional Air-Climat-Energie*

[181] See Table 13

[182] Emissions from heating without B1 subsidy = *Current* emissions from heating + *Current* emissions reduction

[183] See Table 14

[184] Potential emissions from heating = Emissions from heating without subsidy – *Potential* emissions reduction

[185] Current (potential) % reduction = $\frac{Current\ (potential)\ emissions\ reduction}{Current\ (potential)\ emissions\ from\ heating}$

[186] Residential & Tertiary - *Source: Plan régional Air-Climat-Energie*

Table 17: Current and potential percentage reduction of SO_2 emissions

Year	*Current* SO_2 emissions from heating[187] (g)	*Current* SO_2 emissions reduction (g)	SO_2 emissions from heating *without B1 subsidy* (g)	*Potential* SO_2 emissions reduction (g)	*Potential* SO_2 emissions from heating (g)	*Current* % of SO_2 reduction	*Potential* % of SO_2 reduction
2009	543,529,411.76	8,427.15	543,537,838.91	19,416.41	543,518,422.50	***0.0016%***	***0.0036%***
2010	532,549,019.61	12,680.62	532,561,700.23	49,052.35	532,512,647.88	***0.0024%***	***0.0092%***
2011	422,745,098.04	12,976.06	422,758,074.10	24,986.50	422,733,087.60	***0.0031%***	***0.0059%***
2012	417,254,901.96	9,093.63	417,263,995.59	19,189.48	417,244,806.11	***0.0022%***	***0.0046%***
2013	422,745,098.04	10,463.25	422,755,561.29	19,400.18	422,736,161.11	***0.0025%***	***0.0046%***

[187] Residential & Tertiary – *Source: Plan régional Air-Climat-Energie*

CONCLUSION

In this paper, it has been attempted to find out whether Open Data can be leveraged to improve environmental policy design. To this end, a theoretical framework has first been set out explaining what Open Data consists of and its current limitations. Then, a decision matrix has been developed in order to identify the cases in which Open Data might be useful in the policy-making context in general. It has been concluded from this decision matrix that Open Data might be useful in the case of a targeted policy since it can help to cope with the information asymmetry, which is one of the main issues that a policymaker faces when designing a targeted policy.

A concrete application of the use of Open Data in the framework of an environmental policy has been made in Part III with an in-depth analysis of the redesign of the current roof insulation subsidy policy in the Brussels-Capital Region. It has been shown that making use of Open Data makes it possible to enhance the effectiveness of the current roof insulation subsidy, as also predicted by the decision matrix that has been developed. Indeed, the use of Open Data through the aerial thermography map of the Brussels-Capital Region has allowed to have a targeted subsidy policy, by directly targeting the houses with poorly insulated roofs, rather than the current self-targeted subsidy policy. The results showed that, with a similar total amount of subsidy granted annually over the 2009-2016 period by the Brussels-Capital Region, the targeted policy could have, under the several assumptions made, benefited more houses in total over the period and allowed more annual energy savings and consequently more CO_2, SO_2, NOx and CO annual emissions reductions than the current roof insulation subsidy. It has also been highlighted that, due to anomalies in the human behaviour, the Brussels-Capital Region should not simply target the houses but find ways to encourage the citizens to follow their recommendation.

Although it has been chosen, in this paper, to focus on the roof insulation subsidy policy in the Brussels-Capital Region to illustrate the use of Open Data in the environmental policy context, its use is not limited to that. Open Data could also potentially be used to improve existing policies or develop new policies in other areas, and for this purpose, the decision matrix developed in Part II might be used to guide the policy-maker.

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APPENDIX

Appendix A: Detailed components of each sub-indicator

Open Data Readiness

Indicator	1. Presence of specific Open Data policy
1.1	Open Data policy and policies supporting re-use, are in place. Open Data policy is the same as the PSI policy. Open Data policy has changed since 2015. A national 5-year strategy exists.
1.2	National, but also regional/local portals are present. The data holders are able to upload the data themselves. The frequency of data collection is standardised. There is a pre-defined approach to ensure data is up-to-date. Approach on how Open Data has changed since 2015.
1.3	Priority domains for the publication of Open Data, are identified. The public administration is using data themselves for decision-making, but promoting the use by others as well by organising events. Revised PSI Directive has been transposed.

