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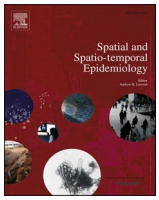

Original Research

Measuring small-area level deprivation in Belgium: The Belgian Index of Multiple Deprivation

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ABSTRACT

Background: In the past, deprivation has been mostly captured through simple and univariate measures such as low income or poor educational attainment in research on health and social inequalities in Belgium. This paper presents a shift towards a more complex, multidimensional measure of deprivation at the aggregate level and describes the development of the first Belgian Indices of Multiple Deprivation (BIMDs) for the years 2001 and 2011.

Methods: The BIMDs are constructed at the level of the smallest administrative unit in Belgium, the statistical sector. They are a combination of six domains of deprivation: income, employment, education, housing, crime and health. Each domain is built on a suite of relevant indicators representing individuals that suffer from a certain deprivation in an area. The indicators are combined to create the domain deprivation scores, and these scores are then weighted to create the overall BIMDs scores. The domain and BIMDs scores can be ranked and assigned to deciles from 1 (the most deprived) to 10 (the least deprived).

Results: We show geographical variations in the distribution of the most and least deprived statistical sectors in terms of individual domains and overall BIMDs, and we identify hotspots of deprivation. The majority of the most deprived statistical sectors are located in Wallonia, whereas most of the least deprived statistical sectors are in Flanders.

Conclusion: The BIMDs offer a new tool for researches and policy makers for analyzing patterns of deprivation and identifying areas that would benefit from special initiatives and programs.

1. Introduction

The creation and use of composite indices for capturing the multidimensionality of deprivation have become extremely popular among researchers and policy makers worldwide (Allik et al., 2020). These complex measures have been an important tool for identifying the most disadvantaged areas at the national, regional, or small area levels (National Statistics 2020; Exeter et al., 2017; McLennan et al., 2019; Noble et al., 2010; Noble et al., 2006). In Belgium, simple measures of deprivation, such as income or education, have been traditionally used and the creation of a multidimensional deprivation index has been long due. This paper presents a theoretical and methodological shift from simple to complex or multidimensional measures of area deprivation in Belgium and describes the development of the Belgian Indices of Multiple Deprivation for the years 2001 and 2011 (BIMD2001 and BIMD2011).

The idea of an area-based composite measure of deprivation stems from the work of Peter Townsend, a British sociologist. In the 1980s,

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Townsend defined deprivation as being multidimensional, composed of material and social deprivation. Material deprivation relates to inadequacies in, for example, goods, services, resources and physical and living environments. Social deprivation includes inadequacies in relationships, functions, customs, rights and responsibilities resulting from being a member of society or its subgroup (Townsend, 1987). Individuals might experience multiple forms of deprivation that might have a cumulative effect. Townsend developed the first multidimensional deprivation index using census-based indicators of deprivation – i.e., unemployment, household overcrowding, non-home ownership and non-car ownership (Townsend, 1987; Townsend et al., 1992).

The first modern Indices of Multiple Deprivation were developed in England in the 2000s, followed by comparable indices for Northern Ireland, Wales, and Scotland, and have since become common in many other countries (National Statistics 2020; Exeter et al., 2017; Noble et al., 2010; Allik et al., 2016). Although based on Townsend's ideas, the modern indices have moved away from a census-based approach by incorporating all routinely collected administrative data. The possibility of using various data sources allowed the indices to include more relevant indicators and to be more frequently updated.

In recent years, these indices have become an important tool for understanding the association between area-based deprivation, health, and social outcomes (Exeter et al., 2017; Butler et al., 2013; Carstairs and Morris, 1989; Exeter et al., 2011; Norman et al., 2011; Kleinschmidt et al., 1995). Besides being used in academic research, indices are key for identifying the most disadvantaged areas and for ensuring that these areas would be directly targeted by the community or government policies. In many countries, e.g. in the UK, national and local organizations use indices to distribute funding or target resources to areas. On a local scale, indices can be used as evidence in the development strategies, interventions or funding applications (Department for Communities and Local Government).

In Belgium, only a handful of studies used a multidimensional measure of socioeconomic deprivation. In 1993, Delhausse et al. (1993) used an aggregate index of deprivation proposed by Desay and Shah (1988) that consisted of a number of consumption events, capturing different aspects of life experience. For instance, a car ownership, quality of housing and home equipment, but also specific goods being consumed for supper or the type of leisure (Delhausse et al., 1993; Desay and Shah, 1988). The disadvantage of the index was its limited coverage as it was computed for 6,000 households only, not covering the whole Belgium.

More recently, Eggerickx et al. (2018) developed a multidimensional indicator for Belgium at the individual level, based on three aspects of social inequalities provided by the national censuses: the level of education, the socio-professional category and the characteristics of housing. This indicator made it possible to divide the whole population of Belgium into eight social groups, but it did not allow exploring the contribution of individual aspects to the overall deprivation, nor their separate use.

In this paper, we present the framework of the first spatial- and time-specific Belgian index of deprivation, the methods that were employed in its development, and describe the domains and indicators that make up the BIMD2001 and BIMD2011. Our main aim is to construct a reliable, multidimensional tool that would enable the measuring of geographical variations in social and economic circumstances in Belgium, either independently or in conjunction with other data, and/or pinpoint areas that would benefit from additional funding or attention through special programmes and initiatives. We encourage and support the use of the BIMD2001 and the BIMD2011 by making them, as well as our findings, publicly available, for all to explore. We hope that these indices will be broadly used by policymakers in communities and local governments, as well as by local authorities and academia.

2. Methods

2.1. Overall approach

The construction of indices of multiple deprivation required multiple steps (Fig. 1). First, we determined the appropriate geographical level and time scale. Second, in sync with a literature review of currently existing indices and in collaboration with Belgian stakeholders and experts, we identified six domains, and their related indicators that measure different but equally relevant aspects of deprivation. Our first aim was to combine indicators into domains and then domains into overall indices, so we would obtain a single summary measure for each domain and overall indices across statistical sectors. The former required standardizing the indicators by ranking, scaling them and adding the scaled scores together using equal weights, or, if possible, weights generated by maximum likelihood factor analysis. The latter involved an exponential transformation of domain scores and combining these scores with explicit weights into overall BIMD scores. For better interpretability, the domain and BIMDs scores were ranked and assigned to deciles from the most (1) to the least deprived (10). The indices were created using the R version 4.1.1 (R version). In what follows, each of these steps will be described in detail.

2.2. Geographical unit and timeframe

The BIMDs are presented at the level of the statistical sector, which is the smallest geographical unit of Belgium, resulting from the subdivision of municipalities (Statistics Belgium 2017).

