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Improving the estimation of the size of the European drug market

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Impressum

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Introduction

The EMCDDA has produced in recent years different estimates of the size of the EU drugs market. To improve and develop these estimates the agency has contracted Addiction Switzerland and the School of Criminal Justice of the University of Lausanne to collect and analyze different materials in order to formulate recommendations for the future. The project has three steps: a literature review, a case study and an expert consultation.

This report presents the main findings, conclusions and recommendations of each of the three steps as well as final recommendations integrating the lessons learned during the project. It starts with the review of the literature, which is followed by the presentation of a case study of a local drugs market estimate made in Switzerland using two different methods. The third part of the report presents the results of a short consultation with a group of experts selected by the EMCDDA on how to improve current drug market estimates.

1 Literature review on estimating the size of illegal drug markets

1.1 Introduction

The review should provide an insight into the conceptual and methodological developments made internationally to assess the size of drug markets.

1.1.1 Definitions

The size of a “drug market” refers generally to the quantities of a given illicit drug available to or used by a given population during a given timeframe. There are however different definitions of the boundaries of illicit drug markets. One issue for example is whether police seizures should be included and, if the answer is positive, if this should encompass all local, national but also international seizures that are relevant for the geographical area and time-period under study. For the literature review (part 1 of the report), we will not use a single concept or definition of drug markets but rather specify the differences whenever necessary.

Conceptually, there are two main strategies to assess a drug market’s size: a supply-side or top-down approach and a demand-based or bottom-up approach. As stated by Kilmer (2011), the strengths and limitations of these strategies differ according to the substance studied. This is also true for the different methods used within these two strategies. Consequently, the best way for estimating a drug market’s size could be different from one substance to another but also from one country to another.

1.1.2 Structure of the review

The paper starts with the method used to identify the relevant papers and the way we classified them. Next, we review the different approaches with a focus on the lessons learned based from the papers individually and collectively, including the pitfalls and some of the solutions to overcome them. We start with the larger group of studies using a demand-based strategy before moving to the less frequent supply-side strategy. A brief insight is also provided into other methods such as wastewater-based epidemiology. The review ends with a set of observations and choices to be made to make the best possible estimate (which might differ according to the market under study) but also to be aware of its limitations.

1.2 Method

1.2.1 Literature research

The peer reviewed studies reporting illicit drug market estimates were primarily collected in December-January 2020 by searching the following databases, available through the web of knowledge search engine: Web of Science Core Collection, BIOSIS citation index, Current Contents Connect, Data Citation Index, KCI-Korean Journal Database, MEDLINE®, Russian Science Citation Index, SciELO Citation Index. We used the following categories of keywords, related to one or multiple aspects of the illicit drug markets estimates:

1. Illicit drug markets: illicit drug* market*" OR "illegal drug* market*" OR "street drug* market*" OR "illicit retail drug* market*" OR "illegal retail drug* market*" OR "street retail drug* market*" OR "cocaine market*" OR "cocaine retail market*" OR "cannabis market*" OR "cannabis retail market*" OR "marijuana market*" OR "marijuana retail market*" OR "heroin market*" OR "heroin retail market*" OR "mdma market*" OR "mdma retail market*" OR "ecstasy market*" OR "ecstasy retail market*" OR "*amphetamine* market*" OR "*amphetamine* retail market*" OR "NPS market*" OR "illicit market*"
2. Illicit drugs: "illicit drug*" OR "illegal drug*" OR "street drug*" OR "cocaine" OR "cannabis" OR "marijuana" OR "heroin" OR "methamphetamine" OR "amphetamine" OR "ecstasy" OR "MDMA")
3. Market: "market*" OR "business" OR "retail" OR "money" OR "supply" OR "demand" OR "pric*" OR "sale*"
4. Size: "size" OR "estimat*" OR "value" OR "transaction" OR "amount" OR "amount spent" OR "supply-side" OR "demand-side" OR "quantity" OR "quantities"
5. Size estimates: "Assessing the size" OR "assessing the scale" OR "estimat* the size" OR "measuring the size" OR "monitoring the size" OR "market* size" OR "measuring drug* market*" OR "estimating the value" OR "assessing the value" OR "how much money" OR "siz*"
6. Number of users: number of users" OR "population estimat*" OR "number of people" OR "population size*" OR "capture-recapture" OR "estimat* the size" OR "size estimat*"
7. Quantities: "amount used" OR "quantity used" OR "number of days" OR "days of use" OR "usual amount" OR "usual quantity" OR "annual consumption" OR "type* of user*" OR "typical consumption" OR "grams" OR "kilograms" OR "consumption volumes"
8. Wastewater: "wastewater" OR "WWBE"

These categories were combined in the following searches equations:

a) Market size estimation: 4 & 5 + 1 & 2 & 3
b) Number of users: 1 & 6
c) Quantities: 1 & 7
d) Wastewater: 1 & 4 & 8 + 1 & 8 + 1 & 8 & "market"

These equations were used to search for content in the titles and, if only few results were obtained, in the topics. For each search, the first hundred titles were examined and, if they appeared relevant, the abstract was read. In addition, Google scholar® was also used with the purpose of identifying non-published sources. All papers and reports which included an explicit estimation of the amounts of any illicit drug for a given area were included in the review, no matter if the estimation was the goal of the research or just a part of it. Two additional papers that did not explicitly estimate quantities were included because their methodology was very close to other demand-based estimates, except that they directly estimated the market value by multiplying the number of users by their average expenditures (Bramley-Harker, 2001; Groom et al., 1998).

1.2.2 Results

Twenty-one papers are included in this review. Nine focus on cannabis only, ten on several illicit drugs, one on cocaine and one on amphetamine type stimulants (ATS). The studies were made for the following countries or areas: Canada (two), Europe (two), Finland (two), France (one), Italy (one), New Zealand (one), United Kingdom (five), United States (six), World (one). The majority use a demand-side approach (14), two a supply-side approach and three use both. The other approaches are wastewater analysis and so called forensic economic approach. Among the 21 papers, nine are peer-reviewed articles, two are books and ten are reports or book chapters[1].

1.3 Bottom-up/demand-side approaches

1.3.1 Direct and indirect methods

The direct method to estimate the size of an illicit drug market (without seizures and stocks[2]) from the demand side is to calculate a "drug consumption estimate" by multiplying the number of users by the amounts of drugs they are taking during a given timeframe. To do so, the main challenges are in counting and dividing the total number of users and in assessing the average quantities they use. As a unique average quantity would not express the various patterns of consumption that exist in different subgroups of users [3], the drug user population needs to be subdivided into relevant categories while also taking into account data availability.

An indirect method for demand side estimations is to first estimate the market's value and then back calculate the quantities used. The method also starts with an estimation of the number of users but estimates their average expenditures instead of their consumption. This can simplify complex calculations of frequency and volume of use by a more straightforward variable that users can possibly better report. The final step is to divide the total expenditures reported for a given drug by the cost of purchasing it. This requires of course additional information about prices, discounts, gifts, etc.

[1] Note : from the series of reports *What America's Users Spend on Illegal Drugs,* only the most recent report related to the period 2006-2016 and published in 2019 was kept, along with the companion report of the 2012 publication (DAEUS), which contains supply-side estimates.

[2] National or local police seizures are sometimes added to the total in a second stage, once the "consumption estimate" has been made. Stocks (stored drugs) are often ignored as there are no data available and/or a hypothesis of stable stocks is made. This might however be wrong, for example in growing or declining markets.

[3] In Switzerland, it is estimated that 11.1% of the citizens who have the highest alcohol consumption are responsible for half of the total alcohol used in the country. Missing or underestimating these users and the large quantities of alcohol they take would lead to major mistakes in the total consumption estimate. Similar results were found in our local drug market estimates for cannabis and for cocaine (Zobel et al., 2018, 2020)

1.3.2 Number of users

Both direct and indirect demand side market size estimates require estimating the number of drug users. As drug use is illegal and often hidden, this is far from being trivial. At least three elements are important to provide good estimates: population coverage (are all possible user groups included?), data availability (are there data about the size of these populations and on drug use prevalence among them?) and data limitations (does the prevalence data reflect the actual situation?).

1.3.2.1 Population coverage

The first issue for a demand-side estimate is to identify all or most population groups in which drug users can be located and to identify data to estimate the actual number of those users.

1.3.2.1.1 Practices and challenges

The estimation of the number of drug users are usually based on representative surveys among the general population (GPS). Prevalence rates are then applied to census data which allows to estimate the overall number of drug users and to classify them according to the (available) data on frequency of use.

Of the 17 studies using a demand-side approach[4], 14 rely on general population survey (GPS) data. Specific sub-populations of drug users might however be under-represented or even fully absent in such surveys[5]. This is why ten studies relying on GPS data – all focusing on drugs other than cannabis – also included additional populations and data (Bouchard et al., 2012; Bramley-Harker, 2001; Casey, 2009; Groom et al., 1998; Hakkarainen et al., 2008; Legleye et al., 2008; Pudney et al., 2016; Van Laar et al., 2013; Werb et al., 2012). The four remaining papers relied only on GPS data and were cannabis market estimates (Gettman, 2007; Kilmer et al., 2011, 2013; Wilkins et al., 2002) and an international drug market estimate (Kilmer & Pacula, 2009).

While this is not always explicitly stated, there seems to be a relative agreement among researchers that data from general population surveys are sufficient for estimating the number of cannabis users but insufficient for other drugs. This assumption may be challenged, as cannabis is used by other populations including teenagers who are often underrepresented in GPS and former or current heroin users.

The ten papers not relying only on GPS data identified a set of additional populations. These include prisoners, marginalized and homeless people, problem drug users[6] and young people (children and teenagers).

[4] 14 used demand-based approach and 3 both demand- and supply-based approaches.

[5] Groom, Davies and Balchin (1998) had already identified the limitation of GPS data coverage in 1998, as they were developing a methodology for estimating illegal economic activities.

[6] Problem drug use is defined by the EMCDDA as « injecting drug use or long duration or regular use of opioids, cocaine and/or amphetamines »

Young people (teenagers)

Teenagers 15 and under are often excluded from GPS or are just a very small part of their samples. They can however include a significant number of drug users, especially for cannabis. Therefore, Werb and colleagues (2012) also used data from the Canadian Youth Smoking Survey to include 11-14 years old drug users in their estimates. Bouchard (2012) also used three regional surveys as proxies to estimate the prevalence rates of ATS consumption by the 12-14 years old in the three main Canadian regions (East, Center, West)[7].

In France, Legleye and colleagues (2008) used data from the European School Survey Project on Alcohol and Other Drugs (ESPAD) to estimate the number of users among 15-16 years old. They also used a national survey (ESCAPAD) to do the same for the 17 years old. Both surveys allowed better estimates of the number of users in these age groups as the national GPS.

In the UK, Pudney and colleagues (2016) also used a specific juvenile survey for the 10-16 years old group in order to complement their counting of adult arrestees and non-arrestees (a distinction driven by the data they used).

Problem drug users

Problem/heavy drug users are a key population for demand side estimates as they generally include the people using the largest quantities of drugs and who are often considered not reached by GPS. Four publications make specific estimations of the number of problem drug users. Three of them start with an estimation of the total number of PDU and then try to apply a relevant prevalence of use rate for the drug of concern[8] (Casey, 2009; Hakkarainen et al., 2008; Van Laar et al., 2013). The fourth study considered the number of problem drug users based on treatment data using the main drug leading to treatment demand (Groom et al., 1998). Then, based on previous research suggesting a ratio of 3.5 to 1 between the total number of heroin users and the known heroin users in treatment, the authors scaled up their estimate to get a final estimate of PDUs.

[7] Two of the surveys were conducted the same year but not the third, highlighting other issues researchers have to deal with when multiple surveys are combined.

[8] Van Laar (2013) estimated the number of users based on existing national studies, Hakkarainen (2008) and Casey (2009) both used former national estimates based on capture-recapture methods. To assess prevalence rates and frequency of use, Casey (2009) used a cohort study of 1,030 drug users undergoing treatment (DORIS) as a proxy. Hakkarainen (2008) simply assumed that one third of PDUs were making use of cannabis, while Van Laar (2013) used data from face-to-face interviews.

Prisoners and homeless

Bouchard (2012) made estimates for the ecstasy and methamphetamine markets in Canada mainly using the GPS ESCCAD providing prevalence rates for the general population aged 15 and older. In addition, he combined different surveys and statistics to include drug use among the homeless and prisoners. He used existing estimates of the number of homeless people in Canada and combined them with ATS use prevalence rates among street youth, assuming that this rate was also applicable to the homeless population as a whole. For prisoners, he used several data sources and made the hypothesis that the relation between the use of ATS and the use of all illicit drugs is the same in the prison population as in the general population.

Bramley-Harker and colleagues derived the number of full-time equivalent prisoners from their estimate of the number of regular users in the general population. This was possible because their estimate of regular users was based on the NEW-ADAM survey, which included questions about time spent in prison during the last year. Finally, they applied specific prevalence rates based on information from drug testing that is randomly conducted in UK prisons.

Other approaches

Instead of predefining the target populations and then assessing their size and their prevalence of use rates, some researcher used other approaches. For the series of reports What America's users spent on drugs, the counting of drug users (for drugs other than cannabis) was based on ADAM[9] data (Caulkins et al., 2015; Midgette et al., 2019). The ADAM survey focuses on drug use among arrestees and probably catches more regular drug users than GPS do. It is however not representative of the national population and many extrapolations and scaling up steps are required to get to a final national estimate. Bramley-Harker (2001) used a similar approach in the UK, based on the NEW-ADAM data. Pudney (2016) argued however that mistakes were done when estimating the total number of regular users, emphasizing that particular care is needed when scaling up methods are applied.

Less conventional methods sometimes change the paradigm. To assess the number of ATS users, Bouchard (2012) explored a method based on a multiplier. An estimated lethal overdose rate for methamphetamine use was applied to the number of people who died from such an overdose. When applying this method in British-Colombia, the researcher found only a very small number of people that had actually died from such an overdose, leading to unreasonably low estimates of the number of users. He concluded that the uncertainty linked to this method is too high. It may however be useful when the population of users is rather homogenous, as it can sometimes be with heroin users. The multiplier must however not depend on external factors such as a difference in the efficiency of emergency assistance.

Rossi (2013) used an even more indirect multiplier: starting with an estimate of the number of drug dealers, using a capture recapture method based on police records of arrests, she applied a ratio of number of users per dealer to estimate the total number of drug users in Italy. Such a ratio was also used by Bouchard (2012) the other way around to assess the number of dealers. One of the main issues with this method is however that drug dealing practices are summarized into a single average ratio of customers per dealer. Drug markets are complex structures and arrested drug dealers may not necessarily be representative of average practices and situations.

[9] Arrestee Drug Abuse Monitoring Program

1.3.2.2 Nonresponse and underreporting

Once the main drug using populations have been identified and the number of drug users has been estimated with the appropriate data sources, it remains important to take into account that - for different reasons - data on self-reported drug use do not always reflect reality. Kilmer (2013) identified three key issues in this area: nonresponses (by people in the sampling frame), underreporting (reporting no use or less frequent use when this is not true) and misreporting of the quantities. This section focuses on the two first issues that impact the estimates of the number of users: non-response and underreporting. Misreporting of quantities is discussed below. Note that the distinction between these three issues is not always done and the term underreporting is often broadly used to englobe multiple and sometimes different issues.

1.3.2.2.1 Practices and challenges

Nonresponse

The nonresponses issue refers to the people who were targeted by a representative survey but did not answer it for some reason. The majority of the reviewed papers did not address this issue and among the 15 papers using surveys to estimate the number of users, 11 did no correction (Bouchard et al., 2012; Bramley-Harker, 2001; Casey, 2009; Caulkins et al., 2015; Hakkarainen et al., 2008; Kilmer & Pacula, 2009; Legleye et al., 2008; Midgette et al., 2019; Van Laar et al., 2013; Werb et al., 2012; Wilkins et al., 2002). However, if the prevalence rate of drug use is for some reason different among people who do not answer the surveys, this might lead to errors in prevalence estimates. Kilmer (2013) argued that based on current knowledge nothing indicates if this error would under- or overestimate the number of users and he therefore applied a correction factor as a normal distribution around 1, with 95% chances to lie between 0.9 and 1.1. In another paper focusing solely on cannabis, he assumed no error for the best estimate but proposed an alternative scenario, with the survey (the NSDUH) missing 25% of past month cannabis users (Kilmer et al., 2011).

An interesting approach is the one used by Pudney and his team (2016) while estimating the size of the UK drugs market. Instead of applying a correction factor, they modelled the missing answers based on shared features between those who did answer the survey and those who did not. In their case, characteristics that were available were descriptors of the local area (household survey) and demographic variables plus circumstances of arrest (data came from a survey among arrestees). These were used to build a model that predicts the frequency of use of non-respondents.