Indicator	2. Licensing norms
2.1	All data on the national portal, is available free of charge.
2.2	All data on the national portal, is open licensed.
2.3	A national data policy provides for a standard licence (or suite of licences) that public sector bodies are encouraged to avail themselves of when allowing PSI re-use.

Indicator	3. Extent of coordination at national level
3.1	National guidelines on the publication of PSI are in place.
3.2	Numerous regions and/or cities run their own Open Data initiatives, like portals or specific policies, and are integrated on the national portal.

Indicator	4. Use of the data
4.1	Overview of portal traffic statistics: • Number of unique visitors relative to the number of inhabitants; • Proportion of visitors that is foreign; • Proportion of traffic towards the portal is human; • Typical profile of visitors of the portal.
4.2	Changes in re-use since 2015. Support re-use of Open Data. Activities launched since 2015 to monitor impact of Open Data. Activities launched since 2015 to promote Open Data portal or Open Data in general?

Indicator	5. Impact
5.1 Political Impact	
5.1.1	Activities are launched since June 2015, to monitor the Impact of Open Data.
5.1.2	High impact on government efficiency and effectiveness.
5.1.3	High impact on transparency and accountability in the country.
5.2 Social Impact	
5.2.1	High impact on environmental sustainability in the country.
5.2.2	High impact on increasing the inclusion of marginalised groups in policy making and accessing government services.
5.3 Economic Impact	
5.3.1	Multiple macro-economic studies assessing the market value of Open Data are done as well as studies regarding better service delivery or looking at related subjects.
5.3.2	The funding model is known.

Portal Maturity	

Indicator	6. Usability of the portal
6.1	Feedback mechanisms are available on the portal to comment on data set quality and get a discussion going.
6.2	Users can access data sets, search, download and contribute themselves.
6.3	An API is available.

Indicator	7. Re-usability of the data
7.1	The proportion of data that is machine-readable is known.
7.2	All data is available in one – bulk – download.
7.3	File formats are searchable and it is known which file format is available the most.

Indicator	8. Spread of data across domains
8.1.	Data sets are numerous and up-to-date.
8.2	Multiple organisations provide a lot of data sets.
8.3	Data sets are searchable by domain with many different domains present.

Source: Open Data Maturity in Europe 2016

Appendix B: Location of the ground-based air pollution monitoring stations of the Brussels-Capital Region

Code	Location
41B001	Bruxelles (Arts-Loi)
41B004	Bruxelles (Sainte-Catherine)
41B006	Bruxelles (EU Parlement)
41B008	Bruxelles (Rue Belliard)
41B011	Berchem-Sainte-Agathe
41MEU1	Neder-Over-Heembeek
41N043	Voorhaven (Haren)
41R001	Molenbeek-Saint-Jean
41R002	Ixelles
41R012	Uccle
41WOL1	Woluwe-Saint-Lambert
47E013	Forest