By definition, a statistical sector may never extend over two municipalities and each geographical point of Belgium belongs to only one statistical sector. In 2001, the structure of the statistical sectors was revised by considering major changes in land use and municipal boundaries and a number of fictitious sectors have been created to determine special situations, such as to assign individuals with unknown sector or diplomats stationed abroad. In total, there were 19,781 and 19,782 statistical sectors spread over 589 municipalities in 2001 and 2011, respectively (Jamagne et al., 2016). These sectors are heterogeneous in population size, with a median population of 299 in 2001 and 315 in 2011.

Due to concerns related to privacy and the unreliability of small population estimates, we excluded from our analysis all statistical sectors with 10 or fewer inhabitants, equalling to 1486 (7.5%) and 1018 (5.2%) sectors, out of which 50.7% (2001) and 36.5% (2011) had zero inhabitants and corresponded to forest, parks, rivers, etc.. The total amount of statistical sectors used in our study was therefore 18,295 (2001) and 18,764 (2011).

The BIMDs were created for the years 2001 and 2011 due to our limited data availability and accessibility for other years. The indices rely heavily on the Belgian national censuses that take place every ten years. Thus, the creation of the BIMD2021 is planned as soon as the data are available. Having indices for two time points allows us to investigate temporal changes in deprivation in Belgium.

2.3. Domains and indicators

The selection of domains and indicators was based on work of Townsend, on the literature review of currently existing indices worldwide (National Statistics 2020; Exeter et al., 2017; McLennan et al., 2019; Townsend, 1987; Townsend et al., 1992; Northern Ireland Statistics and Research Agency 2017), and on the discussion with Belgian stakeholders and experts involved in the follow-up committee of the ELLIS project (more information in Table S31 in Supplementary materials). Six domains of deprivation were selected: income, employment, education, housing, health and crime (Fig. 1). Each domain consists of a number of indicators (Table 1) that aims to comprehensively capture various aspects of deprivation based on the available data (in total 24

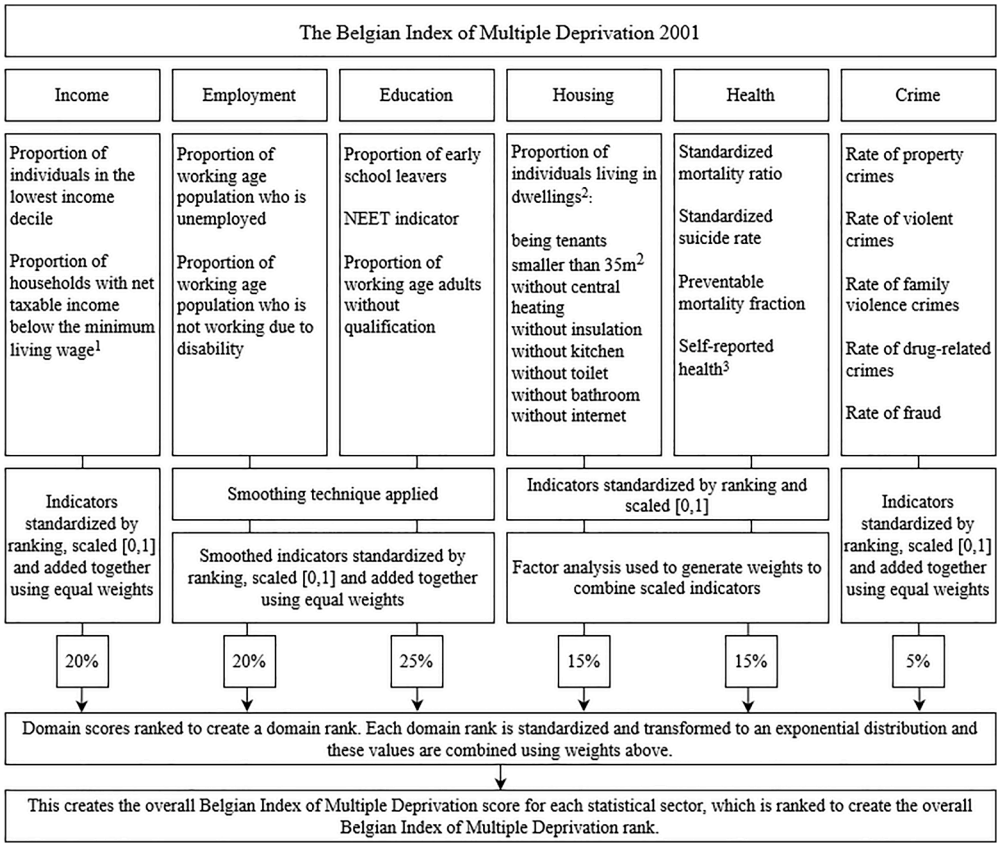

Fig. 1. The model of the Belgian Index of Multiple Deprivation 2001.
[1] In the BIMD2011, this indicator is weighted by the household size.
[2] The housing domain 2011 contains four indicators: proportion of individuals living dwellings with less than 0.5 room/person; without central heating; without bathroom; and proportion of tenants.
[3] The health domain 2011 does not contain the self-reported health indicator.

Table 1
Overview of indicators used in the BIMD2001 and BIMD2011.

Domains and their indicators	BIMD2001	BIMD2011
Income		
Proportion of individuals in the lowest income decile	X	X
Proportion of households with net taxable income below the minimum living wage	X	X
Employment		
Proportion of working age population who is unemployed	X	X
Proportion of working age population who is not working due to disability	X	X
Education		
Proportion of early school leavers	X	X
NEET indicator	X	X
Proportion of working age adults without qualification	X	X
Housing		
Proportion of tenants	X	X
Proportion of individuals living in dwellings:		
smaller than 35 m2	X	
less than 0.5 room/person		X
without central heating	X	X
without insulation	X	
without kitchen	X	
without toilet	X	
without bathroom	X	X
without internet	X	
Health		
Standardized mortality ratio	X	X
Standardized suicide rate	X	X
Preventable mortality fraction	X	X
Self-reported health	X	
Crime		
Rate of property crimes	X	X
Rate of violent crimes	X	X
Rate of family violence crimes	X	X
Rate of fraud	X	X

indicators in 2001 and 19 indicators in 2011).

In the vast majority, indicators in the BIMD2001 and BIMD2011 are expressed as rates or proportions measuring the probability of an individual in a particular area to experience a form of deprivation in 2001 or 2011. Due to poor data availability or accessibility for the year 2001, some of the indicators are based on data from the following years (e.g. the proportion of households with net taxable income below the minimum living wage). In addition, due to the small population numbers, some indicators are built with data collapsed over multiple years (e.g. standardized mortality ratios). All indicators measure major features of deprivation, are statistically robust, are available at the level of statistical sector level or municipality, refer to the period around 2001 and 2011 and can be updated for future iterations.

The *income domain* captures the proportion of the population that is experiencing deprivation related to low or no income. The *employment domain* measures the proportion of those who are unable to work due to unemployment or disability and who are, thus, excluded from the labor market. The *education domain* measures the paucity of educational attainment and skills in the overall population. The *housing domain* captures the shortcomings and poor quality of housing. The *health domain* captures poor physical or mental well-being in the Belgian population, and the *crime domain* measures the rate of material and personal victimization.