Underreporting

Not reporting drug use or underreporting its frequency (underreporting) while responding to a survey is more often addressed in the reviewed papers. Among the 15 papers using survey data, seven apply one or several correction factors for underreporting in order to provide new prevalence rates or a range for it. Of these papers, five use data from comparisons between self-reported use and biological tests (Bouchard et al., 2012; Kilmer et al., 2011, 2013; Kilmer & Pacula, 2009; Pudney et al., 2016). This approach requires among others to use an appropriate window of time that allows such comparison: questions about drug use must match the detection window of the biological test, which is typically a few days in urine for the most common drugs. Another issue is that such studies often focus on very specific subpopulations (often arrestees) and it is difficult to know to what extent the results apply to the broader general population. Underreporting might also be different over time and geographically, and using external data might be problematic. This is probably why corrections for underreporting are often used to provide alternative scenarios to a best estimate and therefore highlight some of its uncertainty or limitations. Kilmer (2013) provides one of the most comprehensive approach around this issue with detailed steps for the calculation of a correction factor. He also takes into account the possibility of wrongfully reporting consumption, which is often not considered.

Two papers use a correction factor of the prevalence rates reported by 12-17 year old in a household survey by using data for the same age group from a school survey (Caulkins et al., 2015; Midgette et al., 2019). Their hypothesis is that data from surveys conducted away from home and parents provide more reliable prevalence rates. The prevalence rates were indeed higher in the school survey compared to the household survey, but underreporting within the first was not addressed.

Among those who did no correction for underreporting, Casey (2009) argued that there is no real evidence that the issue exists and Van Laar (2013), who used multiple countries' estimates (that generally do not take underreporting into account) found hazardous to apply a single correction factor to all countries. They both highlight a need for research on this topic as it might have quite a big impact on the estimates.

Overall, underreporting has been identified as a potentially significant source of underestimation of the total number of users. In the reviewed papers, with rates up to 40-50% used to correct the initial estimates of the number of users or to suggest alternative scenarios (e.g. Kilmer et. al (2001), Bouchard et. al (2012)). Studies focusing on underreporting are however very specific and researchers had difficulties in applying the approach to the populations under study. This situation leads to huge differences in practices, with some researcher not correcting their estimates at all (e.g. Casey et. al (2009)) and other doing it heavily.

1.3.3 Assigning quantities

Once the number of drugs users in different populations has been estimated and these users have been assigned to different categories according to their frequency of use, the next step is to estimate the quantities they use. The usual way of computing annual quantities to estimate the size of a drug market is to multiply the number of days of use by the quantities used on a typical day of consumption. For cannabis, the assessment is often further broken down in two steps: assessing the number of joints used on a typical day and the usual amount of marijuana put in a joint. If such strategies seem at first sight simple, their implementation raises a number of questions discussed below.

Of the 16 demand-based papers in which calculations were made[10], ten based their estimates on such an approach (Casey, 2009; Groom et al., 1998; Hakkarainen et al., 2008; Kilmer et al., 2011, 2013; Kilmer & Pacula, 2009; Legleye et al., 2008; Pudney et al., 2016; Van Laar et al., 2013; Wilkins et al., 2002). Three used available external data and did no other calculations (Bouchard et al., 2012; Rossi, 2013; Werb et al., 2012) and two (referring to the same study) used an indirect method starting with an estimate of the expenditures (Caulkins et al., 2015; Midgette et al., 2019).

[10] Gettman 2007, is not included here as its demand-based section is more a listing of possible parameters to discuss a possible match with supply-side estimates than an estimation per se

1.3.3.1 Data on quantities

General population surveys do not include questions that allow to directly estimate the quantities of drugs that are used. Only two of the surveys listed in the papers asked about the number of joints on a typical day of cannabis use: The French ESCAPAD survey targeting 17-year-olds in France (with a question about the number of joints smoked during the last session) and the New Zealand APHRU survey among 15–45-year-old nationals (question about the typical number of joints during a session) (Legleye et al., 2008; Wilkins et al., 2002). Both did however not collect information about the typical quantities of cannabis put in a joint.

Additional data sources are therefore required to estimate the quantities used during a given period of time. The common option is to use data from another survey targeting a sub-population of users. Kilmer and colleagues (Kilmer et al., 2011) estimated for instance the typical quantity per joint through an analysis of the ADAM survey (among arrestees). Similarly, Pudney and colleagues (Pudney et al., 2016) based their quantities estimates on data from another survey among arrestees. A typical drawback of using such surveys is that they sometimes reach only a small number of drug users from a specific subgroup.

Another option, is to collect data on quantities with non-representative surveys that typically target drug users of different kinds. Kilmer and colleagues (2013) created for instance a specific survey for their estimate of the Washington State cannabis market before the legalization. The survey was inspired by the one used earlier in Europe by Van Laar and colleagues (2013) and that has later led to the EMCDDA's European web survey on drugs. This kind of approach was also used by Casey and colleagues (2009), who based their estimates of quantities used by PDUs from a cohort of 1,030 drug users who entered treatment.

When no quantitative local data are available, estimated quantities used can be based on qualitative data, or assumptions made from the existing literature. Several researchers (Bouchard et al., 2012; Casey, 2009; Hakkarainen et al., 2008; Kilmer & Pacula, 2009; Legleye et al., 2008; Wilkins et al., 2002) had to use such data for part of their estimates, thereby highlighting the lack of good information about typical quantities that are available.

1.3.3.2 User type distinction

1.3.3.2.1 Challenges and practices

Using a unique average annual quantity to be multiplied by the total number of users would not accurately address the disparities that exist across different groups of drug users. To make reasonable estimates, it is thus necessary to distinguish different user groups based on the quantity they use.

Most of the time, groups are defined according to their frequency of use. It has been shown that more intensive users not only use drugs on more days but also on more episodes per day and in larger quantities per episode (see for instance Van Laar and colleagues (2013) for cannabis). Among the reviewed papers, 10 computed groups based on the frequency of use (Groom et al., 1998; Hakkarainen et al., 2008; Kilmer et al., 2011, 2013; Kilmer & Pacula, 2009; Pudney et al., 2016; Rossi, 2013; Van Laar et al., 2013; Werb et al., 2012). The ways of categorizing users found in the literature (also depending on the substance) can be very different, going from simply separating "last month" from "last year but not last month" users, to more sophisticated groupings with up to six different categories. Ideally, categories should be as uniform as possible regarding the consumption rates of the users in the groups. A category that includes every "last month" user is therefore not very useful since it might well include both intensive and occasional users. Hakkarainen and colleagues (2008) presented a good example of dealing with this issue. In addition to distinguish last month users in different groups, they also separated people who used cannabis 1-3 times in the last month in two groups (occasional and experimenters) based on the date they first tried cannabis.

Practical considerations often limit the possibilities of grouping. If the categories are too restrictive, the recruitment of people representing them to gather information about quantities used could become an issue. Second, as long as the estimate of the number of users and the estimate of quantities do not come from the same data sources, the grouping must be consistent between the two datasets. This often drastically limits the possibilities of classifying the categories of users.

1.3.3.3 Misreporting of quantities

1.3.3.3.1 Challenges and practices

Collecting data on quantities used comes also with a set of challenges. The first issue is linked with the underreporting issues mentioned by Kilmer and colleagues (2013). It is about people who report using drugs but voluntary or involuntarily fail to report it correctly. This misreporting issue is rarely addressed in the papers or it is not clearly separated from global underreporting issue. There are however indications in other fields, particularly alcohol consumption, that people tend to underestimate the quantities they use. Different issues can be distinguished here. One is related to cognitive aspects or how respondents really understand and interpret the questions they have to answer. The second is about how respondents are able to correctly answer a question that they correctly understood. This includes difficulties linked to the respondents themselves (can they remember the number of days in which they used drugs during the last year? Do they know how much drug they are using at a time?) and to the questionnaire (do the respondents have the possibility to give the answer they want?[11]).

These issues are related and the way of framing the questions might help users to correctly remember or better evaluate the quantities they are using (a typical example are the pictures coming along with the questions about quantities in the questionnaire used by Van Laar and colleagues, 2013). The three steps above (understanding, knowing and answering) are all linked to the validity and reliability of the questionnaires. It goes beyond the scope of this literature review but, apart from the recent validity and reliability study conducted as part of the EMCDDA Web Survey on Drugs (Skarupova et al., 2019), there seem to be few recent research around these issues. As a result, little is known about the extent and the direction of possible under- or over reporting of frequencies and/or quantities. As proposed by Kilmer and colleagues (2013), given the actual knowledge, an uncertainty level must at least be added to the final estimates.

The last question in that process is how researchers interpret the given answers. As stated by Van Laar and colleagues (2013), it is notably difficult to define what is a plausible answer or not when it comes to very heavy users. Extreme values are often removed during the data cleaning process but this is a very sensitive issue. Better qualitative knowledge and further research is required to know how to correctly manage this issue.

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[11] An example of limitation in surveys is the highest category for cannabis quantities in a joint in the survey used in Van Laar et. al (2013) with a category defined as "more than…". Here the respondent has no possibility to give a precise answer, which will make the interpretation more difficult. Another example in the same survey is the fact that users could not give an answer below 1 for the number of joints per day. All these limitations were identified and discussed by the authors.

1.3.3.3.2 Cannabis sharing

One issue related to surveys is the way in which the drug sharing is addressed and understood by respondents. Due to consumption practices, this issue is of special concern for cannabis market estimates as it could include a lot of double counting. Van Laar and colleagues (2013) found sharing practices to be common across all categories of users, especially among less frequent users. However, most of the times surveys do not investigate this when asking about the number of joints used. Legleye and colleagues (2008), as well as Van Laar and colleagues (2013) both argued that it was unclear if users answered about their own consumption or not. In the latter study, the authors compared the answers from people who shared during the last occasion and concluded that there is no real evidence of a global overestimation. While they finally did not correct their estimate for the issue of cannabis sharing, they strongly recommended further research in this area. Legleye and colleagues chose another option and divided the reported number of joints by 2 for people who reported having shared during the last session. Hakkarainen and colleagues (2008) also assumed that experimenters were likely to share their joints and adjusted their quantities by a factor 3 for this group. Aware of this issue, Kilmer and colleagues (2013) addressed the issue directly in their questionnaire. This might be the best way to avoid tricky interpretations of the answers about the number of joints.

1.3.4 Demand-side estimates through expenditures and prices

In the What America's Users Spend on Illegal Drugs report series, the authors begin with an estimation of the market value. They also make an estimation of the quantities by dividing the value by the cost of purchase (Midgette et al., 2019). Doing so requires an estimation of the expenditures instead of the quantities used, and information about prices. For the expenditures estimate, the principles are the same as for the quantities. Since the expenditures were found to be correlated to the frequency of use, user groups must also be defined according to this variable (Caulkins et al., 2015).

To get quantities from expenditures, the authors first make an adjustment to account for drugs that are not purchased with cash. A subjective correction factor of 1.125 was applied to account for barter, trade and gifts. In a second step, they compute a national average price per pure gram for each drug. Without going into the details, this is done by adjusting the median amount spent for street purchases in the ADAM survey (arrestees) using standard quantities (quantities typically purchased) (Kilmer 2014).

A limitation of such an approach is that, even if the computed national average price takes regional variations into account, these variations will not be reflected in the final estimate. If the market is not proportional between regions in terms of quantities, estimates should be done separately, taking each relevant price into account. The same principle also applied to different typologies of users. These were considered in the expenditures estimates but not for the prices. However, discounts could typically be applied for big quantities purchased, allowing for example more intensive users to pay less per gram.

1.3.5 Managing uncertainties in demand-side estimates

The considerations made above highlight that every estimate comes with multiple sources of uncertainty. To acknowledge this, the first option is to list all the limitations but still provide a single final value (see for instance Legleye et. al (2008)). This might lead the reader to minimize the range of issues affecting the estimate as he is not provided with an information about what the extent of the problem could be. Another (better) option is to give the reader a range of values that takes into account its limitations. Several papers provided such a range with low and high estimates based on one or multiple parameters involved in the calculations (Bouchard et al., 2012; Hakkarainen et al., 2008; Kilmer et al., 2013; Kilmer & Pacula, 2009; Van Laar et al., 2013, 2013). A similar option is to provide a best estimate, along with alternative scenarios resulting from different parameter settings (see for instance Kilmer et. al (2011)). This approach is simple and gives the reader a sense of the error's possible magnitude. It also fits reality, that is to take parameters from multiple sources, and does not provide the false impression that the correct value is within a range that was in fact not statistically computed. The last possibility and the most formal one is to use Monte Carlo simulations. Werb and colleagues (2012) as well as Pudney and colleagues (2016) used this statistical method to compute 95% confidence intervals. The advantage of this method is to include each source of uncertainty, linked to each parameter, together in the same calculations, taking the magnitude of each uncertainty into consideration. One limitation is however that the parameters involved in the calculation do not always come with a formal evaluation of their uncertainty. It remains however still more appropriate to make assumptions on the error linked to each parameter than to address a global assumed uncertainty. Using Monte Carlo simulations thus offers the possibility to account for the sensitivity of each parameter estimate.

1.3.5.1 Parameter sensitivity

Methods presented above provide the framework to correctly address uncertainties that come along with market estimates. However, as stated by Kilmer (2011), knowing how to deal with uncertainties does not mean that there is no need to improve parameter estimate to reduce this uncertainty.

Not every parameter has the same impact on the final estimate and knowing which are the more sensitive is useful to know were improvements might be most needed. Gathering information on the sensitivity of each parameter can be done by making them vary in a given range and evaluate the impact they have. In a more or less formal framework, some researchers have focused on that question. Kilmer (2011) reveals for instance that the estimated size of a joint can have a major impact on the final estimates for cannabis markets.

1.4 Top-down approaches (supply-side)

Top-down or supply-side approaches estimate the quantities of a drug that are available for consumption (instead of being consumed). These approaches can be classified into two main models: production-based estimates and seizure-based estimates (Kilmer et al., 2011). Basically, the first model starts with an estimation of the total amount of drug that is produced before removing police seizures (and sometimes losses) and quantities that are not intended for the market under study. This should provide an estimate of the amount of drug that is available in a given geographical region. The second approach simply divides the amount of police seizures by an estimated seizure rate to get the available quantities of drugs available on the market.

Among the reviewed papers, five used supply-side approaches. The paper from Kilmer and colleagues (2011) only discussing the limitations of this approach is not included in this count. The two papers that presented the more comprehensive studies used production-based estimates (Abt. Associates, 2012; UNODC, 2005). Seizure-based estimates were used in two papers (Gettman, 2007; Groom et al., 1998) and one paper used a different approach based on estimates of the number of dealers and of the average number of doses they sell (Rossi, 2013).

1.4.1 Production-based estimates

The starting point for these estimates is to assess the quantities of drugs that are produced. Different approaches have been used for different types of drugs. For heroin and cocaine, the most common strategy consists in estimating the size of cultivation areas in the producing countries, relying mostly on satellite or other imagery-based surveys, and then estimating average yields and production efficiency. This strategy was used by both the UNODC in the World Drug Report 2005, and the Abt. Associates in the Drug Availability Estimates in the United States report (DAEUS, companion report of the What America's Users spend on Illegal Drugs) to estimate the production of heroin and cocaine (Abt. Associates, 2012; UNODC, 2005). For cannabis, this strategy covers only part of the production. It was applied by the UNODC to assess the production of resin and by the Abt. Associates for an estimation of the cannabis produced abroad from the US. Data on precursors can also be used instead to estimate the production of amphetamine type stimulants (ATS).

1.4.1.1 Challenges and practices

Many challenges are associated with the use of these methods. Data on average yield and production efficiency is necessary to move from field-size estimates to the final quantities of pure drugs available in the production countries. Information about the distribution process and seizures are also needed.

Accounting for every step from the production countries to the final destinations also requires extremely complex models. In the one developed by the UNODC, produced quantities are further distributed between countries based on geographical proximity with the production countries. Seizures made in different countries are then successively removed from the amount of drug that is available for the following destination countries. The model allows for adjustments based on previous knowledge such as known particular ethnic links or established international trafficking routes. It remains however a model and cannot be fully data driven.

For national estimates, as the one made in the DAEUS report (Abt. Associates, 2012), the number of steps is limited and if the trafficking route is not too long, it might seem easier to give reliable estimates. However, there is a main limitation: since the estimate is focused on a single country, an additional step is required to subtract quantities intended to the rest of the world. In the DAEUS report for cocaine, this crucial step is for instance based on a simple assumed proportion of the distribution of cocaine between the United States and the rest of the world.

1.4.1.2 Cannabis

As stated by Kilmer (2011), this method is even more complicated for estimations related to cannabis, mainly because production often occurs indoor in western countries. In the two consulted papers, the UNODC abandoned this method for herbal cannabis (but used it for resin), where the Abt. Associates applied it to the foreign production only, relying on seizures-based method (see below) for the domestic production.