Source: http://www.irceline.be/en/air-quality/measurements

Appendix C: Description, sources and effects of the main atmospheric pollutants

Pollutant	Description and sources	Health and environment effects
Sulphur dioxide (SO2)	SO_2 is formed by oxidation of sulphur (S), mainly through combustion of fuels containing S. The electricity generation sector is the most important source of SO_2. SO_2 also can contribute to the formation of secondary sulphate particles in the atmosphere.	SO_2 aggravates asthma and can reduce lung function and inflame the respiratory tract. It can cause headache, general discomfort and anxiety. SO_2 contributes to acid deposition, the impacts of which can be significant, causing damage to forests and ecosystems in rivers and lakes.
Nitrogen oxides (NO_x)	NO_x is emitted during fuel combustion e.g. from industrial facilities and the road transport sector. NO_x is a group of gases comprising nitrogen monoxide (NO) and nitrogen dioxide (NO_2). NO makes up the majority of NO_x emissions. NO_x contributes to the formation of ozone and particulate matter.	NO_2 is associated with adverse effects on health: it can affect the liver, lung, spleen and blood. It can also aggravate lung diseases leading to respiratory symptoms and increased susceptibility to respiratory infection. As with SO_2, NO_x contributes to acid deposition but also to eutrophication of soil and water.
Particulate matter (PM)	PM is a mixture of aerosol particles (solid and liquid) covering a wide range of sizes and chemical compositions. PM_{10} ($PM_{2.5}$) refers to particles with a diameter of 10 (2.5) micrometres or less. PM is either directly emitted as primary particles or it forms in the atmosphere from emissions of SO_2, NO_x, NH_3 and NMVOCs. PM is emitted from many anthropogenic sources, including both combustion and non-combustion sources. Important natural sources of PM are sea salt and natural re-suspended dust.	PM can cause or aggravate cardiovascular and lung diseases, heart attacks and arrhythmias. It can also affect the central nervous system and the reproductive system, and can cause cancer. One outcome of exposure to PM can be premature death. PM also acts as a greenhouse gas, mainly cooling the earth's climate, although in some cases it can lead to warming. PM in the atmosphere can also alter rainfall patterns, and affect the surface albedo properties of snow (the extent to which the snow reflects light).
Ozone (O3)	Ground-level (tropospheric) ozone is not directly emitted into the atmosphere. Instead, it forms in the atmosphere from a chain of chemical reactions following emissions of certain precursor gases: NOx, carbon monoxide (CO) and NMVOCs and methane (CH_4).	Elevated levels of ozone can cause respiratory health problems, including decreased lung function, aggravation of asthma, and other lung diseases. It can also lead to premature mortality. Ozone is also a greenhouse gas contributing to warming of the atmosphere.
Ammonia (NH3)	The vast majority of NH_3 emissions come from the agricultural sector, in connection with activities such as	Exposure to high levels of ammonia may irritate skin, eyes, throat, and lungs and cause

	manure storage, slurry spreading, and the use of synthetic nitrogenous fertilisers. It also contributes to the formation of secondary particles.	coughing. People with asthma may be more sensitive to breathing ammonia than others. NH_3, like NO_x, contributes to eutrophication and acidification.
Non methane volatile organic compounds (NMVOCs)	NMVOCs produce photochemical oxidants by reacting with NO_x in the presence of sunlight. Anthropogenic NMVOCs are emitted from sources including paint application, road transport, dry-cleaning and other solvent uses. Biogenic NMVOCs are emitted by vegetation, with the amounts emitted dependent on species and on temperature.	NMVOCs include a variety of chemicals. Certain NMVOC species, such as benzene (C_6H_6) and 1,3-butadiene, are directly hazardous to human health. NMVOCs are also precursors of ground-level ozone.
Carbon monoxide (CO)	CO is emitted due to incomplete combustion. Important sources of CO include road transport, businesses, households, and industry. CO reacts with other pollutants producing ground-level ozone.	CO can lead to heart disease and damage to the nervous system. It can also cause headache, dizziness and fatigue.
Methane (CH4)	CH_4 is produced by both anthropogenic and natural sources. Significant anthropogenic sources include the agriculture sector (from the enteric fermentation of CH_4 from livestock), the waste sector, and 'fugitive' emissions from coal mining and gas.	Methane is an important greenhouse gas, and is one of the gases controlled under the UNFCCC's Kyoto protocol. At the regional and global scale methane also contributes to the formation of ground level ozone.

Source: European Environment Agency - Air pollution fact sheet 2014: Malta

Appendix D: Confidentiality agreement with Brussels Institute for Environmental Management

ACCORD DE CONFIDENTIALITE

ENTRE LES SOUSSIGNE(E)S :

D'une part,

M. Mourad EL ROUGY étudiant à l'Université Libre de Bruxelles.

ET

D'autre part,

Bruxelles Environnement (IBGE), dont le siège est situé au 86C, Avenue du Port, 1000 Bruxelles
Représentée par M. Frédéric FONTAINE, Directeur Général.

PREAMBULE :

M. Mourad EL ROUGY ayant sollicité la consultation d'informations et données statistiques relatives aux primes-énergie dans le cadre de la réalisation de son travail de fin de maitrise en gestion de l'environnement, Bruxelles Environnement consent à mettre les informations dont il dispose à sa disposition selon les termes de l'accord suivant :

IL EST CONVENU ET ARRETE CE QUI SUIT :

ARTICLE 1 – CONFIDENTIALITE :

M. Mourad EL ROUGY et l'Université Libre de Bruxelles s'engagent à garder strictement confidentiel et à ne pas divulguer ou communiquer à des tiers, par quelque moyen que ce soit, les informations qui lui seront transmises par Bruxelles Environnement ou auxquelles il aura accès à l'occasion de l'exécution du présent accord.
M. Mourad EL ROUGY et l'Université Libre de Bruxelles prendront toutes les mesures nécessaires pour préserver le caractère confidentiel des informations. Ces mesures ne pourront pas êtres inférieures à celles prises pour la protection de ses propres informations confidentielles.