Detailed information on each indicator, its data source, and methodology of each domain are available in Supplementary materials.

2.4. Data

To build the income, employment, education, and housing domains, we used a pseudonymized dataset, built upon the demographic database produced by Statbel. Our database covers the period 1991–2020, and includes several administrative data sources, such as the 2001 and 2011 Belgian population censuses, data from the National Register on all-

cause mortality and population structure, and data on cause-specific mortality from death certificates (Statistics Belgium; Eggerickx et al., 2019). Individuals in these data sources are deterministically linked by a multi-digit code specific to the project. The pseudonymization prevents linkages of the data with other administrative databases or databases located in other research centers. The database covers all persons officially residing in Belgium at the reference period when computed over multiple years or at the time of the census. Thus, individuals who lived in Belgium and were not officially registered were not included in our datasets.

The 2001 Belgian population census was conducted on October 1st, 2001 and was a semi-administrative census, with most of the socioeconomic variables collected through a mandatory postal survey organized by the Federal Public Service Economy (Statbel 2022). In 2011, the individual survey was replaced by the use of data that were already available in administrative databases. Thus, the 2011 census was fully administrative and it was a snapshot of the Belgian population on January 1st, 2011.

In addition, aggregated data on the proportion of households below the minimum living wage at the statistical level, included in the income domains for 2001 and 2011, were obtained from Statbel.

While building the employment domain for 2011, we created an indicator of the proportion of health insurance beneficiaries (aged 20–64) who received long-term disability benefits utilizing data from the Intermutualistic Agency (IMA). These data are publicly available in the IMA Atlas database (https://atlas.ima-aim.be/databanken/).

Finally, counts of criminal crimes that occurred between 1 January 2001 and 31 December 2001, and 1 January 2011 and 31 December 2011, aggregated at the level of municipality, were provided by the Federal Police Belgium. They are publicly available at https://www.stat.policefederale.be/criminaliteitsstatistieken/interactief/grafiek-tijdslijn-criminele-figuren/.

More detailed information on data sources is found in Supplementary materials.

2.5. Smoothing of indicators

When the population at-risk in the statistical sector is large, the variance is usually small and the direct estimates are robust and reliable. However, in statistical sectors with small populations, estimates are often unreliable. Although we excluded all statistical sectors with 10 or fewer inhabitants, the issue with the small number of events still arose when we calculated indicators referring to a subset of the population, such as the proportion of the working age population that is unemployed. To smooth these estimates, we fitted a simple space-time Bayesian model using the *smoothSurvey* function from the *SUMMER* package (Li et al., 2022; R-INLA project 2022), as detailed in Supplementary materials.

2.6. Combining indicators into domains

Several methods were explored to combine indicators into domains, such as maximum likelihood factor analysis (ML FA), principal component factor analysis (PCA), and the use of equal weights. The final, chosen method varied by domain. To decide on the method to be applied in each case, we conducted a thorough literature review on methodology of deprivation indices worldwide, and multiple sensitivity analyses to empirically test the impact of various combination techniques.

When combining indicators into domains, the first step was the same across all indicators. In order to prevent large numbers or outliers from having a disproportionate effect on the overall scores, the indicators needed to be measured on comparable scales. The indicator values were therefore ranked from 1 to 18,295 in the BIMD2001 and 18,764 in the BIMD2011, from the least to the most deprived and transformed so their values ranged between 0 and 1.

Indicators of the income and employment domains were combined by simply adding them together (i.e. using equal weights). We tested correlation of individual indicators with the housing domain which was constructed first (Otavova et al., 2022). This method was used by Exeter et al. when selecting the weights for indicators used in the deprivation index of New Zealand (Exeter et al., 2017). The income domain indicators were consistently, similarly correlated with the housing domain. In 2001 and 2011, the Spearman correlation coefficient between the housing domain and the indicator 'the proportion of individuals in the lowest income decile' corresponded to $\rho = 0.20$ and $\rho = 0.19$; and between the housing domain and the indicator 'the proportion of households with net taxable income below the minimum living corresponded to $\rho = 0.19$ and $\rho = 0.16$.

Satisfactory stable Spearman correlation coefficients were also found for the employment domain. In 2001, the Spearman correlation coefficients between the housing domain and the indicators 'the proportion of the working age population who is unemployed' and 'the proportion of population who is not working due to disability' were equally $\rho = 0.45$. In 2011, these Spearman correlation coefficients between the housing domain and the employment domain indicators corresponded to $\rho = 0.13$ and $\rho = 0.20$. Given the fact that indicators were standardized and showed stable associations with the housing domain, the least complex method was chosen for the income and employment domains, i.e. the indicators were combined using equal weights.

The education domains 2001 and 2011 were initially built using 1) equal weights and 2) weights derived by the ML FA. The latter method can only be used if there are at least three indicators, and an underlying factor is suspected – conditions satisfied by this domain. In addition, ML FA is most appropriate where indicators are not perfectly reliable or measured without error, and does not depend on the scale of measurement of the input indicators (Northern Ireland Statistics and Research Agency 2017).

We then conducted multiple correlation tests. We tested the association between individual indicators ('early school leavers', 'working-age adults without qualification', and 'the NEET') and the housing domain scores (in 2001, $\rho = 0.42$, $\rho = 0.45$, $\rho = 0.48$; in 2011, $\rho = 0.57$, $\rho = 0.65$, $\rho = 0.60$), and association between the domain scores created by equal weights and FA weights ($\rho > 0.90$ in both years 2001 and 2011). As the associations were stable across indicators and housing domain scores, and between the two education domain scores, we used the least complex method of equal weights.

The crime domain is the only domain that was constructed on the level of the municipality, implying that statistical sectors within a municipality obtained the same score. As in the case of the education domain, we compared two crime domain scores created by: 1) adding the rates together (i.e. equal weights) and 2) using the ML FA. The Spearman correlation coefficient between the two crime domain scores was 0.98. In addition, the crime domain scores were ranked and assigned to deciles, and a confusion matrix was used to see the matching in domain deciles. The results were highly satisfying – 96% match in the most deprived decile. Thus, the selected method was the one with equal weights.

Indicators of the housing and health domains were combined with weights obtained by maximum likelihood factor analysis (Northern Ireland Statistics and Research Agency 2017).

We used the *fa* function from the *psych* package (Revelle, 2022). More information on transformation, combination of indicators, and ML FA can be found in Supplementary materials.