1.4.2 Seizure-based estimates

Seizures based models are based on the assumption that the efficiency of police enforcement to seize drugs is roughly constant. Kilmer (2011) used the term unsettling to qualify this approach, because it is obvious that it cannot be data driven and because seizures depend on law enforcement strategies and efforts. Still, in the paradigm of an adaptive supply, in which suppliers would be able to adjust the production and shipment of drugs to balance the efficiency of law enforcement, and thus meet the demand, it is not completely uninteresting. The method has also one major advantage: it is extremely simple to use. It has however absolutely no scientific basis and seizures-based estimates thus almost exclusively relies on assumptions and cannot be recommended without additional data.

Among the referenced papers, Gettman (2007) assumed a 10% seizure rate to estimate the total amount of cannabis available in the US, where Groom, Balchin and Davies applied a 5% to 15% range for seizure rates of all drugs by the UK low enforcement forces. The Abt. Associates (2012) also used this method for their estimate of the domestic production of cannabis, assuming law enforcement forces destroy one third of the total amount of cannabis available in the US. They stated however that this approach was not a build on a “sound basis”.

1.4.3 Alternative approach

Rossi (2013) proposed another approach based on the number of dealers and the average amount of drug they sell. Proportions of dealers selling the targeted drugs was obtained from literature data and an average number of doses per dealer and per week was computed from a survey from persons in therapeutic communities and low threshold services. Methodological issues were not addressed in the paper.

1.4.4 Main lessons

Since reliable data related to the top levels of the supply chain are generally very difficult to get, supply-side approaches always heavily rely on assumptions such as the yield of the production fields or about trafficking routes. Moreover, given the top-down process, any wrong assumption would have severe and direct impact on the estimates. The main potential of this approach relies in the global scale estimates for cocaine and heroin that it allows as production zones are relatively concentrated and outdoor.

The method proposed by Rossi (2013) at a national level could theoretically be more data driven. For this method, the challenges are much closer to those linked to the demand-based approach. The first step being to fully cover all populations of dealers. Data on the quantities that are sold should then be collected and applied to different typologies of dealers, similarly to what is done for users in the demand-based approach. However, collecting representative data on the dealers’ side might even be more complicated than with users.

1.5 Other approaches

1.5.1 Forensic Economics

Parey and Rasul (2020) recently published an article based on what they call a forensic economic approach to estimate the size of the UK cannabis market. Their method builds on the fact that joints are not only made from illegal cannabis, but also from rolling papers and roll-your-own tobacco, which are legal goods. This strategy allows to base part of the estimate on available data, using the sales of these two legal products as inputs to the model. The authors then express a series of relations between the number of rolling papers, the average number of papers per joint and per legal cigarette, the quantities of roll-your-own tobacco, the weight of rolled cigarettes and joints into a system of equations. This system is then expressed into one single equation in which the quantity of cannabis is the only unknown variable remaining. The key to solve the equation is to assess at some point the quantities of roll-your-own tobacco and/or rolling papers that are dedicated to one of the two sectors (legal cigarettes or joints). This is done indirectly by gathering information on the number of rolled cigarettes smoked in the UK. This information comes from the General Lifestyle Survey (GLS), a general population survey conducted in the UK.

The major advantage of this technique is to entirely skip the estimation of the number of users. However, the method still requires estimating other quantities such as the amount of cannabis typically added in a joint. It also requires information about the weight of a typical joint, the weight of a typical rolled cigarette, the average number of papers per joint and cigarette and, as explained above, the number of rolled cigarettes that are smoked. Information about the typical weight of cigarettes and joints is taken from international literature (mean of available data). The average number of papers is set at 1 for cigarettes and 1.98 (which is equivalent to a king size paper in the model). Finally, the number of cigarettes is estimated from the GLS.

The estimation of the number of users, required for a classic demand-based approach, is replaced by an input about legal sales of rolling papers and roll-your-own tobacco. The method thereby has an undeniable advantage over the demand-based approach. Instead of the number of days of cannabis use and the typical number of joints per day for the demand-based approach, it just needs the number of cigarettes that are smoked which is probably more reliable than declarations about cannabis use.

The method has however also major drawbacks. The average weight of joints and cigarettes must be assessed and, as with the typical amount of cannabis in joints, these are sensitive parameters. Moreover, as no information is available about the practices of roll-your-own tobacco users, the authors must assume that every smoker of each sector (cigarettes vs joints) behave in a homogenous way. That is, the weights of cigarettes and joints are homogenous, as well as the quantities of cannabis in a typical joint. There is however strong evidence of very different intensities of use among cannabis users. The model also implicitly assumes that tobacco from cigarettes (not hand-rolled) is negligible, which would require further investigation. Finally, not all cannabis is used in joints and there are many other ways to use the substance.

1.5.2 Wastewater-based epidemiology

Wastewater-based epidemiology (WWBE) has shown very useful to gather information on drug use at a community level. A significant advantage of this method over classical demand-based estimates is that it catches drug use without the need to identify drug users. If this technique has been increasingly used to estimate levels of drug use in terms of quantities per number of people in selected cities and a lot of information has been gathered by the SCORE network for EMCDDA wastewater annual campaigns across EU[12]. However, we only found one paper that generalized the results for drug market estimates in Finland (2016). In this study, Kankaanpaa and colleagues (2016) sampled respectively 10 and 14 Finish cities during one week in 2012 and 2014. People living in these cities represent more than 40% of the national population and the authors thus assumed the results to be representative of the whole finish population. They applied a correction factor published in the scientific literature to convert raw measures into quantities

[12] See EMCDDA dedicated web page: https://www.emcdda.europa.eu/topics/wastewater_en.

of pure drugs that were consumed. Finally, an average purity rate for each drug was applied to convert pure quantities into consumption-quality quantities.

1.5.2.1 Challenges

It was beyond the scope of the article from Kankaanpaa and colleagues (2016) to detail every methodological pitfalls and limitations linked to the use of wastewater-based methodology in the context of a market size estimation. Going through the different steps they mention still allows to point out the main challenges linked to the use of such a method[13].

1.5.2.1.1 Population coverage

In their study, kankaanpaa sampled up to 14 cities and argued that these included more than 40% of the national population. Even if this is a really coverage for wastewater-based epidemiology, it remains difficult to generalize the results to the whole population. As mentioned in the article, consumption in cities is probably higher than elsewhere. Secondly, there is no indication about who is really contributing to the water samples collected in a given city. What is recovered in the waters of a given treatment plant does not directly inform on the consumption but rather on the excretion. The quantities that are excreted are not only function of the quantities that are consumed, but also depend on other factors. Among these, population flows, kinetics of the excretion processes, and even the time, location and type of consumption play significant roles. These issues make it difficult to extrapolate the data from one or several cities to the whole country.

1.5.2.1.2 Sampling

In the demand-based approach, consumption estimates refer to a given period. It is thus possible to gather information about a given time frame (typically the last month or the last year) with a unique questionnaire. This is more complicated with a methodology based on wastewater analysis. Indeed, a unique water sample (most of the time collected over a 24-hour period) gives information that is strictly limited to that period. It informs about the excretion that occurs during this limited timeframe, which is only partially linked to the consumption during the same period (because excretion is delayed). However, consumption in a given area is likely to vary from one day to another. For example, party drugs such as ecstasy have their consumption related to variations in social activities (typically weekdays versus weekends) and events (for instance festivals). If the goal is to assess an average consumption across a year, particular attention must be paid to the sampling strategy to assure representativeness for the investigated time frame. In the paper from Kankaanpaa and colleagues (2016), results are based on sampling campaigns that occurred during one week only. Even if the week is selected to avoid particular events, there is no way to ensure this particular week is accurate to assess yearly consumption. Results must then include confidence intervals, which can be pretty high depending on the investigated market.

1.5.2.1.3 Back-calculations

What is measured in the wastewater does not directly inform about the consumption and several calculations are needed to convert the concentration measures into amounts of drugs that were initially consumed. Kankaanpaa and colleagues used a computed correction factor proposed in another paper to

[13] Many of these challenges are discussed in the publications of the SCORE group and some of them are summarized on the EMCDDA dedicated web pages: https://www.emcdda.europa.eu/topics/wastewater_en.

make these corrections. This factor is not further discussed in the article, but it is depending on several parameters such as the stability of the drug in the sewage system, the adsorption rates of the molecules on macro particles in the sewage, but also on the excretion rate of the drug by the human body. The two first parameters depend on the length of the sewage system, which is variable across different cities. The third (the excretion rate of a given drug) varies across individuals and according to the administration route of the drug. If the number of people contributing to the investigated area is high enough, it is reasonable to take an average excretion rate. However, this average rate could vary across cities if the consumption practices are different. Typically, if cocaine is mostly snorted in a given city, the average excretion rate for cocaine users in this place would be different than the one of another city, with a high prevalence of crack smoking.

Kankaanpaa and colleagues used police data to account for the yearly average purity of each drug. Since chemical analysis detect pure substances, purity at consumption level must indeed be added in the calculations if one wants to know the weight of the final product, which make more sense in the context of a market analysis. This is however another parameter that varies in space and time. Thus, combining the wastewater measurements and drug purity data in time series is an important consideration.

1.5.2.1.4 Main lessons

Wastewater-based epidemiology is a promising tool for market size estimates, but certainly not free from uncertainties. The first type of uncertainty is due to the sampling strategy. The question of time coverage must carefully be addressed to give reliable estimates, that are not attached to very large confidence intervals. A second type of uncertainty is linked to the parameters used in the back-calculations. Values coming from scientific experiments exist however and the error can be handled rather formally from a statistical point of view. Attention must be paid if local features are of interest to assess these parameters. Beside these formal errors, the interpretation of the results in the context of market size analysis is another difficulty linked to wastewater-based epidemiology, that is not addressed in the article. Who really contributed to the analyzed water samples and how to extrapolate results from geographically limited sampling point(s) to larger areas? These questions need further investigations.

If the sampling is appropriate and if formal errors are adequately addressed, wastewater analysis offers however an alternative approach. Indeed, if one takes a conservative estimate for the average purity and makes no extrapolation but just adds up the different sampling sites in the targeted area, this technique will give a highly reliable lower bounds for the estimates. The main challenge in this case becomes the coverage of the territory. At large scale (e.g. European estimates), this issue would be significant.

1.6 Discussion

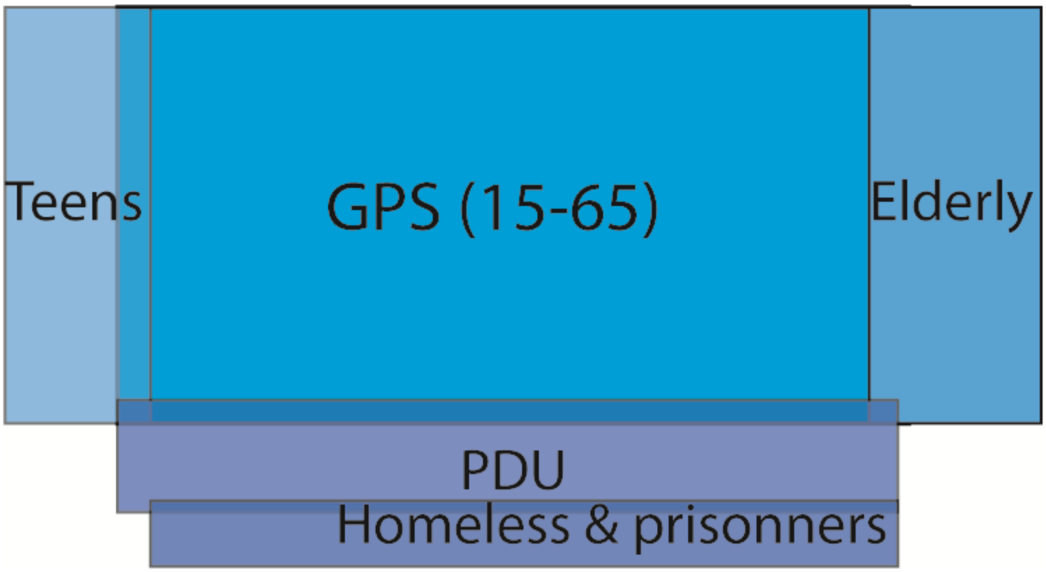
This review showed that there have been relatively few attempts to estimate the size of drug markets, most probably because it is a very difficult task. The existing studies mostly rely on bottom-up/demand-based strategies as this is also where most and the best data are available. Top-down or supply-side approaches often seem straightforward but rarely rely on good data and rigorous science. New approaches such as wastewater analysis are promising but also very complex and had only very few applications up to now.

In this context, demand-based approaches remain probably the best – and possibly the only – way to estimate the size of a complex construct like the European drug market. As there are many uncertainties and often insufficient data it is worth to pragmatically improve these estimates step by step. The list below might serve as guidance for this.

1. As GPS data do not reach the entire population and as drug use is often more prevalent among "hidden" subpopulations, there is a need to identify all/most additional groups were drug users can potentially be located (homeless, youth, problems drug users, homeless, prisoners, etc.)
2. Data on the size of all relevant subpopulations and on the prevalence of drug use within these need to be found or extrapolated from other sources; if data are not available this needs to be clearly stated and the risk of underestimating the market by not including some subpopulations clearly mentioned
3. Non-reporting and under reporting of drug use in surveys, including GPS, or other sources needs to be acknowledged;
4. Drug users need to be classified into relevant categories (type, level of use) that are as homogeneous as possible in order to allow collecting or using existing data on their (average) consumption
5. Separate data collections are needed to estimate the average quantities used by different types of drug users. These data collections can be improved over time, but also compared or combined with other data sources. More attention is needed to the different forms of drugs available.
6. The risk of over- and underreporting of the quantities in these data sources needs to be acknowledged
7. Ranges or alternative estimates need to be developed in order to show the limitations/context of the best estimate of the market size

All the steps above are important and they need to be addressed when estimating the size of a drug market with a demand-based approach. For example, step 1 requires to identify all drug users' populations that need to be taken into account. Figure 1 below is an illustration of how these populations can be conceptually defined, including their overlaps. It shows that, while GPS data for 15-64 year old may play a key role in estimating the number of drug users, there are several other populations that may be overlooked and which in some cases, as it could be for heroin, may even include the majority of users.

Figure 1: Representation of some of the most important groups within which drug users can be found and of the overlaps between these (sub-)populations



Once the relevant populations have been identified, data on their size and on the prevalence of drug use need to be identified and combined to estimate the number of individuals using drugs. This is not always possible. When data are insufficient, a statement could be made that a given subpopulation of drug users (prisoners, homeless or other groups) couldn't be considered for the estimate and that this will lead to underestimate the market size. Transparency, both at the conceptual and at the data availability level, might be one of the most important step to work towards better drug market size estimates.

One might consider that a basic demand-based drug market estimate should include at least the following populations: teenagers as estimated by youth surveys prevalence data, the general population as estimated by GPS prevalence data and problem/heavy drug users as estimated by a multiplier, capture-recapture or another method. For drugs that are rarely used before being an adult, the combination of GPS data and problem drug use data might be sufficient. Less than these two populations are likely to lead to significant underestimations of the size of the drug market, including for cannabis.

The use of other methods to estimate indirectly the actual total number of users through ratios (applied to the number of fatal overdoses, of dealers, of people in treatment) can be promising but usually include biases that seem hard to assess and to overcome. There might also be differences in reporting between countries.

Once the drug user populations and their respective size have been identified there are still many challenges to overcome, mainly classifying the type of users and estimating the average quantities they use. Many times multiple assumptions must be made in a context where the average quantity used is likely to be one of the most sensitive parameters of the estimates and could significantly impact the outcome. Given how difficult it can be to add specific questions on quantities in general population surveys, continuing to put efforts in the development of surveys specifically dedicated to that question, as the European Web Survey on Drugs, surely helps to fill the gap of knowledge in this domain.

Based on this review, there seem to be no better approach than to move in a transparent way step by step towards improving the estimate as has been done in the two first EU drug market reports. In practice, this would mean to continue or engage the following: 1. A systematic use of youth surveys (especially for cannabis) + general population surveys (all drugs) + problem drug use estimates/samples (all drugs) 2) To develop estimates of the number of users based on available data or best available proxies (data from similar countries, averages, etc.) 3) To develop a global margin of error or a range of estimates linked among others with nonresponses and underreporting. 4) To clearly state the limitations at all levels (populations, data) as well as the improvements compared to the previous estimate.

1.7 Conclusion

Demand-based estimates seem to be the best approach to estimate the size of large drug markets but improving the different parameters is still very much necessary. It is also worth to consider the use of another method in order to gather more confidence regarding the estimates. The use of two uncorrelated approaches that may point to the same range of market size can be a warrant for the validity of the results. Currently, confronting the results of demand-based estimates with wastewater-based estimates is probably the best way to reinforce the validity of the results. This is the approach that was selected at the local level in Switzerland and it has allowed improving both approaches (demand and wastewater) by constantly reviewing the reasons why they provided different outcomes. While this dual approach is not possible at the European level, the EMCDDA might encourage countries/regions/cities to use it to improve their estimates and to develop confidence range for them.