ARTICLE 2 – UTILISATION DES INFORMATIONS :

Les informations obtenues par M. Mourad EL ROUGY et l'Université Libre de Bruxelles ne pourront être utilisées que pour l'exécution de l'objet du présent accord, visé par le préambule. Toute autre utilisation sera soumise à l'autorisation préalable et écrite de Bruxelles Environnement. Le travail de fin d'étude de Mourad EL ROUGY sera tenu par le

sceau de la confidentialité sauf obtention explicite d'une autorisation de publication par Bruxelles Environnement.

ARTICLE 5 – DUREE :

5.1 – Le présent accord prend effet le 09 février 2017 et demeure en vigueur jusqu'au terme du travail de recherche de M. Mourad EL ROUGY, et au plus tard, le 1er septembre 2017.
5.2 – Les dispositions de confidentialité prévues au présent accord s'appliqueront pendant toute la durée de celui-ci et pendant dix ans après son échéance ou sa résiliation quelle qu'en soit la cause.

ARTICLE 7 – LITIGES :

En cas de difficultés sur l'interprétation ou l'exécution du présent contrat, les parties s'efforceront de résoudre leur différend à l'amiable.
En cas de désaccord persistant, les différends seront portés devant le tribunal compétent.

Fait en deux exemplaires originaux.

A : Bruxelles

Le : 09 février 2017

Pour Bruxelles Environnement :
M Fréderic FONTAINE :

M. Mourad EL ROUGY :

Pour l'institut de Gestion de l'Environnement et de l'Aménagement du Territoire de l'Université Libre de Bruxelles :
M. Jean-Michel DECROLY :

Appendix E: Confidentiality agreement with Eurosense Belfotop BVBA

DECLARATION

I, Mourad EL ROUGY, living at Rue Breesch n° 31-33 1020 Laeken, declare that I will receive the following data from EUROSENSE BELFOTOP BVBA, a company with its legal seat of business at Oude Stationstraat 144, 8700 Tielt, company number 0405.198.296:

- results of the thermographic survey of Brussels that was executed in 2008: *mosaique _bruxelles.img*;
- derived statistics by building:
    - *UrbAdm_Thermo.shp*;
    - *UrbAdm_Thermo_database.xlsx*;
    - *UrbAdm_Thermo2.shp*;
    - *UrbAdm_Thermo_database2.xlsx*.

I declare to know that all intellectual property rights on the mentioned data exclusively belong to EUROSENSE BELFOTOP BVBA. I shall only use the mentioned data for the purpose of writing my thesis and I will not use the mentioned data for any other purpose. When using the data I will always clearly mention the following text: © EUROSENSE BELFOTOP BVBA.

I shall refrain from selling the data or from using the data in any commercial way. I am not permitted to transfer the right to use the data to any third person. When I use the data I will strictly respect the applicable legislation with regard to the protection of personal data.

Done at …Brussels…….. on …13/03/2017……..

Mourad EL ROUGY

Appendix F: Sensitivity Analysis – *Inside and outside air temperature*

- **Total energy savings during the 2009-2016 period (kWh):**

Inside air temperature

Outside air temperature	Self-Targeting	17°C	18°C	19°C	20°C	21°C
	8.7°C	50,994,581.95	57,138,507.48	63,282,433.02	69,426,358.55	75,570,284.09
	9.7°C	44,850,656.41	50,994,581.95	57,138,507.48	63,282,433.02	69,426,358.55
	10.7°C	38,706,730.87	44,850,656.41	50,994,581.95	57,138,507.48	63,282,433.02
	11.7°C	32,562,805.34	38,706,730.87	44,850,656.41	50,994,581.95	57,138,507.48
	12.7°C	26,418,879.80	32,562,805.34	38,706,730.87	44,850,656.41	50,994,581.95