2.7. Exponential transformation

Prior to integrating the domain scores into the overall indices of multiple deprivation, we ensured that the domain scores had a common distribution, were scale independent, and had an appropriate level of cancelation. The method of transformation of the ranks to an exponential distribution met these criteria (Noble et al., 2006). We followed a

methodology of the exponential transformation used in existing indices worldwide (National Statistics 2020; McLennan et al., 2019; Northern Ireland Statistics and Research Agency 2017; Noble et al., 2004). The standardization involved ranking the domain scores from 1 to 18,295 in the BIMD2001 and 18,764 in the BIMD2011, from the least to the most deprived. The ranked scores were then scaled to the range [0,1], where $R = 1/N$ for the least deprived, and $R = N/N = 1$ for the most deprived. N is the number of statistical sectors included in the BIMD2001 and BIMD2011 (Noble et al., 2004). The exponential transformation is explained in Supplementary materials. The exponentialized domain scores represent the final domain scores ranging from 0 (least deprived) to 100 (most deprived), with the most deprived 10 percent of statistical sectors obtaining scores between 50 and 100, covering 50% of the distribution of scores (McLennan et al., 2019).

2.8. Integration of domains into the Belgian Index of Multiple Deprivation (BIMD)

Integrating the different domains into an overall BIMD2001 and BIMD2011 involves weighting the domains (National Statistics 2020; Exeter et al., 2017; McLennan et al., 2019; Northern Ireland Statistics and Research Agency 2017). Noble et al. (2006) described five possible approaches to domain weighting: based on existing literature on multiple deprivation; empirically driven; determined by policy relevance; determined by consensus; entirely arbitrary (Noble et al., 2006). The distribution of our selected set of weights reflected the existing literature on deprivation indices and was supported by Belgian stakeholders and experts, as well as it considered the ability of the domains to directly measure different forms of deprivation.

To investigate the impact of various weights on the overall indices, we conducted a sensitivity analysis by creating the BIMD2001 and BIMD2011 using different weights. These were (1) weights selected to reflect research and opinion of the Belgian stakeholders and experts (denoted as the final, chosen weights); (2) various weights used in the currently existing indices (for instance, in England, New Zealand, Scotland, and Northern Ireland) (National Statistics 2020; Exeter et al., 2017; McLennan et al., 2019; Northern Ireland Statistics and Research Agency 2017); (3) weights generated by ML FA; and 4) weights as in 1 but in a reversed order. Table 2 shows all weights used. Correlation analysis of all indices is shown in Supplementary materials.

2.9. Spearman's rank correlation coefficient

We used Spearman's rank correlation coefficient to describe a monotonic relationship between ranked indicators, domains, and overall BIMDs. The coefficient can assume values between $\rho = -1$ and $\rho = +1$ when two paired variables have a perfect monotonic and negative or positive relationship. The more the coefficient ρ approaches 0, the less the value pairs share a perfect monotonic relationship (Cleff, 2014).

2.10. Higher-level area summary measures

We produced multiple summary measures for the higher-level area geographies for the BIMD2001 and BIMD2011 and their domains. These include a simple measure, such as a proportion of statistical sectors in most deprived 10 percent nationally; and a population-weighted measures, such as an average score, an average rank, and an extent (McLennan et al., 2019). The population-weighted measures take into account that statistical sectors population sizes can vary. The methodology of the higher-area level summaries is described in detail in Supplementary materials and follows the methods used worldwide (National Statistics 2020; McLennan et al., 2019; Northern Ireland Statistics and Research Agency 2017).

2.11. Availability of the BIMD results

A full list of the data files and supporting documents is available via GitHub at https://github.com/bimd-project/bimd. The files contain the overall BIMDs and their domains scores, ranks, and deciles. We also publish the R codes allowing the end user to tailor the construction of BIMDs to their research or policy aims.

3. Results

3.1. Belgian indices of multiple deprivation and their deprivation domains

Fig. 2 displays the Belgian Index of Multiple Deprivation 2001 and 2011 scores, which were ranked and assigned to deprivation deciles from the most (1) to the least (10) deprived.

The distribution of deprivation by the BIMDs differed across space (the Belgian statistical sectors) and time. In Fig. 2, a clear gradient is observed between Flanders and Wallonia, suggesting greater overall deprivation in the French-speaking region. The spatial distribution of the most and least deprived statistical sectors has not changed over time. In 2001 and 2011, about 78% of the most deprived statistical sectors were located in Wallonia, while 90% of the least deprived statistical sectors in Flanders. The most deprived areas were more spatially concentrated and clustered together, which also reflects their greatest concentration in the municipality of Charleroi (containing 11% of all most deprived statistical sectors), whereas the least deprived areas showed greater spatial variations.

In 2001, the greatest number of most deprived statistical sectors in terms of income (5.5%), employment (10.6%), education (11.0%), housing (6.7%) and crime (8.0%) were located in the municipality of Charleroi, which is the municipality with the second highest number of statistical sectors in Belgium. The greatest number of most deprived statistical sectors in terms of health (7%) were located in the municipality of Liège. Across all six domains, the majority of the most deprived statistical sectors was in the region of Wallonia, ranging from 68% in terms of housing deprivation and up to 98% in terms of health deprivation (Fig. 3). On the contrary, the spatial distribution of least deprived statistical sectors varied greatly. Across all six domains, no evidence was found for a concentration of the least deprived statistical sectors in one municipality. Overall, the majority of the least deprived statistical sectors was found in Flanders, fluctuating between 60% in terms of housing deprivation and 95% in terms of employment. Interestingly, no least deprived statistical sector in terms of crime was identified in the Brussels-Capital region. Similar results were found in 2011, suggesting no significant change in the distribution of the most and least deprived statistical sectors.

Table 2
Overview of alternative weights applied in the BIMD2001 and the BIMD2011.

Domains	England IMD	NZ IMD	Scotland IMD	Northern Ireland IMD	ML FA weights	Reversed final chosen weights	Final chosen weights
Income	24.5	28	12	25	4	15	20
Employment	24.5	28	12	25	42	15	20
Education	15	15	6	15	44	5	25
Housing	10.5	10	1	10	12	20	15
Health	15	14	6	15	5	20	15
Crime	10.5	5	2	10	3	25	5