Finally, based on this review supply-side approaches are simply too simplistic to be true other than by chance. For example, in our study we found that local police seizures account indeed for small proportion of the market but that that these proportions can vary significantly by drug. Simply estimating that police seizures represent 5 or 10% of the market size therefore cannot be considered a reliable method to estimate the market size even though it might sometimes not be far from the truth.

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2 Case study: the MARSTUP project

2.1 Introduction

This paper presents the main findings of a study estimating the size of a local drugs market in two regions of Switzerland. A consortium of three research institutes implemented the project, which allowed exploring two methods and using multiple data sets to estimate the market size for different substances. While some of the methods and data used in this project are not transferable to larger projections such as the EMCDDA's estimates of the size of the EU drugs market, its findings may be useful to improve the approach and interpret the results.

2.2 The MARSTUP project[14]

The project is a collaboration between two public health research institutes (Addiction Switzerland and Unisanté) and a forensic sciences research institute (School of Criminal Justice of the University of Lausanne). Its initial aim was to **understand and describe the structure and size of the drugs market of the canton de Vaud**, the third largest Swiss canton with a population of about 0.8 million. Funding came from the regional public health authority and the project had an advisory board with representatives from the police (municipal, regional and national), justice (public prosecutor's office) and public health.

The research team also implemented a second, almost identical, study in another canton (Geneva (pop. ~ 0.5 million), although excluding the cannabis market. Compared to Vaud, Geneva is mostly urban and has larger number of workers crossing daily the border between France and Switzerland. It also has an international airport used by about 50'000 travellers every day.

2.2.1 Describing the drug market

Understanding and describing the main features of an illicit drug market is a complex task that requires a research structure. First, the drug market was conceptually divided into three submarkets expected to be different in size and structure: opioids, stimulants and cannabinoids. Studying them separately allowed a more targeted approach, without ignoring connections that may exist between these submarkets. Three consecutive studies - lasting about one year each - were conducted for each of the submarkets and led to the publication of three extensive reports (Zobel et al., 2017, 2018, 2019).

[14] MARSTUP (MARché des STUPéfiants) was implemented between 2016 and 2020. A follow up project called MONITOR-STUP will start in 2022 and last until 2025. While MARSTUP described the main features of the drug market MONITOR-STUP will monitor the market over time.

The second decision was to study the drugs market with a similar approach as for any other goods, focusing on four key dimensions:

1. **Products**: what is on offer (molecules, purity levels, cutting agents, packaging, price)?
2. **Size**: what are the quantities available?
3. **Structure and organisation**: how are the products made or imported? How are they distributed and sold? Who are the main market players? What are their strategies and behaviours?
4. **Value**: what is the market's turnover and what are the revenues both overall and by business type? What are the average expenditures of the customers?

To explore these four key dimensions and to answer the related questions, we collected, compiled and analysed many different sets with quantitative and qualitative data. These included survey data (GPS, Swiss data from the EU Web Survey on Drugs (hereafter EWSD), survey among users of low-threshold facilities), annual statistics (treatment, law enforcement), interviews (drug users, social workers, police officers and their informants, experts), judicial files, wastewater samples, drug seizures and residues in used syringes.

This paper covers the work done for the second key dimension of the drugs market: its size. It includes a description of the methods used and of the main results without exploring in-depth all (methodological, statistical) issues. The aim is to describe how a given approach may allow a better understanding of the strengths and limitations of demand-based drug market estimates, the approach used by the EMCDDA to estimate the size of the EU drugs market.

2.2.2 Estimating the market size

As reported in the short literature review drafted for the EMCDDA (Udrisard et al., 2021), there are only very few methods available – all associated with multiple data collection and analysis issues – when estimating the size of an illicit drug market. Focussing on a small local market and being an interdisciplinary research group provided a set of opportunities to overcome some of these problems, notably through an access to individual data (surveys, seizures, wastewater, etc.) and the possibility to develop ad hoc studies to collect additional data when required. As drug market estimates have a strong component of “learning by doing”, the capacity to re-analyse data and to access additional information has been very valuable and allowed to solve several (but not all) issues along the way.

This learning process has allowed a continuous improvement of the drug market size estimates as is shown in the three submarket reports (Zobel et al., 2017, 2018, 2019). For this case study report, we have re-calculated all our estimates based on the knowledge acquired during the study and made them more comparable than before.

2.2.2.1 Methods and approach

MARSTUP has been one the first studies implementing and comparing the results of two largely independent methods to estimate the size of a drugs market: **a demand (survey) based approach and a wastewater based approach**[15]. Both are associated with multiple methodological and data availability issues and may lead to significant under- or overestimations. Comparing and confronting their results is, however, one of the few possibilities that allows to question and improve the estimates.

Demand and wastewater approaches do not measure exactly the same thing. While demand looks at the market size from the perspective of **the population of a given region (drug use by locals)**, wastewater considers primarily **a given region (drugs used locally)**. Results should therefore be different. A typical example for this are large cities in which drug users from other localities gather because of drug markets, drug scenes or nightlife. In such cities, estimates based on wastewater should be larger than those based on the demand of the city's population. Elsewhere the situation is the opposite with demand estimates overestimating the market size because the local population buys and uses drugs in other places.

The two regions under investigation (Geneva and Vaud), one very urban and with a lot of external mobility and the other with a mix of urban and rural regions with comparatively less external mobility, might therefore also yield different ratios between the two estimates, with the hypothesis that differences between the estimates should be larger in the first. In both cases however, because of external mobility (workers coming from other regions) and significant nightlife and drug scenes, wastewater estimates should be above demand based estimates.

Deciding which estimate of drug consumption is appropriate for calculating the size of a drugs market remains an open question. Considering for example that not all outsiders who use drugs locally buy them on the local market, the answer might be that the most appropriate estimate of consumption reflecting purchases on the local market is somewhere in between the results of the two approaches.

In any case, it is important to remember that some differences between the two types of estimates are not due to measurement issues but to the differences in what is measured. This may be particularly the case when studying an urban region such as Geneva but should be less relevant when considering a region as large as the EU.

2.2.2.2 The estimates

We estimated the **annual size of the local drug market** for six different substances: heroin, cocaine, ecstasy, amphetamine, methamphetamine[16] and cannabis. The yearly estimates cannot be attached to single years as we had to use data collected between 2011 and the year the estimate was calculated (2017-2019)[17] for each group of substances (opioids, stimulants, cannabinoids).

[15] Both approaches measure the demand for drugs. One is relying mainly on survey and similar data while the other relies on residues of drug use.

[16] For methamphetamine, only a wastewater based estimate could be performed as there were no GPS data to estimate the number of users for a demand-based estimate.

[17] Most data were collected the year before the estimate was made. However, annual GPS data were compiled for the period 2011-2016 and the data from the EWSD were collected in 2016.

For this study, we defined the size of the market as **the addition of drug consumption and of drug seizures made by the local police[18]**. This definition implies that local stockpiling and flows are inexistent or remain constant over time, which may of course be wrong. There are however no data available on stocks and flows and we couldn't address the issue otherwise. Additional drug market data collected during the Covid-19 lockdown in early 2020 strongly suggest that stockpiling exists[19] but it is not possible to assess variations in this area.

2.3 Demand-based estimates

Demand-based drug market estimates try to size **the volume of drugs used by a given population over a given period,** usually one year. They mainly rely on two core variables: 1) the number of drug users in the population and 2) the average quantities they use.

To estimate the number of drug users we considered the members of the general population aged 15-64 reached by general population surveys (GPS). There are however strong indications that some groups are partially or fully missed by this type of surveys. These include children and teenagers below 15, problem drug users (PDUs), inmates, homeless and other marginalised populations. Because of lack of data on the size, the prevalence of drug use and/or on the quantities used, most of these groups could not be included in our calculations and our demand-based estimates are therefore prone to underestimate drug use within the population. We were however able to include one of the "hidden" populations: problem drug users (PDUs). There might be some overlap between this population and the population responding to GPS but we expect it to be small. Differently from other studies we reviewed, we tried to remain as consistent as possible when including the two population groups (general population and PDUs): for heroin, we also took into account occasional users responding to GPS; for cannabis, we also included the use by PDUs whose main "problem drug" is generally considered to be heroin or cocaine. For some drugs (ecstasy, amphetamines) this was however not possible because of lack of data and we could only consider the populations reached by GPS.

2.3.1 Data

2.3.1.1 General population

To estimate the number of users in the general population and to classify them into different groups according to their frequency of use we relied on data from the cantonal samples of the annual survey on addiction in Switzerland (CoRolAR) which was conducted between 2011 and 2016 (Gmel et al., 2017). The survey was not designed to be fully representative at the cantonal level and we therefore compiled the samples from the six years of the study in order to increase the sample size. Prevalence levels remained however stable over the six years of the survey both at the national and at the cantonal levels.

Based on data availability in the GPS, we defined two groups of users: "occasional users" as those who reported using a drug during the last year but not during the last month and "regular users" as those who

[18] While this is possible at local level where quite specific data is available, it could be more challenging to apply at EU level.

[19] https://www.addictionsuisse.ch/fileadmin/user_upload/DocUpload/Bulletin_marche_des_drogues_et_Covid_Numero2.pdf

reported using the drug during the last month. This differentiation is not very sensitive but was the only one available for three substances (heroin, ecstasy and amphetamine). For cocaine we could improve the situation by adding to the category of "occasional users" those who used only 1-3 days during the last month thereby limiting "regular users" to those who use the drug "weekly or more" (at least 4 days during the last month)[20]. For cannabis, we could develop additional sub categories within "occasional users" and "regular users".

To get estimates of the total number of users in the canton we multiplied the prevalence for each category of users and age group by the age structure of the general population provided by the cantonal office for statistics (Table 1).

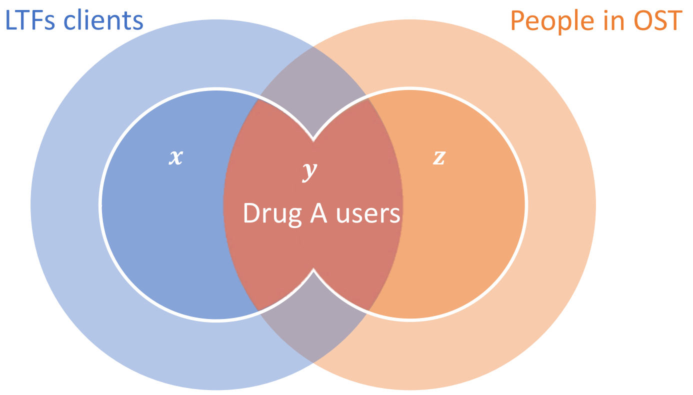
2.3.1.2 Problem drug users

To estimate the number of active users among PDUs we applied a relatively simple multiplier method using the only available (anonymous) data: OST statistics and a survey among LTFs users. Differently from some other studies we used the actual average daily number of persons in OST during the year instead of the annual figure for all people undergoing such treatment in a given year during various periods of time. This allows to better estimate the actual number of days of drug use by OST patients. This figure was calculated using routine data collected by doctors during their last encounter with their patients in OST[21], during which they ask them if they still use illicit substances and, if yes, with what frequency.

To estimate drug users out of OST we used data from a survey with the users of low-threshold facilities as a multiplier. Figure 2 illustrates the groups included in the estimate of PDUs. Below Figure 2 is an example that shows what data we used, and how we performed the calculations (values do not refer to any reality).

[20] This also means that out estimates for the different substances are not fully consistent. This is because our goal was always to develop the best possible estimate for each substance based on data availability.
[21] Such encounters should occur more than once a year.

Figure 2 Illustration of the groups included in the estimate of PDUs



1. Average daily number of persons in OST during the year: 100
2. Proportion of OST clients reporting the use of drug A to their physician during the last encounter: 60%
3. Estimated number of OST clients using drug A (y+z): 100*60% = 60
4. Estimated number of drug A users who are OST clients and LTFs clients (y): 20[22]
5. Proportion of LTFs users reporting the use of drug A and being in OST: 70%
6. Estimated number of (hidden) PDUs using drug A (while not being in OST, x): (20 / 70%) - 20 = 9
7. Total estimated number of PDUs who use drug A (x+y+z): 60 (in OST) + 9 (not in OST) = 69

This method has several flaws and limitations but allows to take into account a) the actual (daily average) number of PDUs in OST b) the most recent measure of their use of a given drug and c) the users of that drug who are not in OST (using as a proxy the population of LTFs users). While this may not provide the best estimate of the number of PDUs using a given drug it provides at least one estimate that relies on a set of recent and easily available data[23].

[22] Data was lacking to estimate the number of drug A users who are both OST and LTFs clients (point 4 in the example). We were however able to assess a minimum number of these users as some of them participated in a LTFs survey. Their maximal number being given by the total number of OST clients, we were able to assess a range. We finally took the central value as our final estimate of the total number of PDUs using drug A.

[23] One of the limitations of our study is however that we did not consider PDUs as potential ecstasy and amphetamine users which could lead to an underestimation of the size of these markets.

2.3.1.3 Estimated number of users by drug

We then compiled the different estimates of the number of drug users based on the available data. Table 1 below shows the estimated number of drug users within the population of the canton of Vaud.

Table 1 Estimated number of users by drug (central values)[24]

	Heroin[25]	Cocaine	XTC[26]	Amphetamine	Cannabis[27]
Regular users (GPS)	0	482	467 454 853	148	4'388 4'377 4'040
Occasional users (GPS)	579	5128	191 186 350	2293	9'193 28'410
PDUs (multiplier)	486 (in OST) 311 (out of OST)	433	Not considered	Not considered	647
Total	1'356	6'043	2'501	2'441	51'055

2.3.1.4 Estimating the quantities used

We then matched the data on the number of users with those from the EWSD (2016) using the frequency of use as the common indicator. The Swiss sample of the survey included about 150-300 respondents for each of the main stimulants (cocaine, ecstasy, amphetamine), about 1'000 for cannabis and only about 20 for heroin (we added a special module for this). For problem drug users, we developed additional data collections through a series of targeted interviews with users of low threshold facilities (heroin, cocaine) and by including a set of questions in a local LTF survey.

[24] Some of the figures above are different from the ones published in the initial reports because of adjustments that are based on findings/learnings made during the project.
[25] For problem heroin users a distinction was made between those in and out of treatment.
[26] Both regular and occasional ecstasy users were divided into three groups according to product preference (from top to bottom): only powder, only pills and both products. This categorisation was based on the EWSD data. For cannabis, we applied a similar approach for herbal cannabis and resin but treated them as two groups instead of three.
[27] For cannabis, the number of users could be calculated for different frequencies of use: for "regular use" 20+ days in the last month, 10-19 days in the last month and 4-9 days in the last month; For "occasional use" 1-3 days in the last month and last year but not last month.

Users may report for a given substance the use of different products (ecstasy in powder or pills, crack or cocaine HCL, herbal cannabis or resin) which do not have the same characteristics (purity, THC levels). We always considered these products separately and tried to estimate the overall quantities used for each of them. However, for comparing the results with those of wastewater analysis we had to do some conversions in the final stage of the analysis.

Table 2 below is an expression of this conversion in average quantities of the (average purity) drug used during a given year. Among others, it allowed to compare our estimates with those from similar studies in other countries and done earlier in Switzerland. In general, our estimates of average quantities by group of users were very close to those found in other studies.

Table 2 Estimated average quantities used (before any adjustment, g/year unless otherwise specified) [28]

	Heroin[29]	Cocaine	XTC[30]	Amphetamine	Cannabis[31]
Regular users (GPS)	-	131.5 [89.3 – 173.7]	4.3 [1.4 – 7.2] g/year or 31.3 [9.9 – 52.6] pills/year or 4.1 [2.5 – 5.6] g/year + 27.7 [17.1 – 38.2] pills/year	65.8 [22.8 – 108.7]	427.6 [363.6 – 491.6] or 83.4 [57.6 – 109.3] or 32.1 [20.4 – 43.7]
Occasional users (GPS)	15.6 [5.3 – 25.9]	10.8 [8.2 – 13.5]	1.6 [0.2 – 2.9] g/year or 10.7 [1.6 – 19.8] pills/year or 2.4 [0 – 5.2] g/year + 16.6 [0 - 35.2] pills/year	13.8 [7.1 – 20.6]	10.5 [1.4 – 19.6] or 42.1 [12.1 – 72.2]
Problem drug users (multiplier)	216.6 [159.6 – 273.5] 283.7 [194.1 – 373.2]	188.9 [117.4 – 260.4]	-	-	464.9 [349.7 – 580.1]

[28] The results in this table are the product of data provided on the number of days of use and the average consumption on a typical day of use.
[29] For problem heroin users a distinction was made between those in (top) and out (bottom) of treatment.
[30] Both regular and occasional ecstasy users were divided into three groups according to product preference (from top to bottom): only powder, only pills and both products. This categorisation was based on the EWSD data. For cannabis, we applied a similar approach for herbal cannabis and resin but treated them as two groups instead of three.
[31] For cannabis, the average annual quantities used could be estimated for different frequencies of use: for "regular use" 20+ days in the last month, 10-19 days in the last month and 4-9 days in the last month; For "occasional use" 1-3 days in the last month and last year but not last month.