Inside air temperature

Outside air temperature	Targeting	17°C	18°C	19°C	20°C	21°C
	8.7°C	122,734,639.21	137,521,945.13	152,309,251.06	167,096,556.99	181,883,862.92
	9.7°C	107,947,333.28	122,734,639.21	137,521,945.13	152,309,251.06	167,096,556.99
	10.7°C	93,160,027.35	107,947,333.28	122,734,639.21	137,521,945.13	152,309,251.06
	11.7°C	78,372,721.42	93,160,027.35	107,947,333.28	122,734,639.21	137,521,945.13
	12.7°C	63,585,415.49	78,372,721.42	93,160,027.35	107,947,333.28	122,734,639.21

- **Total CO_2 emissions reduction during the 2009-2016 period (kg):**

Inside air temperature

Outside air temperature	Self-Targeting	17°C	18°C	19°C	20°C	21°C
	8.7°C	9,230,702.77	10,342,835.63	11,454,968.49	12,567,101.36	13,679,234.22
	9.7°C	8,118,569.90	9,230,702.77	10,342,835.63	11,454,968.49	12,567,101.36
	10.7°C	7,006,437.04	8,118,569.90	9,230,702.77	10,342,835.63	11,454,968.49
	11.7°C	5,894,304.18	7,006,437.04	8,118,569.90	9,230,702.77	10,342,835.63
	12.7°C	4,782,171.31	5,894,304.18	7,006,437.04	8,118,569.90	9,230,702.77

Inside air temperature

Outside air temperature	Targeting	17°C	18°C	19°C	20°C	21°C
	8.7°C	22,216,614.60	24,893,315.15	27,570,015.70	30,246,716.26	32,923,416.81
	9.7°C	19,539,914.04	22,216,614.60	24,893,315.15	27,570,015.70	30,246,716.26
	10.7°C	16,863,213.49	19,539,914.04	22,216,614.60	24,893,315.15	27,570,015.70
	11.7°C	14,186,512.93	16,863,213.49	19,539,914.04	22,216,614.60	24,893,315.15
	12.7°C	11,509,812.38	14,186,512.93	16,863,213.49	19,539,914.04	22,216,614.60

- **Total SO_2 emissions reduction during the 2009-2016 period (g):**

Inside air temperature

Outside air temperature	Self-Targeting	17°C	18°C	19°C	20°C	21°C
	8.7°C	91,790.25	102,849.31	113,908.38	124,967.45	136,026.51
	9.7°C	80,731.18	91,790.25	102,849.31	113,908.38	124,967.45
	10.7°C	69,672.12	80,731.18	91,790.25	102,849.31	113,908.38
	11.7°C	58,613.05	69,672.12	80,731.18	91,790.25	102,849.31
	12.7°C	47,553.98	58,613.05	69,672.12	80,731.18	91,790.25

Inside air temperature

Outside air temperature	Targeting	17°C	18°C	19°C	20°C	21°C
	8.7°C	220,922.35	247,539.50	274,156.65	300,773.80	327,390.95
	9.7°C	194,305.20	220,922.35	247,539.50	274,156.65	300,773.80
	10.7°C	167,688.05	194,305.20	220,922.35	247,539.50	274,156.65
	11.7°C	141,070.90	167,688.05	194,305.20	220,922.35	247,539.50
	12.7°C	114,453.75	141,070.90	167,688.05	194,305.20	220,922.35

- **Total NOx emissions reduction during the 2009-2016 period (g):**

Inside air temperature

Outside air temperature	Self-Targeting	17°C	18°C	19°C	20°C	21°C
	8.7°C	6,976,058.81	7,816,547.82	8,657,036.84	9,497,525.85	10,338,014.86
	9.7°C	6,135,569.80	6,976,058.81	7,816,547.82	8,657,036.84	9,497,525.85
	10.7°C	5,295,080.78	6,135,569.80	6,976,058.81	7,816,547.82	8,657,036.84
	11.7°C	4,454,591.77	5,295,080.78	6,135,569.80	6,976,058.81	7,816,547.82
	12.7°C	3,614,102.76	4,454,591.77	5,295,080.78	6,135,569.80	6,976,058.81