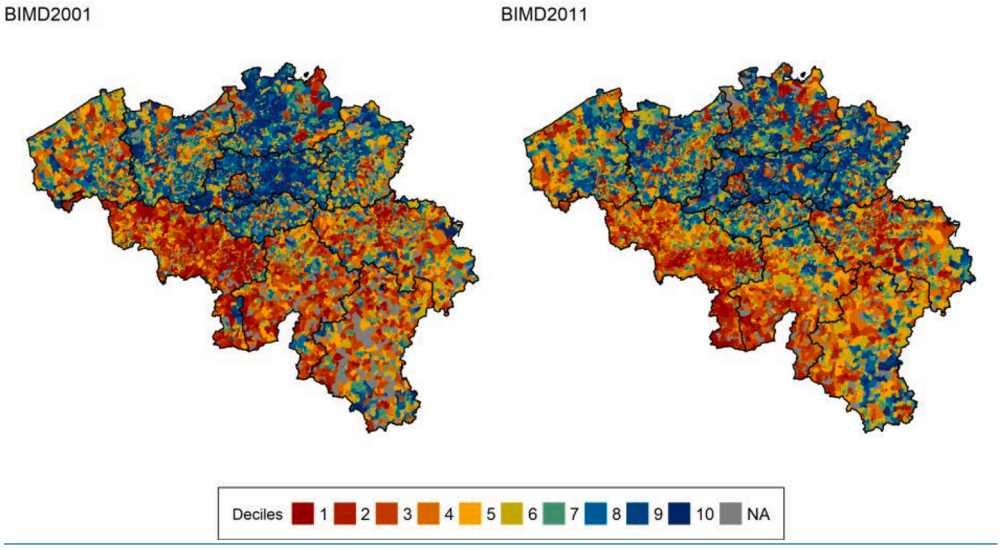

Fig. 2. Distribution of the BIMD2001 and BIMD2011 deprivation deciles across Belgian statistical sectors in 2001 and 2011. The most deprived statistical sectors fall into the first deprivation decile (dark red).

Population-weighted higher-level summary measures, based on the BIMDs or domain scores or ranks, identified the municipality of Saint-Josse-Ten-Noode, Farciennes and Colfontaine among the ten most deprived, whereas the municipality of Hove, Herent, and Oud-Heverlee among the least deprived Belgian municipalities in 2001 and 2011. The municipality of Saint-Josse-Ten-Noode was also identified as the most deprived in terms of income, education, and housing. In 2011, the same municipality was still on the top of deprivation related to income and education, but the municipality of Mesen became the most deprived in housing. The municipalities of Colfontaine and Waarschoot were found the most deprived in terms of employment and crime, and the municipalities of Engis and Momignies in terms of health in 2001 and 2011. An overview of all Belgian municipalities and their deprivation on the BIMD2001 and BIMD2011 is shown in Supplementary materials.

Population-weighted higher-level summaries, such as the ranked average score, can be used to measure deprivation at the higher area-division units. Fig. 4 demonstrates the distribution of average score ranks by Belgian districts, which are the area-division units above municipalities. The 43 districts are ordered by the median average score rank (measured across municipalities) in descending levels of deprivation. In both years, the district of Mons had the lowest median average score ranks (45 in 2001 and 29 in 2011), while the district of Antwerpen and Leuven had the highest median average score ranks in 2001 and 2011 (552 in 2001 and 541 in 2011). The distribution of domain average score ranks across districts is shown in Figs. S7 and S8 in Supplementary materials.

Using the BIMDs 2001 and 2011, the distribution of individual indicators by deprivation deciles was investigated. The results showed that the size of each indicator linearly increases with an increase in deprivation, measured by deprivation decile (i.e. the greatest proportions/rates were in the most deprived decile). This trend was observed in all indicators in 2001 and 2011. The absolute differences in the proportions between the most and least deprived areas, assigned to deprivation deciles, varied greatly. In 2001, the percentage of the population with the lowest income was almost two times higher in the most deprived areas, compared to the least deprived areas (10% against 5%). In 2011, the population with the lowest income was more than six times higher in the most deprived areas (27% against 4%). In 2001 and 2011, the unemployment rate was more than five times higher in the most deprived decile, compared to the least deprived decile (16% against 3% in 2001, 13% against 2% in 2011). The share of youth aged 15–24 who were neither in employment nor education or training (NEET indicator) was almost five times higher in 2001 (29% against 6%) and almost seven times higher in 2011 (20% against 3%). There were also stark differences in housing quality. In 2001, it was four times more common to live in a dwelling without a toilet or bathroom (similarly for both indicators 5% against 1%), if these dwellings were located in the most deprived areas. In 2001, overcrowding was four times more frequent in the most deprived areas (11% against 3% in the least deprived decile) and even six times higher in 2011 (13% against 2%). The percentage of the population without a central heating was two times higher in 2001 (36% against 16%) and four times higher in 2011 (20% against 5%) in the most deprived areas, compared to the least deprived areas. Compared to the national mortality rates, in 2001 and 2011, individuals living in the most deprived areas suffered from 16% and 21% excess mortality, while risks of dying among those residing in the less deprived sector were 10% and 20% lower than the national average. In both years, the standardized suicide rate was about three times higher in the most deprived areas, compared to the least deprived. The preventable mortality fraction, i.e. the fraction of mortality that could be avoided if the public health policies focused on wider determinants of public health, such as lifestyle, was 20% and 19% in 2001, and 17% and 15% in 2011, in the most deprived, compared to least deprived areas. In 2001, individuals living in the most deprived areas reported were almost three times more likely to report poor health, compared to those living in the least deprived areas (11% against 4%). More details on the distribution of indicators by the overall BIMD2001 and BIMD2011 are in Supplementary materials.

Our results showed that the age and sex population structure varied among deciles, but not between domains. In 2001 and 2011, the mean age of the male population living in the most deprived statistical sectors was 42.0 and 42.9 years, compared to 40.7 and 42.5 years in the least deprived statistical sectors. The mean age of the female population in the most and least deprived areas was higher, reaching 44.4 and 42.1 years in 2001, and 45 and 43.6 years in 2001 and 2011, respectively.

Although the deciles contained the same number of statistical sectors, the number of individuals across deprivation deciles varied. In 2001, the greatest proportion of the population was consistently identified in the most deprived decile in terms of crime (28%), education (17%), housing (15%), and employment (15%), suggesting that highly populated areas are at risk of deprivation. A similar trend was observed in the population allocation across deciles in 2011, with the greatest proportion of the population in the most deprived deciles, i.e., crime (29%), education (20%) and income (19%), employment (13%). There