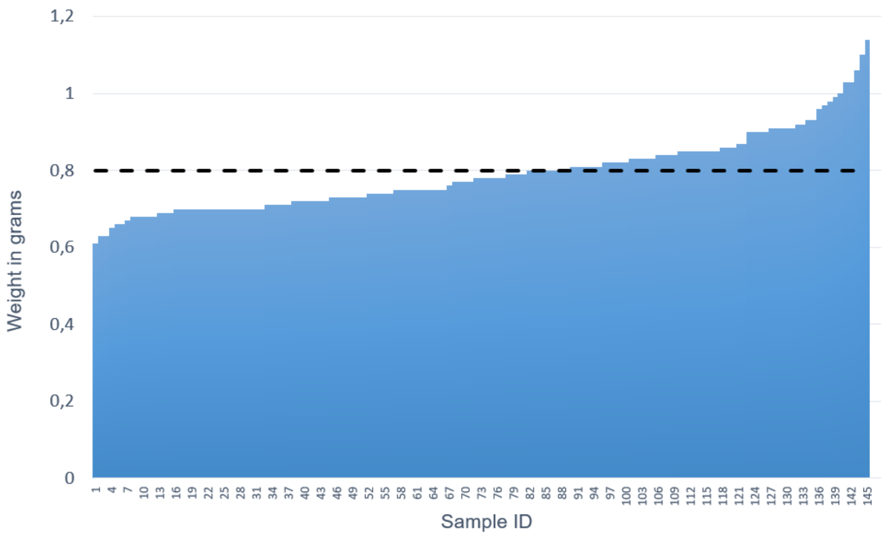
Table 2 indicates a key finding of drug market studies that reflects observations already made in the alcohol field: regular (daily) users tend to use disproportionate quantities compared to all the other groups of users. Our estimates also suggest that regular (socially integrated) cocaine users may use quantities, close to those reported by problem cocaine users. Conversely, problem drug users may use on average larger quantities of cannabis than daily (socially integrated) cannabis users. Both groups (regular (socially integrated) users and problem drug users) should therefore be considered very carefully when making drug market estimates as their consumption plays a very significant role.

2.3.2 Adjustments

As mentioned before, our demand-based estimates miss populations (school-aged children, homeless, inmates) and the amount of drugs used by some of their members. There are also risks for under-estimations due to the difficulties in reaching drug users within the targeted populations (15-64 general population and PDUs). Drug users might also report lower figures than the quantities they use when filling in web surveys, talking to their doctor or during face-to-face interviews.

There are also circumstances that can lead to an overestimation of the number of users or of the quantities used. Some people might for various reasons report using drugs when this in not the case or reporting larger quantities than they actually use. This also includes unwanted mistakes associated with the (lower) quantities they get from their dealer. In the MARSTUP study we found that cocaine users rarely received the expected amount when they bought the drug. Analysing 147 street samples seized by the police, we found that the units sold as one gram weighted on average 20% less. This means that the users are likely to report larger quantities than they use.

Figure 3 Street samples sold as "1 gram" real weight



To address underestimation, we applied the framework described by Kilmer and colleagues (2013), who broke down the issue into four components:

1. Consumption by people who are not reached by the surveys
2. Consumption by people targeted by the surveys but not surveyed
3. Misreporting of use
4. Misreporting of quantities that are used

The first component was partially addressed when adding estimates for PDUs (though only for the heroin, cocaine and cannabis estimates). Other populations were however missing in our estimates (adolescents, inmates, etc.).

For components 2 and 4 there were no data but it is obvious that these parameters increase the uncertainty of the estimates (upwards or downwards). To address this, we followed Kilmer and defined it as a normal distribution centred around 1, with a 95% chance of being between 0.9 and 1.1.

To address the misreporting of use (component 3), we referred to existing published work and defined ranges based on the findings of three papers comparing self-reported use with the results of urine analysis (Basurto et. al, 2009, Harrison et. al, 2009 and Hunt et al., 2015). Specific distributions were assessed for cannabis, cocaine and heroin, using a methodology adapted from Kilmer et. al (2013)[32]. More information is provided in the annex 0. Without good data available, we decided to extend the distribution defined for cocaine to the other stimulants (ecstasy and amphetamines).

Finally, the four components were combined into a unique correction factor that was applied to the final volume estimates.

[32] Cannabis: normal distribution around 1.175, with 95% CI between 1.0 and 1.35. Cocaine: normal distribution around 1.75 with 95% CI between 1.3 and 2.2. Heroin: normal distribution around 1.25 with 95% CI between 1.0 and 1.5.

For estimating the final number of users, we combined components 1 and 3 to provide a range within which the “real number” of users should be found (Table 3).

Table 3 Adjusted estimated number of users by drug[33]

	Heroin	Cocaine	XTC[34]	Amphetamine	Cannabis
Regular users (GPS)	0	626 – 1’059	607-1’027 590-999 1’109-1’877	192-326	4’388-5’923 4’377-5’909 4’040-5’454
Occasional users (GPS)	579-869	6’667-11’282	248-420 242-409 455-770	2’981-5’045	9’193-12’411 28’410-38’353
PDUs (multiplier)	466-699 (treatment) 311-467 (no treatment)	563-953	Not considered	Not considered	647-873
Total	1’356-2’035	7’856-13’294	3’251-5’503	3’173-5’370	51’055-68’923
Estimated annual prevalence	0.2-0.3%	1-2%	0.5-0.8%	0.5-0.8%	7.7%-10.5%

The prevalence levels we used are thereby above those usually reported for drug use in the region under study. This is due to the addition of users in the general population and PDUs, and to the correction we applied to each substance on the basis of available data. All in all, the prevalence, and thereby the number of users, is often double or even triple the one from the GPS data.

In general, we didn’t change the estimated average quantities, as we had no indications or available studies showing that these might be wrong. We reduced however the quantities for cocaine given that there was the almost systematic cheating of -20% by the dealers. In addition, for all the drugs we added a component of uncertainty because of possible misreporting of quantities in surveys.

[33] These adjusted numbers are given as an indication. For the final estimate, the adjustment for the number of users is included in a more formal calculation with a global correction factor.

[34] Both regular and occasional ecstasy users were divided into three groups according to product preference (from top to bottom): only powder, only pills and both products. This categorisation was based on the EWSD data. For cannabis, we applied a similar approach for herbal cannabis and resin but treated them as two groups instead of three.

Table 4 Adjusted (only cocaine) quantities used (g/year unless otherwise specified)[35]

	Heroin[36]	Cocaine	XTC	Amphetamine	Cannabis[37]
Regular users (GPS)	-	94.7 – 115.7	3.9 – 4.7 g/year or 28.2 – 34.4 pills/year or 3.7 – 4.5 g/year + 24.9 – 30.4 pills/year	59.2 – 72.3	384.8 – 470.4 75.1 – 91.8 28.9 – 35.3
Occasional users (GPS)	14.5 – 17.2	7.8 – 9.5	1.4 – 1.7 g/year or 9.7 – 11.8 pills/year or 2.2 – 2.7 g/year + 15.0 – 18.3 pills/year	12.6 – 15.4	9.4 – 11.5 37.9 – 46.4
Problem drug users (multiplier)	194.9 – 238.3 255.3 – 312.1	136.0 – 166.2	-		418.4 - 511.4

[35] For presentation purposes, the intervals presented in this table only reflects the uncertainty associated with the adjustment for misreporting (and for cocaine, the adjustment for cheating). The error associated with the sample is not shown.

[36] For problem heroin users a distinction was made between those in and out of treatment.

[37] For cannabis, the average annual quantities used could be estimated for different frequencies of use: for "regular use" 20+ days in the last month, 10-19 days in the last month and 4-9 days in the last month; For "occasional use" 1-3 days in the last month and last year but not last month.

2.3.3 Estimated market size

Table 5 below shows the estimated demand for the different drugs when multiplying the estimated number of users by the estimated average quantities used by year. Results are adjusted for underestimation issues as describe above and the 95% confidence interval is obtained using Monte Carlo simulations. The whole process is described in the annexes.

Table 5 Estimated demand by drugs and groups of users (kg/year unless otherwise specified)

	Heroin[38]	Cocaine	XTC	Amphetamine	Cannabis[39]
Regular users (GPS)	-	89.7 [47.4 – 147.5]	9.7 [5.8 – 14.6] + 66'863 [39'711 – 100'880] pills/year	17.2 [8.8 – 29.1]	1'876 [1'559 – 2'216] 363.6 [244.8 – 502.6] 128.0 [88.2 – 93.4]
Occasional users (GPS)	11.5 [3.7 – 23.7]	78.5 [50.2 – 113.2]	2.0 [1.2 – 3.1] + 13'811 [8'208 – 20'939] pills/year	56.1 [31.1 – 89.2]	68.2 [46.4 – 93.4] 795.4 [525.1 – 1'099.3]
PDUs (multiplier)	128.1 [72.5 – 23.7] 112.1 [54.2 – 194.2]	115.9 [56.4 – 200.3]	Not considered	Not considered	356.5 [223.1 – 522.2]
Total	251.7 [156.0 – 371.6]	284.2 [179.6 – 412.3]	11.7 [7.4 – 17.1] + 80'674 [50'381 – 117'773] pills/year	73.3 [43.9 – 111.1]	3'588 [3'107 – 4'095]

The "adjusted" yearly demand based estimates were 252 [156 - 372] kg heroin, 284 [180 - 412] kg cocaine, 12 [7 – 17] kg ecstasy powder and 80'500 [50'500 – 117'500] ecstasy pills[40], 73 [43.9 – 111.1] kg amphetamine and 3.6 [3.1 – 4.1] tons cannabis.

[38] For problem heroin users a distinction was made between those in (top) and out of treatment (bottom).

[39] For cannabis, the average annual quantities used could be estimated for different frequencies of use. 20+ days in the last month, 10-19 days in the last month, 4-9 days in the last month, 1-3 days in the last month, last year but not last month. A difference was also made between the use of herbal cannabis and resin (not shown here). This distinction was also made for other substances by type of product: cocaine (HCL or crack), ecstasy and amphetamines (pills or powder).

[40] Which translates, based on data about purity levels, into 17.1 [10.7 – 25.0] kg pure MDMA (8.6 [5.4 – 12.6] kg for powder (73% purity) and 8.5 [5.3 – 12.4] kg for pills (content 108 mg))

Finally, we added the local police seizures to estimate the market size as we had defined it (Table 6).

Table 6 Final market size estimates (Vaud)

	Heroin	Cocaine	Ecstasy (pure)	Amphetamine	Cannabis
Estimated demand size	251.7 kg [156.0 – 371.6]	284.2 kg [179.6 – 412.3]	17.1 kg [10.7 – 25.0]	73.3 kg [43.9 – 111.1]	3'588 kg [3'107 – 4'095]
Local police seizures	18 kg	39 kg	1.4 kg	1 kg	186 kg
Estimated market size	269.7 kg [174.0 – 389.6]	323.2 kg [218.6 – 451.3]	18.5 kg [12.1 – 26.4]	74.3 kg [44.9 – 112.1]	3'774 kg [3'293 – 4'281]
Estimated seizures by the police	6.7% [4.6 – 10.3%]	12.1% [8.6 – 17.8%]	7.6% [5.3 – 11.6%]	1.3% [0.9 – 2.2%]	4.9% [4.3 – 5.6%]

The final market size estimates were 270 [174 - 390] kg of heroin, 323 [219 - 451] kg of cocaine, 19 [12 - 26] kg of pure ecstasy, 74 [45 – 112] kg of amphetamine and 3.8 [3.3 – 4.3] tons of cannabis.

Police seizures were estimated to be in the range 1.3 - 12.1% of the (local) market size when only considering the central values, and 0.9 - 17.8% when including the confidence intervals. While this confirms that the police seize only a limited part of the volume of the drug market it also indicates a huge variability in the actual proportion this represents. Drug market estimates based on drug seizures may therefore be highly unreliable due to significant variations in this area.

2.3.4 Results for Geneva

The same data, methods and adjustments were applied to Geneva using the data for this canton.

Table 7 Adjusted estimated number of users by drug (Geneva)

	Heroin	Cocaine	XTC[41]	Amphetamine	Cannabis
Regular users (GPS)	0	263-445	399-675 389-658 731-1'236	126-213	Not studied
Occasional users (GPS)	579-869	4'956-8'387	164-277 160-271 299-506	1'964-3'324	Not studied
PDUs (multiplier)	388-582 (treatment) 259-389 (no treatment)	433 - 733	Not considered	Not considered	Not studied
Total	1'029-1'543	5'652-9'564	2142-3623	2'090-3'538	Not studied
Estimated annual prevalence (15-64 y.o)	0.2-0.4%	1.3-2.3%	0.5-0.8%	0.5-0.8%	Not studied

The prevalence levels were slightly higher in Geneva than in Vaud for cocaine but similar for the other drugs.

We applied then the estimated average quantities we had collected with the EWSD on drugs and other data collected in the canton de Vaud (same quantities as shown in Table 4). This allowed us to estimate de size of the market in Geneva (Table 8).

[41] For ecstasy, we applied the proportions of users of only powder, only pills or both to the data from the GPS to try to estimate the number of users of each product or of both of them

Table 8 Estimated demand by drugs and groups of users (kg/year and when specified pills/year) in Geneva

	Heroin[42]	Cocaine	XTC	Amphetamine	Cannabis[43]
Regular users (GPS)	-	37.6 [19.6 – 62.6]	6.5 [3.9 – 9.9] + 44’090 [26’243 – 66’752] pills/year	11.3 [5.6 – 19.6]	Not studied
Occasional users (GPS)	11.5 [3.7 – 23.7]	58.5 [37.3 – 84.3]	1.3 [0.8 – 2.1] + 9’0.93 [5’372 – 13’927] pills/year	36.9 [20.5 – 59.1]	Not studied
PDUs (multiplier)	106.8 [60.3 – 169.1] 93.3 [44.9 – 161.8]	89.0 [43.3 – 154.6]	Not considered	Not considered	Not studied
Total	211.6 [131.4 – 312.2]	185.2 [116.5 – 271.2]	7.9 [4.9 – 11.5] + 53’184 [33’287 – 77’892] pills/year	48.2 [28.7 – 73.3]	Not studied

The “adjusted” yearly demand based estimates for Geneva were 212 [131 - 312] kg heroin, 185 [117 - 271] kg cocaine, 8 [5 – 12] kg ecstasy powder and 53’000 [33’000 – 78’000] ecstasy pills[44], 48 [29 - 73] kg amphetamine.

[42] For problem heroin users a distinction was made between those in (top) and out (bottom) of treatment.

[43] For cannabis, the average annual quantities used could be estimated for different frequencies of use. 20+ days in the last month, 10-19 days in the last month, 4-9 days in the last month, 1-3 days in the last month, last year but not last month. A difference was also made between the use of herbal cannabis and resin (not shown here). This distinction was also made for other substances by type of product: cocaine (HCL or crack), ecstasy and amphetamines (pills or powder).

[44] Which translates, based on current data about purity levels, into 11.3 [7.0 – 16.5] kg pure MDMA (5.7 [3.5 – 8.3] kg for powder (73% purity) and 5.6 [3.5 – 8.2] kg for pills (content 108 mg))

Finally, we added the local police seizures to estimate to total market size as we had defined it (Table 9).

Table 9 Final market size estimates (Geneva)

	Heroin	Cocaine	Ecstasy (pure)	Amphetamine	Cannabis
Estimated demand size	211.6 kg [131.4 – 312.2]	185.2 kg [116.5 – 271.2]	11.3 kg [7.0 – 16.5]	48.2 kg [28.7 – 73.3]	Not studied
Local police seizures	31.7 kg	34.6 kg	1.4 kg	0.5 kg	Not studied
Estimated market size	243.3 kg [163.1 – 343.9]	219.8 kg [151.1 – 305.8]	12.7 kg [8.4 – 17.9]	48.7 kg [29.2 – 73.8]	Not studied
Estimated seizures by the police	13% [9.2 – 19.4%]	15.7% [11.3 – 22.9%]	11.0% [7.8 – 16.7%]	1.0% [0.7 – 1.7%]	Not studied

In Geneva, annual police seizures were estimated to be in the range 1 - 15.7 % of the (local) market size when only considering the central values, and 0.7 - 22.9% when including the confidence intervals. These figures, which have even a larger interval than in the canton of Vaud, confirm that it might be very difficult to estimate the market size based on the amount of drugs seized.