Inside air temperature

Outside air temperature	Targeting	17°C	18°C	19°C	20°C	21°C
	8.7°C	16,790,098.64	18,813,002.09	20,835,905.55	22,858,809.00	24,881,712.45
	9.7°C	14,767,195.19	16,790,098.64	18,813,002.09	20,835,905.55	22,858,809.00
	10.7°C	12,744,291.74	14,767,195.19	16,790,098.64	18,813,002.09	20,835,905.55
	11.7°C	10,721,388.29	12,744,291.74	14,767,195.19	16,790,098.64	18,813,002.09
	12.7°C	8,698,484.84	10,721,388.29	12,744,291.74	14,767,195.19	16,790,098.64

- **Total CO emissions reduction during the 2009-2016 period (g):**

Inside air temperature

Outside air temperature	Self-Targeting	17°C	18°C	19°C	20°C	21°C
	8.7°C	2,570,126.93	2,879,780.78	3,189,434.62	3,499,088.47	3,808,742.32
	9.7°C	2,260,473.08	2,570,126.93	2,879,780.78	3,189,434.62	3,499,088.47
	10.7°C	1,950,819.24	2,260,473.08	2,570,126.93	2,879,780.78	3,189,434.62
	11.7°C	1,641,165.39	1,950,819.24	2,260,473.08	2,570,126.93	2,879,780.78
	12.7°C	1,331,511.54	1,641,165.39	1,950,819.24	2,260,473.08	2,570,126.93

Inside air temperature

Outside air temperature	Targeting	17°C	18°C	19°C	20°C	21°C
	8.7°C	6,185,825.82	6,931,106.03	7,676,386.25	8,421,666.47	9,166,946.69
	9.7°C	5,440,545.60	6,185,825.82	6,931,106.03	7,676,386.25	8,421,666.47
	10.7°C	4,695,265.38	5,440,545.60	6,185,825.82	6,931,106.03	7,676,386.25
	11.7°C	3,949,985.16	4,695,265.38	5,440,545.60	6,185,825.82	6,931,106.03
	12.7°C	3,204,704.94	3,949,985.16	4,695,265.38	5,440,545.60	6,185,825.82

Appendix G: Sensitivity Analysis – *Results obtained by insulating 1m² of a roof*

- **Annual energy savings (kWh):**

R_pre \ R_post	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10
0.10	708.90300	710.92267	712.53840	713.86036	714.96200	715.89415	716.69314	717.38560	717.99150	718.52612	719.00133	719.42653	719.80920
0.74	80.07705	82.09672	83.71245	85.03442	86.13605	87.06821	87.86720	88.55965	89.16555	89.70017	90.17539	90.60058	90.98325
0.75	78.76700	80.78667	82.40240	83.72436	84.82600	85.75815	86.55714	87.24960	87.85550	88.39012	88.86533	89.29053	89.67320
1.39	34.13091	36.15058	37.76631	39.08828	40.18991	41.12207	41.92106	42.61351	43.21941	43.75403	44.22925	44.65444	45.03711
1.40	33.75729	35.77695	37.39269	38.71465	39.81629	40.74844	41.54743	42.23989	42.84579	43.38040	43.85562	44.28081	44.66349
2.04	17.46418	19.48384	21.09958	22.42154	23.52318	24.45533	25.25432	25.94678	26.55268	27.08729	27.56251	27.98770	28.37038
2.05	17.29032	19.30998	20.92572	22.24768	23.34932	24.28147	25.08046	25.77292	26.37882	26.91343	27.38865	27.81384	28.19652
2.69	8.85200	10.87166	12.48740	13.80936	14.91100	15.84315	16.64214	17.33460	17.94050	18.47511	18.95033	19.37552	19.75820
2.70	8.75189	10.77156	12.38729	13.70925	14.81089	15.74304	16.54203	17.23449	17.84039	18.37501	18.85022	19.27542	19.65809
3.34	3.59186	5.61153	7.22726	8.54923	9.65086	10.58302	11.38201	12.07446	12.68036	13.21498	13.69020	14.11539	14.49806
3.35	3.52688	5.54655	7.16228	8.48424	9.58588	10.51803	11.31702	12.00948	12.61538	13.15000	13.62521	14.05041	14.43308
3.99	0.02731	2.04697	3.66271	4.98467	6.08631	7.01846	7.81745	8.50991	9.11581	9.65042	10.12564	10.55083	10.93351