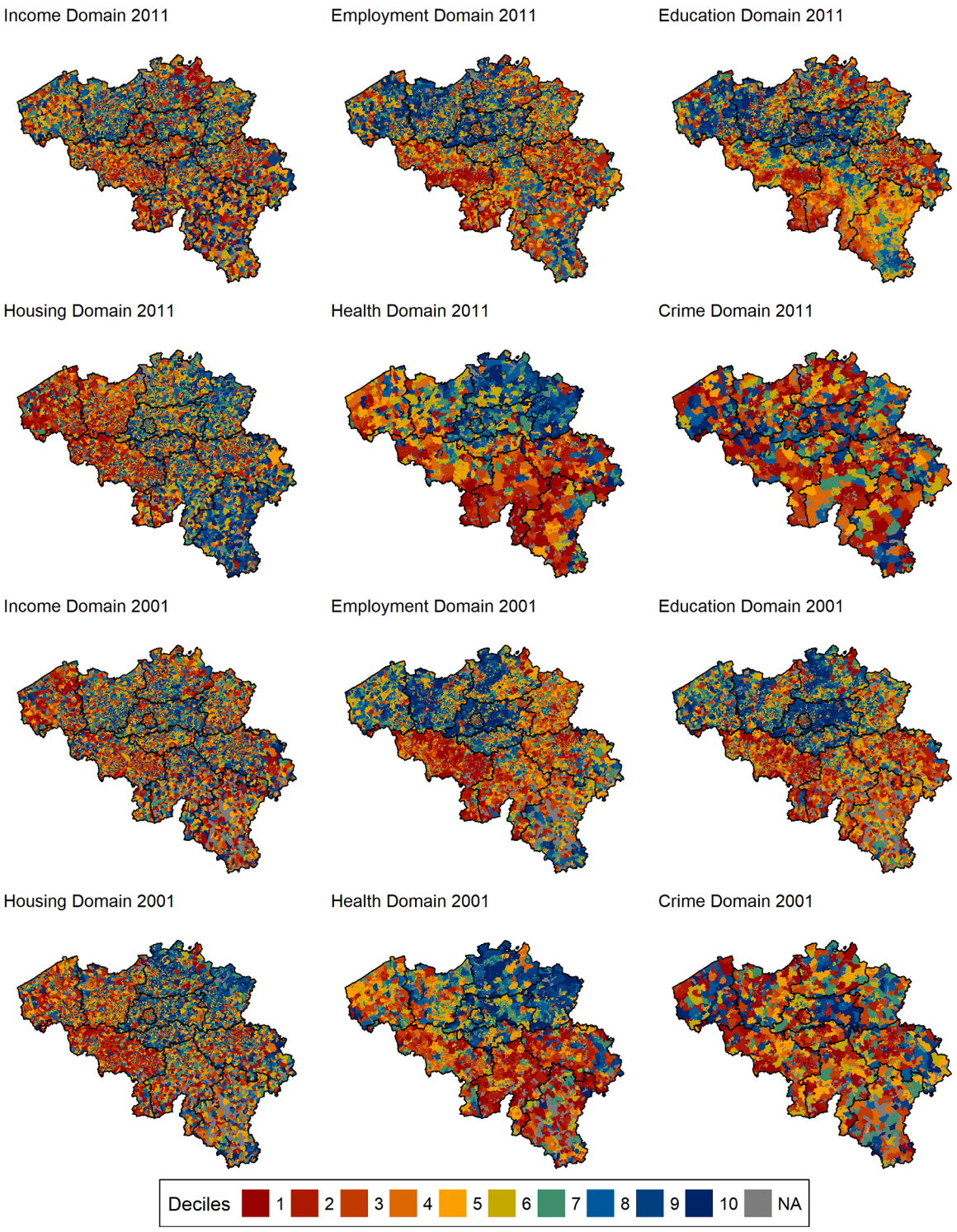

Fig. 3. Distribution of the deprivation domain deciles across Belgian statistical sectors in 2001 and 2011. The most deprived statistical sectors fall into the first deprivation decile (dark red).

were no significant differences in the proportions of men or women observed across deciles. Population pyramids are shown in Figs. S5 and S6 in Supplementary materials.

3.2. Correlations between the BIMD2001 and BIMD2011 and their respective domains at the statistical sector level

The Spearman's Rank Correlations, ρ, are presented in Tables 3 and 4. All of the correlations are highly statistically significant ($\rho < 0.001$). The education and employment domain scores are very strongly associated with the overall BIMD scores, in both 2001 ($\rho = 0.85$ and $\rho = 0.80$) and 2011 ($\rho = 0.83$ and $\rho = 0.79$, respectively). Similarly, in 2001 the housing domain scores are strongly correlated with the overall BIMD scores ($\rho = 0.72$), while the income, health, and crime domain scores are only moderately correlated with the overall BIMD scores ($\rho = 0.56$, $\rho = 0.56$, $\rho = 0.40$). In 2011, the income domain scores are strongly correlated with the overall BIMD score ($\rho = 0.65$), whereas the crime, health, and housing domain scores are moderately correlated with the BIMD

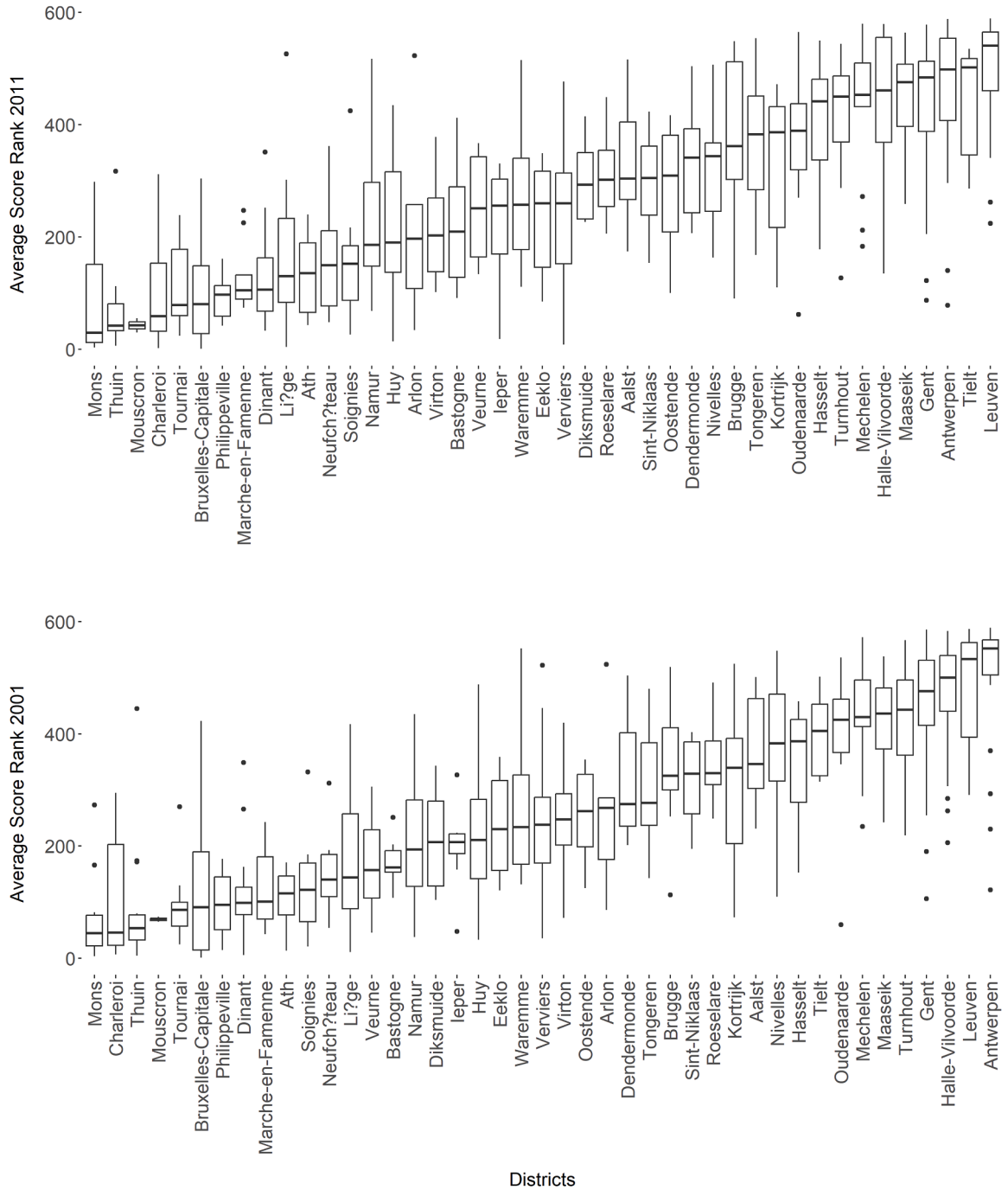

Fig. 4. Distribution of the average score ranks across Belgian districts, from the most to the least deprived (from left to right).