Finally Table 10, provides a comparison of the estimated size of the two drug markets calculated with the demand-based approach

Table 10 Market size estimates for the two cantons

	Heroin	Cocaine	Ecstasy (pure)	Amphetamine	Cannabis
Vaud	269.7 kg [174.0 – 389.6]	323.2 kg [218.6 – 451.3]	18.5 kg [12.1 – 26.4]	74.3 kg [44.9 – 112.1]	3'774 kg [3'293 – 4'281]
Geneva	243.3 kg [163.1 – 343.9]	219.8 kg [151.1 – 305.8]	12.7 kg [8.4 – 17.9]	49.2 kg [29.7 – 74.3]	Not studied
Delta	-9.8%	-32%	-31.4%	-33.8%	-

The canton of Vaud's population is about 60% larger than the one of Geneva and this difference is reflected in the market size estimates for cocaine, ecstasy and amphetamine. For heroin, the estimated size of the market was much closer, reflecting a proportionally larger population of PDUs in Geneva.

2.4 Wastewater based estimates

Monitoring substance use with wastewater first appeared as a tool for epidemiological research in 2001 (Daughton, 2001). The technique relies on a relatively simple principle: when someone uses a drug, the body will eliminate traces via the faeces and urine, either as a modified form (metabolite) or not (parent substance). Taking samples at the inlet of the sewage treatment plants allows detecting and quantifying these traces and then back calculating drug use among the population contributing to the sewage system.

While this principle is relatively simple, its implementation is very complex. Many parameters, such as the metabolism and excretion of the substances by human bodies or the stability of the substances in the sewage system, are difficult to assess. In addition, the use of similar substances, including for licit medical purposes, must be taken into account. Other variables, such as street drug purity, type of products and routes of administration, are also critical parameters to convert pure quantities into street drug volumes that allow comparison with demand-based estimates.

2.4.1 Data

2.4.1.1 Sampling

Samples were regularly collected in different wastewater treatment plants (hereafter WWTPs) in the cantons of Vaud and Geneva from 2014 onwards. The city of Lausanne, was involved since the early stages of the development of drug testing in wastewater in 2014. However, due to major transformation undertaken in 2016 at the city's WWTP, the sampling site had to be moved upstream for 3 years, thereby changing the size of the population under observation. Geneva, whose structural and demographic characteristics are different from Lausanne, was added in 2017.

To estimate consumption volumes on a canton-wide scale, we used a multiplier based on a combination of the size of the population with, for heroin, statistics on the number of people undergoing substitution treatment and, for the other drugs, differences in the prevalence of use in the canton and the sampling site (GPS data). Other sites in the canton of Vaud were added afterwards to confront this initial strategy for extrapolating results to the canton from a single town. To this end, four other cities were included in the study from 2017. Table 11 summarizes the sampling campaign.

Table 11 Sampling campaign

Site	Connected population (2017)	Years	Sampling strategy (best case)	Total number of samples analysed
Lausanne 1	238'098	2014-2016	56 / year (2014) 28 / year (2015-2016)	72
Lausanne 2	185'464	2017 - 2019	28 / year	46
Yverdon	32'768	2017 - 2019	28 / year	48
Vevey	52'047	2018 - 2019	28 / year	42
Montreux	39'858	2018 - 2019	28 / year	43
Villeneuve	9'505	2018 - 2019	28 / year	44
Geneva	445'100	2017 - 2019	28 / year	70

2.4.1.2 Other sources of marker

Ideally, the concentration of the targeted residue, commonly known as a marker, should provide exclusive information on the illegal use of the drug of interest (Zuccato et al., 2008). However, this need for specificity is not the only criterion that guides the choice of a marker and most of the time, it is not fully guaranteed. Except for cocaine, all selected markers had potential other sources of origin than illicit consumption. Three different cases could be identified:

1. There is a discharge of the drug in the sewage without previous consumption. This becomes an issue if the marker is already present as part of the drug before its metabolism, which is typically the case when the marker is the main active ingredient. This is the case for MDMA, amphetamine and methamphetamine.
2. The drug is also prescribed in a legal medical context. In this case, no matter which marker is selected, it will not provide specific information on illegal consumption. This was the case for cannabis and amphetamine, but only for small quantities as both marker/substances can be prescribed.
3. The (legal or illegal) use of a chemically close drug lead to the production of metabolites that are identical to the targeted marker. This is the case for amphetamine (a metabolite of methamphetamine), and for heroin.

The most problematic case is heroin. The drug is mainly metabolised to 6-monoacetylmorphine (6-MAM, which is specifically derived from the breakdown of heroin), which is then hydrolysed to morphine (Baselt, 2011). Unfortunately, 6-MAM is highly unstable in wastewater, excreted in low concentrations and its use as a marker for heroin shows inconsistencies (Been, Benaglia, et al., 2015). For the MARSTUP study, we therefore selected morphine, the main metabolite excreted following heroin use. Morphine is however widely prescribed as an analgesic or as a substitute for heroin (Table 2.1). It is therefore necessary to subtract the quantities associated with medical use ("therapeutic" quantities) from those resulting from illegal heroin use.

Most of the products whose consumption leads to the excretion of molecules identical to the selected markers are controlled substances in Switzerland. This is the case for morphine, diamorphine (heroin), lisdexamfetamine, amphetamine, methamphetamine and THC (unless its concentration is less than 1%). All these substances are thus subject to notification, and all deliveries are therefore recorded in a centralised system. We used that system to estimate the consumption of these substances.

2.4.1.3 Calculation parameters

Parameters related to body metabolism (excretion) and transportation in the sewage (adsorption and stability) were taken from the scientific literature. When possible, values have been adjusted for local specificities. This was for instance the case in determining an excretion rate of benzoylecgonine (cocaine metabolite) that takes into account the different modes of administration of cocaine (smoking, snorting, injection). To do this, we also distinguished between PDUs and other users. We then estimated the size of these two populations (demand-based estimates) and assigned frequencies for the different administration routes based on a national survey among PDUs and on the EWSD for other cocaine users. This method has limitations but may avoid a bias when specifying the excretion rate, especially if there are special drug use features in the investigated area (for instance, high prevalence of crack use).

Drug purity has been estimated from the analysis of local police seizures when a sufficient number of samples was available (cocaine and heroin). In cases where the number of samples was too low, we used a national database (from the Swiss Society for Forensic Medicine), which gathers analysis results from different services (police, forensics). This source was used to assess average purity for ATS and THC-levels for cannabis. Some adjustments were made regarding the substance of interest. For instance, we have removed data for cannabis seized with less than 2% of THC to avoid a bias associated with legal CBD samples seized by the police[45].

For substances existing in different forms, we estimated their relative quantities (for instance herb and resin for THC or powder and pills for MDMA) based on the EWSD 2016 Swiss sample.

All parameters are listed in the Annex 0.

2.4.1.4 Extrapolation from sampling sites to larger areas

Since the sampling sites did not cover the whole areas under study, we had to extrapolate the results. We applied different methods. For Geneva, where the WWTP covers a high percentage of the population (89% in 2017), we simply applied a multiplier based on the size of the population. In the canton of Vaud, we considered the prevalence of use (based on GPS data) in the different areas (connected or not to WWTP), to refine the multiplier. For heroin, reliable prevalence levels were not available and we used data on substitution treatment as a proxy.

[45] In Switzerland, cannabis with less than 1% THC is legal since 2016.

2.4.2 Results

2.4.2.1 Vaud

Table 12 shows the estimated markets sizes in the canton Vaud using the wastewater method. Quantities refer to “street drug” quality, except for ecstasy. Quantities and uncertainties shown refer to an average yearly quantity for the investigated period, without referring to a given year. The investigated period was 2014-2016 for heroin (65 samples), cocaine (64 samples), ecstasy (65 samples) and methamphetamine (60 samples). For amphetamine, data quality was poor in 2014-2016 and a new estimate was made based on 2017-2019 data (43 samples). For cannabis, which is the last substance we studied, the estimate is based on a multi-site study including 4 additional towns in the canton of Vaud. For this estimate, 200 samples (between 37 and 43 by site), collected between 2017 and 2019 were used.

Table 12 Estimated markets size in Vaud after conversion in street drug quality (except for ecstasy and methamphetamine)

	Heroin	Cocaine	Ecstasy (pure)	Amphetamine	Cannabis	Methamphetamine (pure)
Estimated demand	100 kg [0 – 251]	498 kg [390 – 625]	38.5 kg [23.5 – 56.0]	45.3 kg [30.8 – 70.6]	5’807 kg [1218 – 10’746]	2.1 kg [1.2 – 3.1]
Local police seizures	18 kg	39 kg	1.4 kg	1 kg	186 kg	0.16 kg
Total estimated market size	118 kg [18 – 269]	537 kg [429 – 664]	39.9 kg [24.9 – 57.4]	46.3 kg [31.8 – 71.6]	5’993 [1’404 – 10’932]	2.3 kg [1.4 – 3.4]
Estimated seizures by the police	15.3% [6.7 – 100%]	7.3% [5.9 – 9.1 %]	3.5% [2.4 – 5.6%]	2.2% [1.4 – 3.1%]	3.1% [1.7 – 13.2 %]	7.1% [4.9 – 11.8%]

The limited number of samples covering the year and the uncertainty associated with each of the parameters included in the calculations lead to relatively large confidence intervals (95%). The interval is larger for heroin because of important daily variations in morphine loads, probably due to legal morphine use[46]. This is problematic and the sample size for this drug needs to be larger to better cover these variations. The central value for heroin is therefore not very robust and it is difficult to know where the true value lies within the confidence interval.

[46] As a reminder, morphine was selected as marker for heroin consumption and legal morphine had to be quantified.

The confidence interval is also larger for cannabis because of difficulties associated with the chemical properties of THC. In that case, increasing the number of samples would not provide a solution since the daily variations are small. To reduce uncertainty, more research is needed. However, the results we have obtained in the different sites are reassuring regarding the major sources of uncertainty and tend to show that it is probably limited.

For other substances (cocaine, ecstasy, methamphetamine), methodological issues should be minor.

2.4.2.2 Geneva

Results for Geneva are shown in Table 13. In Geneva, the investigated period was 2017-2019 for every substance. Estimates are based on 62 samples for heroin, 61 for cocaine, 60 for ecstasy, 44 for amphetamine and 60 for methamphetamine. The remarks made for Vaud in the previous paragraph regarding uncertainty also apply to Geneva.

Table 13 Estimated markets size in Geneva after conversion in street drug quality (except for ecstasy and methamphetamine)

	Heroin	Cocaine	Ecstasy (pure)	Amphetamine	Cannabis	Methamphetamine (pure)
Estimated demand	53.2 kg [0 – 165.8]	769 kg [630 – 930]	35.7 kg [26.7 – 47.0]	8.8 kg [4.0 – 14.1]	Not studied	5.4 kg [4.4 – 6.6]
Local police seizures	31.7 kg	34.6 kg	1.4 kg	0.5 kg	Not studied	0.9 kg
Total estimated market size	84.9 kg [31.7 – 197.5]	804 kg [665 - 965]	37.1 kg [28.1 – 48.4]	9.3 kg [4.5 – 14.5]	Not studied	6.3 kg [5.3 – 7.5]
Estimated seizures by the police	37.3% [16.4 – 100%]	4.3% [3.6 – 5.2 %]	3.8% [2.9 – 5%]	5.4% [3.4 – 11.1%]	Not studied	14.3% [12 – 17%]

2.5 Comparing the results of the two approaches[47]

Table 14 and Table 15 below show the final estimates for both methods in the canton of Vaud and Geneva, and the relative difference between the wastewater-based estimate and the demand estimate.

Table 14 Comparison of demand-based and wastewater-based market estimates in the canton of Vaud

	Heroin	Cocaine	Ecstasy (pure)	Amphetamine	Cannabis
Demand-based estimates	269.7 kg [174.0 – 389.6]	323.2 kg [218.6 – 451.3]	18.5 kg [12.1 – 26.4]	74.3 kg [44.9 – 112.1]	3'774 kg [3'293 – 4'281]
Wastewater-based estimates	118 kg [18 – 269]	537 kg [429 – 664]	39.9 kg [24.9 – 57.4]	46.3 kg [31.8 – 71.6]	5'993 [1'404 – 10'932]
Delta	- 56%	+66.2 %	+ 116%	- 37.7 %	+ 58%

Large differences were observed between the two approaches with the central values of the wastewater-based estimates being outside the confidence interval of the demand-based estimate for every substance except amphetamine. Wastewater-based central estimates were around 60% higher for cocaine and cannabis and 115% higher for ecstasy compared to demand-based estimates. They were however lower for heroin (-56%) and amphetamine (-38%) (Table 14).

Table 15 Comparison of demand-based and wastewater-based market estimates in the canton of Geneva

	Heroin	Cocaine	Ecstasy (pure)	Amphetamine	Cannabis
Demand-based estimates	243.3 kg [163.1 – 343.9]	219.8 kg [151.1 – 305.8]	12.7 kg [8.4 – 17.9]	49.2 kg [29.7 – 74.3]	Not studied
Wastewater-based estimates	138 kg [32 - 363]	804 kg [665 - 965]	37.1 kg [28.1 – 48.4]	9.8 kg [5.0 – 15.1]	Not studied
Delta	- 43.3%	+266 %	+192 %	-80 %	Not studied

The same pattern was observed in Geneva with wastewater-based estimates being higher for cocaine and ecstasy and lower for amphetamine. Differences are however more pronounced in Geneva with a maximal difference of +266% for cocaine in wastewater.

[47] As a reminder, for methamphetamine, only a wastewater based estimate could be performed as there were no GPS data to estimate the number of users for a demand-based estimate. For this reason, no comparison is presented in this section for methamphetamine.

Table 16 Comparison of the difference between demand-based and wastewater-based market estimates in the two cantons (only central values)

	Heroin	Cocaine	Ecstasy (pure)	Amphetamine	Cannabis
Vaud	- 56%	+66.2 %	+ 116%	- 37.7 %	+ 58%
Geneva	- 43.3%	+266 %	+192 %	-80 %	Not studied

Confronting the results of the two methods shows not only important variations but also that these can be either way (Table 16). For some substances (cocaine, ecstasy and cannabis) waste water estimates tend to be much higher than demand-based estimates, despite the fact that several correction factors were applied to improve their coverage and accuracy. For two other substances (heroin and amphetamine), the relation is reversed with demand-based estimates being much higher than wastewater estimates.

2.5.1 Explaining the differences

Below are some explanations as to why such differences were found and what this might mean for larger scale estimates such as those for the EU dug markets.

2.5.1.1 *Heroin*

We tried to be quite systematic when estimating the heroin market with the demand approach. A note of caution is however that we used average quantities that are sometimes above those estimated in other international studies. Our correction factors may have been too large for this drug.

The results when using the wastewater approach show a very large confidence interval and there is also the uncertainty related to the central value estimated. This underlines the importance of improving the procedures related to the analysis of residues of heroin use in wastewater.

2.5.1.2 *Cocaine and ecstasy*

Two methods, two measures

As mentioned in the description of the methods, the two approaches do not measure strictly the same demand/use. The demand-based estimate measures the consumption of residents, whereas the wastewater-based estimate measures the consumption of all persons whose urine is collected at the treatment plant. In urban centres, where inward mobility is generally higher than outward mobility, the wastewater method is therefore likely to reflect more than just the consumption of residents.

For the canton of Vaud, the wastewater estimates are based on measurements in Lausanne (capital city), where the range of festive activities and the drug scene certainly attracts people who use cocaine and/or ecstasy from outside the canton. Since the excretion of the markers begin early after consumption, these users contribute to the quantities measured in Lausanne's wastewater, which could explain some of the discrepancies observed between the two methods. This applies in particular to cocaine consumption as the main metabolite is mainly excreted between 4 and 8 hours after consumption, and to a lesser extent to ecstasy, the excretion of which begins early but is then spread over several days.

Geneva, like Lausanne, has a thriving nightlife. It also attracts a very large number of workers living outside the canton as a proportion of its resident population[48] and includes an international airport connected to the wastewater network. Approximately 17 million passengers transit every year through that airport, an average of 50'000 a day. The difference between the resident population and the population of wastewater contributors should therefore be even greater in Geneva, which seems to be reflected in the observed results (+66% for wastewater-based cocaine estimate in Vaud, +266% in Geneva, see Table 14 and Table 15). Since this difference between residents and wastewater contributors is mainly due to population flows during the day, it should primarily influence the regular consumption of drugs. This could explain why the difference between the two methods is bigger for cocaine.