- **Annual CO_2 emissions reduction (kg):**

R_pre \ R_post	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10
0.10	128.32094	128.68653	128.97900	129.21829	129.41770	129.58644	129.73106	129.85641	129.96608	130.06286	130.14888	130.22584	130.29511
0.45	14.49502	14.86061	15.15308	15.39237	15.59178	15.76051	15.90514	16.03048	16.14016	16.23693	16.32295	16.39992	16.46919
0.81	14.25788	14.62347	14.91594	15.15523	15.35464	15.52338	15.66800	15.79335	15.90302	15.99980	16.08582	16.16278	16.23205
1.16	6.17815	6.54374	6.83621	7.07550	7.27491	7.44365	7.58827	7.71362	7.82329	7.92007	8.00609	8.08305	8.15232
1.52	6.11052	6.47611	6.76858	7.00787	7.20728	7.37601	7.52064	7.64599	7.75566	7.85243	7.93845	8.01542	8.08469
1.87	3.16125	3.52684	3.81931	4.05860	4.25801	4.42674	4.57137	4.69671	4.80639	4.90316	4.98918	5.06615	5.13542
2.22	3.12978	3.49537	3.78784	4.02713	4.22654	4.39527	4.53990	4.66524	4.77492	4.87169	4.95771	5.03468	5.10395
2.58	1.60233	1.96792	2.26039	2.49968	2.69909	2.86782	3.01245	3.13779	3.24747	3.34424	3.43026	3.50723	3.57650
2.93	1.58421	1.94980	2.24227	2.48156	2.68097	2.84970	2.99433	3.11967	3.22935	3.32612	3.41214	3.48911	3.55838
3.29	0.65018	1.01576	1.30823	1.54752	1.74694	1.91567	2.06030	2.18564	2.29532	2.39209	2.47811	2.55507	2.62434
3.64	0.63841	1.00400	1.29647	1.53576	1.73517	1.90391	2.04853	2.17388	2.28355	2.38033	2.46635	2.54331	2.61258
3.99	0.00494	0.37053	0.66300	0.90229	1.10170	1.27044	1.41506	1.54041	1.65008	1.74686	1.83288	1.90984	1.97911

- **Annual SO_2 emissions reduction (g):**

R_pre \ R_post	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10
0.10	1.27603	1.27966	1.28257	1.28495	1.28693	1.28861	1.29005	1.29129	1.29238	1.29335	1.29420	1.29497	1.29566
0.45	0.14414	0.14777	0.15068	0.15306	0.15504	0.15672	0.15816	0.15941	0.16050	0.16146	0.16232	0.16308	0.16377
0.81	0.14178	0.14542	0.14832	0.15070	0.15269	0.15436	0.15580	0.15705	0.15814	0.15910	0.15996	0.16072	0.16141
1.16	0.06144	0.06507	0.06798	0.07036	0.07234	0.07402	0.07546	0.07670	0.07779	0.07876	0.07961	0.08038	0.08107
1.52	0.06076	0.06440	0.06731	0.06969	0.07167	0.07335	0.07479	0.07603	0.07712	0.07808	0.07894	0.07971	0.08039
1.87	0.03144	0.03507	0.03798	0.04036	0.04234	0.04402	0.04546	0.04670	0.04779	0.04876	0.04961	0.05038	0.05107
2.22	0.03112	0.03476	0.03767	0.04005	0.04203	0.04371	0.04514	0.04639	0.04748	0.04844	0.04930	0.05006	0.05075
2.58	0.01593	0.01957	0.02248	0.02486	0.02684	0.02852	0.02996	0.03120	0.03229	0.03326	0.03411	0.03488	0.03556
2.93	0.01575	0.01939	0.02230	0.02468	0.02666	0.02834	0.02978	0.03102	0.03211	0.03308	0.03393	0.03470	0.03538
3.29	0.00647	0.01010	0.01301	0.01539	0.01737	0.01905	0.02049	0.02173	0.02282	0.02379	0.02464	0.02541	0.02610
3.64	0.00635	0.00998	0.01289	0.01527	0.01725	0.01893	0.02037	0.02162	0.02271	0.02367	0.02453	0.02529	0.02598
3.99	0.00005	0.00368	0.00659	0.00897	0.01096	0.01263	0.01407	0.01532	0.01641	0.01737	0.01823	0.01899	0.01968