Table 3
Spearman correlation between the BIMD2001 and its domains.

	BIMD2001	Income	Employment	Education	Housing	Crime
BIMD2001	1					
Income	0.56	1				
Employment	0.80	0.24	1			
Education	0.85	0.29	0.77	1		
Housing	0.72	0.37	0.51	0.56	1	
Crime	0.40	0.10	0.32	0.33	0.25	1
Health	0.56	0.07	0.38	0.36	0.35	0.23

Table 4
Spearman correlation between the BIMD2011 and its domains.

	BIMD2011 score	Income	Employment	Education	Housing	Crime
BIMD2011	1					
Income	0.65	1				
Employment	0.79	0.40	1			
Education	0.83	0.47	0.70	1		
Housing	0.42	0.14	0.23	0.19	1	
Crime	0.50	0.31	0.35	0.45	0.05	1
Health	0.47	0.07	0.31	0.20	0.21	0.18

scores ($\rho = 0.50$, $\rho = 0.47$, $\rho = 0.42$).

In both indices, the employment's strongest association is with the education domain ($\rho = 0.77$ and $\rho = 0.70$), while the income's greatest associations in BIMD2001 are only weak with the education ($\rho = 0.29$), employment ($\rho = 0.24$) and housing domains ($\rho = 0.37$). In the BIMD2011, the income domain's strongest association is with the education domain ($\rho = 0.47$).

We also explored the Spearman correlation between domains 2001 and 2011. The greatest association is between the crime ($\rho = 0.88$) and education domains ($\rho = 0.84$). The employment ($\rho = 0.77$) and housing domains ($\rho = 0.66$) are also strongly correlated, followed by the health ($\rho = 0.58$) and the income domains ($\rho = 0.50$). These two domains differ in indicators in the years 2001 and 2011, which may explain their moderate correlations.

4. Discussion

To our knowledge, this is the first study in Belgium employing multiple highly-reliable data sources to create an area-based, multidimensional deprivation measure. This represents a major methodological shift from the use of a simple measure of deprivation, such as income or education, at the individual level, to a more sophisticated composite measure of deprivation at the aggregate level of the smallest administrative unit in Belgium. The BIMD2001 and BIMD2011 are built on six domains of deprivation (income, employment, education, housing, health and crime), comprising 24 and 19 unique indicators, respectively. The process of combining indicators into domains, and domains into the overall BIMDs resulted in each statistical sector being given a domain and overall BIMDs score, rank, and decile. Using one of those, a statistical sector can easily be classified as deprived relative to other areas in either a particular dimension or in overall deprivation.

When constructing the indices, we had to make several crucial methodological choices. One of the first decisions regarded the units of our analysis, i.e. whether we should create the BIMDs using individuals or groups of people living in a clearly defined geographical area. We chose the latter for several reasons. Firstly, we were interested in capturing all three meanings of area deprivation: a compositional meaning, a collective meaning and an environmental meaning (Macintyre, 1997). The compositional meaning of area deprivation is where an area is considered to be deprived if it contains a large proportion of deprived people. The collective and environmental meanings refer to the additional deprivation in an area which is beyond those attributable to the concentration of deprived people and they can be seen as synonymous with the 'neighborhood effect'. The neighborhood effects have been increasingly researched, specifically in relation to health or housing, and studies have shown that neighborhoods affect their inhabitants, even after accounting for individual risk factors (Duncan et al., 1999; Pickett and Pearl, 2001; Cubbin et al., 2000; Shaw, 2004; Dunn and Hayes, 2000). Evidence has been accumulating that the area where a person lives may influence various aspects of their lives, such as employment, child outcomes, criminal behavior and other socioeconomic phenomena (Dietz, 2002). By creating our indices at the level of the statistical sector, we were able to include all three dimensions. Secondly, using aggregate data enabled us to better accommodate the privacy, security and confidentiality issues associated with using administrative and survey data. In addition, data on some crucial indicators were only obtainable at the aggregate level. Finally, as the sectors' characteristics are relatively stable over time, our aggregate approach allows more easily to identify areas in need of interventions that would benefit from area-based policies.

Belgium is administratively divided into regions, provinces, districts, municipalities and statistical sectors. We aimed to construct the BIMDs at the smallest workable spatial scale, with the selected units being relatively homogeneous. This choice was also justified by the fact that statistical sectors are the official units in Belgium and thus, they represent actual communities or neighborhoods; their boundaries change little over time; and they are also in most cases large enough to provide statistically robust estimates of socioeconomic or health indicators with limited smoothing required.

Measuring different aspects of deprivation and combining these into an overall multiple deprivation measure raised several concerns. A major concern regarded the issue of to which extent the same individuals should be represented in more than one indicator of the same domain or across multiple domains. For instance, an individual who is a tenant might also live in a dwelling smaller than $35m^2$, but he might also be unemployed. Our stance on that is that experiencing multiple forms of deprivation is worse than experiencing only one of its forms. Therefore, we did not aim to eliminate double counting either within or between domains.

Another concern involved the cancelation effect and its extent. For instance, if an area has high levels of education deprivation but low levels of employment deprivation, should the latter cancel out the former and to which extent? To control the cancelation effect, we used exponential transformation of the domain scores – a method commonly used in indices worldwide, for instance in the UK indices (McLennan et al., 2019). The exponential distribution does not eliminate the cancelation effect but it minimizes it by spreading out the most deprived distribution in the tail. This property ensures that indices are specifically constructed to identify deprivation and not affluence (National Statistics 2020; McLennan et al., 2019; Noble et al., 2010; Northern Ireland Statistics and Research Agency 2017).