These considerations are probably not sufficient to explain the entire difference measured between the two methods. Indeed, even if we include workers living outside the canton in our demand-based estimate, the volume of consumption would only increase by about 12% and would remain much lower than the estimate based on wastewater analysis.

Purity

It is also possible that the average purity level we have used to convert the quantities of pure cocaine measured in wastewater is too low, which would artificially increase the volume of (street-level) cocaine used. Although we tried to define the most accurate purity level possible, there is a risk that cocaine seizures represent only a part of the market and that purity levels are higher in other parts of that market. The high purity levels measured by drug checking projects in Switzerland suggest that this could be the case and that purity data from police seizures alone are not sufficient to help estimate the market size.

Underestimation with the demand-based approach

The previous considerations probably only partially explain the difference observed between the two methods. This suggests that the demand-based estimates probably underestimate the consumption volumes, even after adjusting for underreporting as we did it.

It is for instance possible that GPS have difficulties in reaching frequent cocaine users. It is also possible that a non-negligible number of PDUs are not identifiable with the existing data that cover only heroin substitution treatment and low threshold facilities.

Overall, the most sensitive parameter is probably the misreporting of the quantities used. As we lacked figures in this area, we simply increased the global uncertainty (see point 2.3.2). However, there are indications in other fields, particularly alcohol consumption, that people tend to underestimate the quantities they use. Such an underestimation could significantly impact the final estimate and this issue requires further investigation.

Other methodological limitations

The significant differences observed in Geneva could also be partially attributed to a methodological factor. Indeed, the demand-based estimate relies on GPS results compiled from 2011 to 2016 for the number of users and on the 2016 EWSD for the average quantities consumed. The wastewater estimate on the other

[48] Around 110,000 people in 2017 for about 500'000 residents.

hand is based on samples collected between 2017 and 2019. It is therefore possible that there has been an increase in consumption, which could also explain one part of the difference measured. The wastewater analyses carried out in Geneva since 2012 as part of the European SCORE project point in this direction with an increasing trend in cocaine loads from 2017[49].

This bias does however not apply to the estimate in the canton of Vaud, for which the wastewater samples were taken between 2014 and 2016.

Conclusions

Several factors (missing populations, population flows, purity levels, measurement biases) can explain some of the differences between the two approaches, and between the two sites, for the market estimates for cocaine and ecstasy. However, there is a suspicion that demand-based estimates underestimate the size of those markets, among others because they do not fully reach the groups including the largest users and because users tend to report smaller quantities than the ones they use. These hypothesises need however to be further investigated,

[49] These results should be interpreted with caution as this campaign is only conducted over seven consecutive days.

2.5.1.3 *Amphetamine*

In the case of amphetamine, the demand-based estimate is higher than the one based on wastewater analysis, for both Vaud and Geneva. This is exactly the opposite of the other substances (except heroin, for which the wastewater methodology lacks robustness). It raises the question of the validity of the demand-based approach for a less common and probably less well-known substance than cocaine or cannabis.

According to the Swiss wastewater analysis data from the SCORE study, amphetamine use is higher in German-speaking cities than in French-speaking ones. However, this is not reflected in the 2016 EWSD data for Switzerland when we compare French-speaking and German-speaking participants. It is therefore possible that the average quantities of use are overestimated because the relatively small sample of 184 French-speaking amphetamine users we have reached could be a subgroup that is not representative of the other amphetamine users.

Another possibility is that respondents to the GPS reported the use of other substances instead of amphetamine. The question asked was about the use of 'amphetamine and/or speed' and the second term may have led to some confusion.

The amphetamine example clearly illustrates the difficulty of estimating the size of an illicit market and the importance of confronting the results obtained with different approaches. For now, we do not have a good explanation as to why the results with this drug show an opposite relationship than for most other drugs.

2.5.1.4 Cannabis

Our estimate of the size of the cannabis market for the canton of Vaud is 58% higher with the wastewater method, which is comparable to what we found for cocaine (+66%) (Table 14).

The discrepancy between cannabis used by locals and cannabis used locally, already discussed in the case of cocaine and ecstasy, is certainly also valid for cannabis. However, its impact may be less important for two reasons. The first is that cannabis use is potentially less linked to functional and festive use, which could preferentially take place in cities (with more workplaces and more nightlife). The second reason is that our wastewater estimate for cannabis includes samples from other locations and not only the main city.

The limitations associated to the demand-side estimates and discussed for cocaine and ecstasy also apply to the cannabis market estimate. It is possible that GPS struggle to reach frequent cannabis users or that our correction for underreporting is too weak. Again, the most sensitive parameter is probably the misreporting of frequency of use and quantities used in surveys. Moreover, a methodological bias, specific to cannabis, had been identified in the 2016 EWSD, as the answers regarding the usual quantities of cannabis added to joints had an upward limit which might be too low.

Another identified limitation is that our demand-based estimation miss school-aged children (under 15), who could play quite a role in this market.

2.6 Conclusions and recommendations

What can be learned from this case study for the EMCDDA's drug market estimates? First, our estimates show that a lot of caution is required when calculating the size of drug markets but also when communicating the results. With many corrections, the inclusion of uncertainty and a large set of specific data, we found large differences when applying two different methods to estimate the size of two local drug markets. While some of the reasons explaining these differences, for example those due to the fact that wastewater and demand approaches do not measure exactly the same thing, might be less relevant at EU level, others, such as the lack of good (and specific) data, might have even more consequences.

For three substances (cannabis, cocaine, ecstasy), two of which are those with the largest drug markets in Europe, our study suggests that demand-based estimates first require non-negligible corrections for underestimation and that, even when those are applied, the estimates could still be below – possibly in a range of about 10-50% - the actual quantities used. To reduce this underestimation, the parameters the most important for cannabis and cocaine appear to be the number of regular users and the quantities they use. Better data in these areas are likely to improve significantly the accuracy of demand-based estimates at the local and at the international levels. In the meantime, there are indications that demand-based market estimates are likely to be below reality.

Our results also show that demand-based heroin estimates still require an alternative method to assess or at least discuss their accuracy. This method is probably the wastewater approach but it needs refinement, especially at the data collection level.

Amphetamine estimates are very problematic. Our calculations show an inverse relationship between the results of the two methods compared to most other drugs. The fact that this has been observed in both sites suggests that there might be a problem with the data. We haven't found it in our wastewater estimates and our guess is that there is a measurement problem with the demand-based estimate. What this problem is, or what these problems are, remains at this stage unknown. The same goes for the impact of a possible mismeasurement on the estimates for other substances, especially methamphetamine. In the meantime, our study suggests that an even higher level of caution is needed when calculating and presenting amphetamine markets estimates. Given the findings of our study, it might even be wise to abstain from estimating the size of that market before an explanation of the differences has been found.

Our study also highlights the difficulties that could exist when trying to estimate the size of a drug market based on drug seizures data. Not only are the seizures very variable overall but their estimated share of the market seems to vary a lot between substances, ranging possibly from less than one percent to much more significant proportions. Even if drug seizures' shares could be a bit more homogeneous at EU level than at the local level, this parameter seems too unreliable for back calculating a drug market size. Finally, for its demand-based EU drugs market estimates, the EMCDDA can rely on multiple data sources but these are often much less specific than the ones we used in the MARSTUP study. This again invites to be extremely careful when presenting the results of the EU estimates. The contextualisation of the results, including the limitations of the available data, is certainly an important area to mention. As figures such as these have a tendency to be misused for budgetary, political or other reasons, researchers should do their best to be as transparent as possible in showing the methods, data and limitations of their studies.

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3 Experts consultation

3.1 Introduction

This last part of the project is a brief consultation with international experts exploring avenues to improve current EU drug market estimates.

3.1.1 Experts panel and questions

The EMCDDA suggested a list of experts who had been involved in drug market estimates at national and/or international level for this consultation:

1. **Alina Arucsandei**, **Sascha Strup** and **Laimonas Vasiliauskas**, Europol, The Hague, Netherlands
2. **Beau Kilmer**, RAND Corporation, Santa Monica, USA.
3. **Margriet Van Laar**, Trimbos Institute, Utrecht, Netherlands
4. **Stéphane Legleye**, Insee, Paris, France
5. **Viktor Mravčík**, Czech National Monitoring Centre for Drugs and Addictions, Prague, Czech Republic
6. **Kamran Niaz**, UNODC, Vienna, Austria
7. **Stanislas Spilka** and **Julien Morel-Darleux,** Observatoire français des drogues et des toxicomanies, OFDT, Paris, France
8. **Jiří Vopravil**, Household Survey Department for the Czech Statistical Office, Prague, Czech Republic

The research team with the support of the EMCDDA developed a set of five key questions meant to collect information that could allow improving the EU drugs markets estimates at different levels:

1. **Methods**: To estimate the size of the EU drugs market, the EMCDDA applies a demand-based approach using data on the number of drug users in Europe and the amount of drugs they use. Do you see any other approach/method (supply-side, wastewater, other) that might allow a reliable EU drug markets estimate? If yes, please specify the approach/method and the required data sources.

2. **Populations**: To estimate the number of drug users in Europe, three population groups are usually included: adolescents (as surveyed by the ESPAD and/or HBSC studies), adults (as surveyed by national general population surveys) and problem drug users (as estimated through national capture/recapture, treatment multipliers or other indirect methods). Are there other (“hidden”) populations that should be included in the estimates? If yes, which populations and what data sources are available to estimate the number of drug users within these populations?

3. **Prevalence**: Survey data tend to underestimate the prevalence and frequency/amounts of drug use in the population. This phenomenon is also true for alcohol and leads to an underestimation of the overall volume used by the population Do you think that it would be possible to offer one or more possible correction factors based on assumed underreporting in survey data and if so what would you base this on? Which methods could address this issue at the national level and could it also be addressed at EU level (for the EU drugs market estimate)?

4. **Quantities**: Demand-based estimates also rely on data about the average quantities of drugs used by different categories of drug users. Currently the data are collected through non-representative web surveys. Do you see a better approach that could provide more accurate and representative data in this area?
5. **Uncertainty**: The EU drug market estimate relies on multiples data sources and calculations with multiple parameters of uncertainty. How would you address this issue at the strategic (develop a best estimate, develop a range, provide different estimates based on different scenarios…) and at the practical (selection of parameters, statistical tools and methods, etc.) levels?

The next pages present a summary of the experts' answers to these questions followed by a short conclusion on the main findings of this consultation.

3.2 Results

3.2.1 Methods

To estimate the size of the EU drugs market, the EMCDDA applies a demand-based approach using data on the number of drug users in Europe and the amount of drugs they use. Do you see any other approach/method (supply-side, wastewater, other) that might allow a reliable EU drug markets estimate? If yes, please specify the approach/method and the required data sources.

The panel members reported few alternative methods to estimate the size of the EU drugs market. Wastewater analysis was mentioned by different experts as a promising approach but with different caveats, including the need for better data in areas such as street drug purity (which is necessary to convert the measured quantities into consumed quantities). A need for better geographical coverage of wastewater analysis, with additional and more heterogeneous data collection sites, was also mentioned as a requirement for drug market estimates to become useful at the national or international level.

One expert explicitly opposed the use of supply-side (supply reduction) indicators for drugs markets estimates, arguing that data are too much influenced by law enforcement activities, but three other experts suggested using them alongside other approaches. Data on drug seizures and arrests, and on precursor trade and trafficking, were seen as valuable information that could feed models estimating the market size. One of the experts suggested introducing flexibility in these models to allow for adjustments based on intelligence regarding trafficking trends and volumes, drug production, prices, money laundering processes or cash payments. For the EU estimates, drugs seized before entering the EU may partially reflect the demand but also inform about the financial losses of traffickers. The timeliness of supply-side indicators/approaches might also be better than current demand-based estimates as these are constraint by data collection delays. Recent changes might be missed and the market could be under- or overestimated because of these delays. Supply-side data could therefore help adjusting estimates for temporal changes.

For demand-based approaches, a suggestion was to ask respondents in surveys to report their drug expenses instead of their drug consumption. This method is a more direct approach to estimate the financial value of the market and may allow for better data. It was used among others to estimate the value of the cannabis market in France[50]. It implies however an additional step when the estimate is to be an amount of drugs: the amount spent needs to be divided by the price paid per gram, which might be quite variable. Such calculations have been done in reports produced by RAND for the White House Office of National Drug Control Policy[51]. If the data on drug expenditures and average prices can be collected, the method also provides an opportunity to develop a second estimate (however not independent from the first one) of the drug market size.

3.2.2 Populations

To estimate the number of drug users in Europe, three population groups are usually included: adolescents (as surveyed by the ESPAD and/or HBSC studies), adults (as surveyed by national general population surveys) and problem drug users (as estimated through national capture/recapture, treatment multipliers or other indirect methods). Are there other ("hidden") populations that should be included in the estimates? If yes, which populations and what data sources are available to estimate the number of drug users within these populations?

The experts mentioned two main other hidden populations that are typically missed by current demand-based drugs market estimates. The first are inmates with one expert stressing that the prison population includes many intensive drug users potentially out of treatment. He suggested the implementation of additional programs such the I-ADAM[52] in EU Member States. The second population includes school dropouts and young people in special education programs or youth care. One expert mentioned that these young people would probably use on average more drugs than their peers from the same age group. It might therefore be appropriate to consider them specifically in demand-based estimates[53].

Homeless people and undocumented immigrants were also mentioned among the population missed by demand-based estimates. One of the experts suggested to develop specific studies to assess drug use in these populations but also noted that such studies for various reasons are difficult to implement.

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[50] Legleye, S., Lakhdar, C. B., & Spilka, S. (2008). Two ways of estimating the euro value of the illicit market for cannabis in France. *Drug and Alcohol Review*, 27(5), 466-472. https://en.ofdt.fr/publications/tendances/cannabis-sales-revenue-france-new-direct-estimate-expenditure-tendances-137-march-2020/

[51] https://www.rand.org/pubs/research_reports/RR3140.html
https://www.rand.org/pubs/research_reports/RR534.html

[52] https://www.ojp.gov/pdffiles1/nij/189768.pdf

[53] Some data exists in the Netherlands about these populations (https://www.trimbos.nl/kennis/feiten-cijfers-drugs-alcohol-roken/explore).

Other populations, which are either a subgroup of the general population or do not belong to it, were also mentioned. This includes non-residents and tourists. In some European countries, tourists can be a relevant group in terms of drug use. As long as they also buy their drugs in Europe they also contribute to the EU market, but caution must be applied to avoid double counting their drug use, both in the country where they purchase and use the drug and in their country of residence as a member of the general population who uses drugs. This mobility issue raises methodological questions for market estimates and also affects wastewater estimates. Other groups such as partygoers, sexual minorities (in relation for example with chemsex practices) or people with therapeutic use (cannabis) were also mentioned because they have specific patterns of drug use that need to be considered when estimating the demand for drugs. Considering these populations separately could help refine the estimates but there would be issues regarding overlaps with the general population.

3.2.3 Prevalence

Survey data tend to underestimate the prevalence and frequency/amounts of drug use in the population. This phenomenon is also true for alcohol and leads to an underestimation of the overall volume used by the population Do you think that it would be possible to offer one or more possible correction factors based on assumed underreporting in survey data and if so what would you base this on? Which methods could address this issue at the national level and could it also be addressed the at EU level (for the EU drugs market estimate)?

Most of the experts agreed that obtaining accurate estimates of drug use is always an issue. They highlighted different possible areas of miss- or underreporting, that were regrouped by one of the experts as the following[54]:

1. Use by people that are not reached by the surveys deployed
2. Use by people targeted by the surveys but not actually surveyed
3. Misreporting of use
4. Misreporting of quantities that are actually used

An important point that emerged from the consultation is that these issues can vary with substances and populations, but also with the surveying method. Social desirability is indeed not the same with self-reported questionnaires as with telephone surveys. In some cases, there may even be an overestimation with, for example, adolescents reporting drinking more than reality because they see this positively.

Network scale up methods (NSUM) were mentioned to improve the estimates of the number of users. Comparing estimates obtained with such a method with GPS prevalence data could help correcting for people who are not reached (point 1 above) and for misreporting of use (point 3 above) in the general population. The method could also be used for some subgroups such as regular users. The expert who mentioned the NSUM method warned that it should be applied at the local level and then extrapolated to larger populations.

[54] See also this RAND report https://www.rand.org/pubs/research_reports/RR466.html

Several suggestions were made to improve points 3 & 4 above and thereby correct for the misreporting in surveys and other data collections:

- Specific field studies such as day to day monitoring, Timeline Follow Back methods (TLFB) or qualitative in-depth interviews;
- Random mixed-mode experiments, combining phone and web questionnaires that would allow to test for measurement biases and allow estimating an overall effect of underreporting;
- Mixed-mode panel experiments with statistical analysis providing estimates of measurement biases at the individual level (in theory) or in small samples (more reasonable);
- Strategies to help participants answer questions, for instance with pictures representing quantities;
- Data on differences measured between demand-based estimates and sales for legal goods such as alcohol or tobacco to estimate underreporting
- Choosing a subsample to take a drug test after they complete the survey to improve prevalence estimates[55].