- **Annual NOx emissions reduction (g):**

R_pre \ R_post	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10
0.10	96.97793	97.25422	97.47525	97.65610	97.80680	97.93432	98.04362	98.13835	98.22124	98.29437	98.35938	98.41755	98.46990
0.45	10.95454	11.23083	11.45186	11.63271	11.78341	11.91093	12.02023	12.11496	12.19785	12.27098	12.33599	12.39416	12.44651
0.81	10.77533	11.05162	11.27265	11.45349	11.60420	11.73172	11.84102	11.93575	12.01863	12.09177	12.15678	12.21494	12.26729
1.16	4.66911	4.94540	5.16643	5.34728	5.49798	5.62550	5.73480	5.82953	5.91242	5.98555	6.05056	6.10873	6.16108
1.52	4.61800	4.89429	5.11532	5.29616	5.44687	5.57439	5.68369	5.77842	5.86130	5.93444	5.99945	6.05762	6.10996
1.87	2.38910	2.66539	2.88642	3.06727	3.21797	3.34549	3.45479	3.54952	3.63241	3.70554	3.77055	3.82872	3.88107
2.22	2.36532	2.64161	2.86264	3.04348	3.19419	3.32171	3.43101	3.52574	3.60862	3.68176	3.74677	3.80493	3.85728
2.58	1.21095	1.48724	1.70828	1.88912	2.03982	2.16734	2.27664	2.37137	2.45426	2.52740	2.59241	2.65057	2.70292
2.93	1.19726	1.47355	1.69458	1.87543	2.02613	2.15365	2.26295	2.35768	2.44057	2.51370	2.57871	2.63688	2.68923
3.29	0.49137	0.76766	0.98869	1.16953	1.32024	1.44776	1.55706	1.65179	1.73467	1.80781	1.87282	1.93099	1.98333
3.64	0.48248	0.75877	0.97980	1.16064	1.31135	1.43887	1.54817	1.64290	1.72578	1.79892	1.86393	1.92210	1.97445
3.99	0.00374	0.28003	0.50106	0.68190	0.83261	0.96013	1.06943	1.16416	1.24704	1.32018	1.38519	1.44335	1.49570

- **Annual CO emissions reduction (g):**

R_pre \ R_post	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10
0.10	35.72871	35.83050	35.91194	35.97856	36.03408	36.08107	36.12133	36.15623	36.18677	36.21372	36.23767	36.25910	36.27838
0.45	4.03588	4.13767	4.21911	4.28573	4.34126	4.38824	4.42851	4.46341	4.49394	4.52089	4.54484	4.56627	4.58556
0.81	3.96986	4.07165	4.15308	4.21971	4.27523	4.32221	4.36248	4.39738	4.42792	4.45486	4.47881	4.50024	4.51953
1.16	1.72020	1.82199	1.90342	1.97005	2.02557	2.07255	2.11282	2.14772	2.17826	2.20520	2.22915	2.25058	2.26987
1.52	1.70137	1.80316	1.88459	1.95122	2.00674	2.05372	2.09399	2.12889	2.15943	2.18637	2.21032	2.23175	2.25104
1.87	0.88019	0.98199	1.06342	1.13005	1.18557	1.23255	1.27282	1.30772	1.33825	1.36520	1.38915	1.41058	1.42987
2.22	0.87143	0.97322	1.05466	1.12128	1.17681	1.22379	1.26406	1.29896	1.32949	1.35644	1.38039	1.40182	1.42110
2.58	0.44614	0.54793	0.62936	0.69599	0.75151	0.79849	0.83876	0.87366	0.90420	0.93115	0.95510	0.97653	0.99581
2.93	0.44110	0.54289	0.62432	0.69095	0.74647	0.79345	0.83372	0.86862	0.89916	0.92610	0.95005	0.97148	0.99077
3.29	0.18103	0.28282	0.36425	0.43088	0.48640	0.53338	0.57365	0.60855	0.63909	0.66603	0.68999	0.71142	0.73070
3.64	0.17775	0.27955	0.36098	0.42761	0.48313	0.53011	0.57038	0.60528	0.63582	0.66276	0.68671	0.70814	0.72743
3.99	0.00138	0.10317	0.18460	0.25123	0.30675	0.35373	0.39400	0.42890	0.45944	0.48638	0.51033	0.53176	0.55105