Furthermore, we faced the issue of what weights should be attached to each domain. The results of our sensitivity analysis revealed that changes in weights make little difference to the overall BIMD2001 and BIMD2011. (Table S21 in Supplementary materials). We accredited the consistency in results to the high correlation between many domains. Based on our findings, our final choice of weight distribution was driven by existing research (Townsend, 1987; Townsend et al., 1992; Townsend, 1991) and consultations with Belgian stakeholders and experts. In addition, we considered the ability of the domains to directly measure different forms of deprivation in Belgium, and the quality and coverage of indicators in each domain. In the final version of the BIMDs, education, income, and employment domains have been given the largest weights, accounting for 65%. The education domain received the greatest weight (25%) as it is the most basic component of socioeconomic status. Besides shaping future occupational opportunities and earning potential, education provides knowledge and life skills that prevent one from deprivation (Adler and Newman, 2002). The housing and health domains received a weight of 15%, whereas the crime domain received the smallest weight (5%) as it is modelled on the level

of municipality.

4.1. Strengths and limitations

A significant strength of the BIMDs is that the six domains may be used in combination or separately to explore their contribution to the overall BIMD in a given statistical sector. To facilitate a wide use of the BIMDs and domains, we publish their scores, ranks, and deprivation deciles at the statistical sector level. Moreover, we publish R codes and datasets that enable to build the BIMDs or compute higher-area level summaries. Publishing these materials opens the door to public health officials, policy makers, stakeholders, or researchers to measure geographical variations in housing inequality to guide policy decision-making. The availability of individual domains' scores enables to identify the type of deprivation that is prevalent in the neighborhood and changes the focus directly on the specific deprivation or geographical area. In case the research interest lies in exploring the association between health and deprivation, the publicly available domains can be combined without the health domain. Moreover, the indices can be updated using the most available datasets in the future, for example once data from the next census are released.

Another strength of our study is the use of the highly reliable pseudonymized dataset from the 2001 and 2011 population censuses and the National Register to build most BIMDs' indicators. These indicators are represented by rates consisting of a numerator (e.g. the number of deprived people in area) and a denominator (e.g. the total number of 'at risk' people living in the same area). Both are computed from the same data sources, ruling out any systematic error that arises from different datasets of different coverages. Working with administrative and exhaustive data gives an added advantage to our BIMDs as it enables us to minimize selection bias and reduce the risk of ecological fallacy. Exhaustiveness is, however, not effective for all variables as high non-response rates are observed for some variables (e.g., education level in some years or housing tenure). Coupling the census data and national register, we were able to impute missing information for some indicators, such as in the case of the housing domain. We should, however, acknowledge that our datasets exclude non-registered inhabitants of Belgium, who are typically more deprived and are not randomly distributed across the territory.

The variability in the level of non-responsiveness might relate to data collection across censuses. In 2001, data were collected through an individual questionnaire, while in 2011 administrative databases were used to update the previously existing information. This difference in data collection can lead to comparability issues for some variables. Of particular concern is the absence of information on the educational level of new migrants in the 2011 census.

Although the final indices are at the level of the statistical sector, we were provided with the crime counts at the municipality level without specific geographical/address information, such as postcodes, map references and address details. Such lack of information prevented us to obtain reliable and robust estimates for statistical sectors. The crime domain was thus built at the municipality level and statistical sectors falling into the same municipality received the identical score, rank and decile. Additional limitations regarding each domain are described in more detail in Supplementary materials.

Many other indices worldwide include a domain referring to the access to services, but the BIMD indices do not. This is because we were not able to access data that we could utilize to build this domain in 2001 and 2011. On the other hand, from the existing literature we know that when an index contains 'access to services' domain, the weight given to this domain is always the lowest, e.g. 10% in the Northern Ireland MDI, or 2% in the New Zealand MDI. Given high correlations between our domains and overall index, including the 'access to services' domain would likely have a very little impact on the final score.

Our BIMDs also have limitations that need to be considered when interpreting the outcomes. We created area-based measures that can be used for comparing statistical sectors across Belgium, identifying the most deprived statistical sectors, exploring the types of deprivation via domains using the domain and BIMDs scores and ranks. The type of deprivation in an area and its scale can be identified by a domain score. Within the domain, the greater the score, the more deprived the area. The scores are, however, not an appropriate tool for a deprivation comparison across domains because they have different minimum and maximum values. Using the ranks, the statistical sectors can be compared in terms of deprivation domains and overall BIMDs. The findings should be reported with attention to their correct formulation. We can make a statement that 'statistical sector A is more deprived than statistical sector B', but we are restricted from making statements such as 'statistical sector A is twice as deprived as statistical sector B'. In addition, the BIMDs are not designed to provide direct comparability between the 2001 and 2011 versions. The changes in deprivation between the two versions can however be described in relative terms, for example, a statistical sector was within the most deprived 30 percent of areas nationally according to the BIMD2011 but within the most deprived 10 percent according to the BIMD2001 (Department for Communities and Local Government).

Although the number of statistical sectors and their borders have changed only slightly overtime, it is also crucial that researchers who are wishing to apply our estimates, make use of the correct statistical sector definitions and shapefiles.

Finally, by creating an area based spatial measure, we can identify areas as more or less deprived, but the tool is not suitable for making such inferences about individuals or specific groups of people. Most importantly, our indices are designed to identify various aspects of deprivation, not affluence. It means that a sector classified as less deprived, is not necessarily among the most affluent sectors in Belgium.

5. Conclusion

We created the first composite and multidimensional tool for measuring the deprivation in Belgium, the Belgian Indices of Multiple Deprivation for the years 2001 and 2011. The BIMDs are built on six domains that can be used in combination or separately to explore their contribution into the overall BIMD in a given geographical area. The domains are created by using a high-quality data and they can be easily updated when the most recent data become available. Although the BIMDs are computed at the level of statistical sector, they can provide information on deprivation at a higher geographical level.

As we make the BIMDs publicly available, we hope that the indices will be used for analyzing patterns of deprivation and identifying areas that would benefit from special initiatives and programs. Policy makers, governmental departments, regional bodies and local authorities as well as academics are encouraged to use the indices to help target policies and funding to ultimately reduce inequalities across multiple domains.

Author's contributions

Data preparation and analysis were performed by MO. The first draft of the manuscript was written by MO and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate

Our dataset is a part of the Causineq database that was obtained from the Belgian statistical office, Statbel, after approval by the Statistical Oversight Committee of the Privacy Commission. The confidentiality contract numbers are STAT-MA-2015–13 and STAT-MA-2016–23. On 31 May 2021 (decision no. 2021/071), the authors obtained the right to update, use and store the Causineq data until 31 December 2034.

The Causineq database is pseudonymized, and contains a multi-digit code specific to this database. It therefore does not enable linkages with

other administrative databases or databases belonging to other research centers.

Availability of data and materials

The data that support the findings of this study are available at the Belgian statistical office, Statbel, but restrictions apply to the availability of these data, which are used under license for the current study, and so are not publicly available. Data are however available from the corresponding author upon reasonable request and with permission of Statbel.

Consent for publication

Not applicable.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sste.2023.100587.

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