More generally, GPS surveys need to be validated every so often and differences in survey modalities need to be taken into account when making comparisons across countries[56]. Two experts also provided their views on how to perform adjustments. One suggested to consider a range for each factor and then combining them. In the same vein, the second one suggested to conduct sensitivity analyses to define the impact of each parameter in order to adjust a confidence interval of the final result.

3.2.4 Quantities

Demand-based estimates also rely on data about the average quantities of drugs used by different categories of drug users. Currently the data are collected through non-representative web surveys. Do you see a better approach that could provide more accurate and representative data in this area?

Web surveys were confirmed as good tools to reach a relatively large number of users and ask them detailed questions about their drug use. However, the experts confirmed that if non-probabilistic studies are used to assess quantities, it is necessary to find a way of matching the data with representative studies (GPS). The most common way of matching is a stratification by frequencies of use but other characteristics (such as demographics) could be added. Even if the use of non-representative samples remains “risky”, as one expert mentioned, there seem to be few existing alternative strategies.

One suggestion is to combine data from different sources, including field studies, to assess the characteristics of users and patterns of use to inform sensitivity analysis (that would further inform global uncertainty). Another suggestion was to conduct face-to-face interviews with drug users from different categories and to compare their answers with data provided by (web)surveys.

To estimate the quantities used by problem drug users, the experts recommended using information collected in all treatment centres and low threshold facilities.

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[55] http://www.buckleysrenewalcenter.com/wp-content/uploads/2012/02/drugtest.pdf

[56] https://www.sciencedirect.com/science/article/pii/S0376871617305197

For cannabis, one strategy could be to compare the results of web surveys with sales data and/or cohort studies in places where the drug is now legal[57].

3.2.5 Uncertainty

The EU drug market estimate relies on multiples data sources and calculations with multiple parameters of uncertainty. How would you address this issue at the strategic (develop a best estimate, develop a range, provide different estimates based on different scenarios…) and at the practical (selection of parameters, statistical tools and methods, etc.) levels?

Two experts provided recommendations to reduce methodological errors. One mentioned the importance to "stratify by types of users, at least by frequency of use (and perhaps demographic variables)" and suggested to use the truncated mean to deal with data on consumption (frequency and amounts of drugs), thus allowing to retrieve implausible data.

The second expert raised the need to assess the independence of each sample or recruitment method to reduce the risk of overlap. If recruitment methods are not independent, weighting should be implemented to correct for multiple counts, and the samples have to be combined.

Regarding the computation and presentation of the estimates, two out of seven experts recommended to present a best estimate. The other experts agreed that the best (or only viable) solution is to present the result with a confidence interval. According to one expert, it would also be acceptable to present results based on different scenarios. This is however not very common and another expert mentioned that "[it] may in fact confuse those who are not familiar with the methods and assumptions".

Monte Carlo simulations were recommended by two experts as a way to deal with the combination of multiple variables and compute credible confidence intervals.

[57] The International Cannabis Policy Survey run by Dave Hammond at the University of Waterloo was mentioned as an example.

3.3 Conclusions

The experts' consultation suggests that there are very few alternatives to the demand-based approach for drugs market estimates. Wastewater epidemiology was mentioned as a promising approach, coming with its own limitations and requiring additional data. Experts disagreed about the reliability of estimates based on supply-side (supply reduction) indicators, which is the only other approach that was mentioned.

Demand-based estimates do not come without uncertainties. Various biases, in particular around misreporting quantities or undercounting drugs users, were identified by the panel.

These include:

- Missing sub-populations that could use drugs in significant amounts, such as inmates, school drop outs and young people who are outside the standard education system, undocumented immigrants and homeless people;
- Misreporting, including non-reporting and under/over-reporting of quantities;
- Mismatching between data from non-representative samples about quantities and GPS data about the number of users.

According to the experts' answers, there is no ready-made solution to remedy all these issues. Further research is therefore required to better understand some of the limitations and biases, and to refine the estimates. To do this, various methods/tools were mentioned either to quantify the bias and thus help correcting for them, or to develop other ways to estimate the parameters involved in the estimates.

Network scale up methods could offer an interesting alternative to GPS. They are however more suitable to small scale estimates (local or national). Other methods could also be implemented to account for specific "hidden" populations missed by GPS and, once again, further research is required to better investigate drug use among these populations.

To help addressing misreporting issues, specific studies such as TFLB, random mixed-mode experiments or mixed mode panel experiments could be conducted. One difficulty is that misreporting affects different groups of users of different substances in different places in a different scale, thus multiplying the need for specific studies.

To refine the estimates, more homogenous user groups should ideally be identified. While the usual stratification by frequency of use meets the need of matching data from non-representative studies with GPS data, it often leads to inhomogeneous grouping (typically, last month users vs. last year but not last month users are broad categories with large variations in terms of quantities used within each category). The categories should be refined or an additional stratification step, based for instance on demographic characteristic, should be performed. This might however lead to very small samples.

Finally, the majority of experts agreed on the need to be transparent about the uncertainty that comes with the results, always presenting confidence intervals rather than just a single value.

Final conclusions and recommendations

In this final section, we summarise the results of the three parts of the study and suggest recommendations for future estimates of the EU drugs market.

The literature review showed that there have been only few attempts to estimate the size of drug markets and that existing studies mostly rely on bottom-up/demand-based approaches. Attempts to use top-down or supply-side approaches also exist. New approaches such as wastewater analysis are promising but had only very few applications up to now.

The demand-based approach has been the most used at the international level and might be the only one that can be applied to estimate the EU drugs market. Supply-side indicators and data might allow for some form of validation, mostly through checking if the estimates are somehow credible, but do not seem to be based on credible data and science.

In this context, the key issue is how to improve the demand-based approach. While there is no silver bullet in this area and that improvements are also very dependent on available data, there are a set of steps that can allow to better estimate the size of the drugs market or, if data are not available, to better highlight the uncertainties and limitations of the estimates. These steps include to better count the number of drug users and to better assess their consumption. This encompasses better taking into account hidden (heavy) drug user populations, better correcting for underreporting of drug use, and collecting better data on the average volumes used. Finally, it is important to show the uncertainty surrounding the estimates.

The MARSTUP study conducted in two Swiss cantons also highlights the need for improved data and the risks of misleading results if uncertainty is not taken into account. Using two largely independent methods (wastewater-based and demand(survey)-based) we found important differences in the estimates, despite having often heavily corrected for underreporting in surveys. While some of the differences might be due to the fact that the two methods measure different constructs, there is still a strong suspicion that demand-based estimates, especially for the most used drugs in Europe, are often well below reality.

The study also highlights the difficulties when trying to estimate the size of a drug market based on drug seizures data. Not only are the seizures very variable overall but their estimated share of the market seems to vary a lot between substances. Even if drug seizures' shares could be a bit more homogeneous at EU level, this parameter seems too unreliable for back calculating the drug market size.

The experts' consultation confirmed that there are very few alternatives to demand-based approaches for drugs market estimates. Wastewater epidemiology was mentioned as a promising approach, coming with its own limitations and requiring additional data. Experts disagreed about the reliability of estimates based on supply-side (supply reduction) indicators.

To improve demand-based estimates, further research is required to better understand some of the limitations and biases, and to refine the estimates. Some methods/tools were mentioned either to quantify the bias and thus help correcting for them, or to develop other ways to estimate the parameters involved in the estimates. These include for example network scale up methods as an alternative for GPS (at the local level) or methods that could account for specific "hidden" populations. TFLB, random mixed-mode experiments or mixed mode panel experiments could also be conducted to help addressing misreporting issues. Conduct studies comparing self-reported consumption with more objective data (drug test), could also help. The definition of more homogenous user groups could also help to refine the estimates. The usual stratification by frequency of use could be improved with an additional step based on demographic characteristic.

The experts finally agreed on the need to be transparent about the uncertainty that comes with the results, always presenting confidence intervals rather than just a single value.

Overall, the results of the three parts of this study highlight the difficulties existing when estimating drug markets. They also suggest that demand-based estimates remain at this stage the best option but that they need to be continuously refined and require full transparency in order to understand their limitations. There are at least four big areas for work: 1) better counting drug users by correcting for non-reporting and by including hidden populations, in both cases with a focus on heavy users; 2) better estimating drug use volumes by correcting for underreporting but also by improving data with (different) studies targeting different user groups; 3) improving the linkage between data sources on the prevalence of drug use and those on the quantities used, including by refining the stratification of user groups; 4) improving the calculations in order to better show the uncertainty surrounding the estimates.

In parallel, local drug market studies such as the MARSTUP study in Switzerland could allow to better understand some of the main limitations of demand-based estimates and help correct them. Currently wastewater-based estimates may indeed be the only approach that allows some kind of validation of the demand(survey)-based approach but also show why estimates based on supply-reduction data might not be reliable. Finally, such local studies might also allow to refine the wastewater based approach and thereby bring it to levels where it might be possible in some years to use it to estimate the size of the EU drugs market. This again highlights that, beyond the short-term needs for the next EU drugs market estimate, there should also be a longer term goal to promote more research into this area within Europe.

Annexes to chapter 2

Methodology applied to define adjustment ranges for the misreporting of use (adapted from Kilmer et. al (2013))

Non-reporting of use is the issue most studied often through research that compares a self-reported use with the results of a urine test (Basurto et al., 2009; Harrison et al., 2007; Hunt et al., 2015). These studies often focus on very specific populations and it is difficult to know to what extent they reflect the behaviour of the general population. They do, however, give an indication of the potential magnitude of the underestimation problem. Figure 4 shows the methodology used to determine a correction factor for this issue (adapted from Kilmer et al. (2013)).

When possible, we adapted the results from the three above mentioned studies to fit the method presented in Figure 4 and calculate a correction factor. We then used the minimal and maximal values calculated as the lower and upper bounds of a 95% confidence interval to define a distribution for the misreporting factor. This factor was finally combined with other ones to define a global adjustment factor (see point 2.3.2, p.32).

Figure 4 Determination of a correction factor to adjust for misreporting of use

$N = n1 + n2 + n3 + n4$		Urinanalysis result -	Urinanalysis result +	Correction factor (f_c) calculation for misreporting of use
Self-report	-	$n1$	$n3$	$f_c = \frac{People\ who\ consumed}{People\ who\ reported} = \frac{(n2 - x + n3 + n4)}{(n2 + n4)}$
	+	$n2$	$n4$	With x, the $n2$ subgroup that falsely report use (between 0 et 20% of people in $n2$).

Urine tests can be falsely negative, especially for occasional users, which is why n2 should be considered in the numerator. However, it is possible that some users who report consumption did not actually consume. We therefore still have to subtract these people (x). In contrast to Kilmer et. al (2013), we assume that users who reported consumption AND tested positive for (n4) actually consumed. Only users who tested negative (n2) are therefore likely to have reported false consumption.

Statistical procedures for confidence interval calculations

Demand-based estimates

To compute credible confidence intervals, Monte Carlo simulations were computed. The process includes the following steps:

1. Annual quantities (number of days multiplied by the quantities per day) are computed for each person reached by the surveys.
2. For each user groups (classified by frequencies of use), a gamma distribution (that avoid negative values) is fitted to the data about annual quantities. This process gives the parameter of a gamma distribution with a 95% confidence interval for the parameters.
3. An annual quantity is simulated for each user in the population (for instance, 482 simulations for the 482 regular cocaine users). For each simulation, gamma parameters are randomly selected within their 95% confidence interval given in the previous step (point 2) before generating an annual quantity. All results (482 in our example) are summed to obtain the total annual quantity for a given user group. The number of users in the population is taken as a fixed parameter at this point because a correction is provided when adjusting for underreporting issues (next step).
4. For each user category, the total quantity is multiplied by a correction factor to adjust for underestimation issues (see point 2.3.2 in the report). This factor is defined as a normal distribution and randomly selected in this distribution. The sum of the quantities for each user group gives an estimation of the market size for a given substance.
5. The whole process is repeated 100’000 times to give a distribution for the final estimate. The mean and 95% confidence interval of this distribution are our final results. To summarize, we simulate for each run:
    a. The parameters of the gamma distribution that fits the annual quantities for each user group.
    b. The annual quantity for each user in the population
    c. The global correction factor for underestimation (underreporting, misreporting, etc.)

Wastewater-based estimates

For wastewater based estimates, Monte Carlo simulations are performed assigning to each parameter of the back-calculations a randomly selected value from their specific distribution. To avoid an artificial decrease on the uncertainty, back calculations are performed from the total yearly charges. The complete process includes the following steps:

1. Calculation of the average charges and standard error for each day of the week from the results of the available samples. For instance, seven wastewater samples collected on Mondays are used to calculate the “usual” Monday charges. Since we are not always measuring the same quantity (we do not repeat measures of the same thing but measure different days that are expected to vary), the standard error does not fully account for uncertainty due to the use of a sample of days as an indicator of the whole period (in our case, one year).
2. To account for this error, we simulate 52 days (each weekday is treated separately) from a normal distribution which parameters are given by the measures (mean and standard error). We then randomly select n values for this simulated year, with n equal to the real number of samples (for instance seven samples collected on Mondays). We compute an annual value from this n values (sum/n*52) and compare the result to the sum computed from the 52 values (this gives an error due to sampling coverage). We repeat this operation many times and take the error value that covers 95% of the simulations. Even if samples were collected across different years, we always simulate a one-year period. This allows to value the number of collected samples across the years. However, the result must then be interpreted as an average yearly estimate that cannot be attached to a given year. This strategy is used only for periods for which we do not suspect (from measures and other indicators) high differences across the years.
3. We then simulate a whole year (52 Mondays, 52 Tuesdays etc.) and sum the simulated quantities. Again, this operation is repeated to obtain a distribution of the yearly charges from which we can derive the average and 95% confidence interval.
4. Back calculations are then performed for each simulated value of yearly charges. Parameters included in the back-calculations are also randomly simulated from their specific statistic distribution (see table below). This gives us a simulated distribution of yearly volumes of consumption, that take into account all kind of errors associated with the whole process.

Parameters used for wastewater back-calculations

	μ	S.E.	Distribution	Source
Flow	Daily flow [L/day]	Residuals of a Gaussian regression of degree 3 on the flow values.	Normal (μ, S.E.)	WWTP of Vidy (VAUD) and Aïre (GENEVA)
Chemical Analysis	Mean concentration of 3 replicates [ng/L]	$\frac{SD}{\sqrt{3}}$	Normal (μ, S.E.)	Standard deviation derived from the validation of the analytical method and the analysis of 3 replicates (n=3)
Excretion	Morphine from morphine consumption 74.6%	1.6%	Beta (a, b)	(Been, Benaglia, et al., 2015)
	Morphine from heroin consumption 42%	3%	Beta (a, b)	(EMCDDA, 2016)
	Benzoylecgonine from cocaine consumption 28.2%	1,6%	Beta (a, b)	(EMCDDA, 2016; Wollschläger et al., 2017; EWSD 2016)
	MDMA from MDMA consumption: 15.78%	1.83%	Beta (a, b)	(Been, Bijlsma, et al., 2015)
	Amphetamine from amphetamine consumption: 29.12%	0.93%	Beta (a, b)	(Been, Bijlsma, et al., 2015)
	Methamphetamine from methamphetamine consumption: 28.56%	2.59%	Beta (a, b)	(Been, Bijlsma, et al., 2015)
	THCCOOH from THC consumption: 6,74%	THCCOOH: 2.92%		(Béen et al., 2015)
Adsorption	Morphine: 4.1%	MOR: 1.1%	Normal (μ, S.E.)	(Been, Benaglia, et al., 2015)
	Benzoylecgonine: neglected	na	na	(Baker & Kasprzyk-Hordern, 2011; Jones et al., 2014)
	MDMA: neglected	na	na	Less than 2.5% (EMCDDA, 2016)
	Amphetamine: 4.15%	1.05%	Normal (μ, S.E.)	(Baker et al., 2012)
	Methamphetamine : 1.75 %	0.55%	Normal (μ, S.E.)	(Baker et al., 2012)
	THCCOOH: 8.5%	2%		(Been et al., 2016)

	µ	S.E.	Distribution	Source
Stability	Morphine: neglected	na	na	(Been, Benaglia, et al., 2015; Senta et al., 2014)
	Bnzoylecgonine : 13,5%	6,5%	Normal (µ, S.E.)	(EMCDDA, 2016) - 2 studies performed at 4°C for 24 hours.
	MDMA: neglected	na	na	(EMCDDA, 2016) - 2 studies performed at 4°C for 24 hours.
	Amphetamine: neglected	na	na	(EMCDDA, 2016) - 2 studies performed at 4°C for 24 hours.
	Methamphetamine: neglected	na	na	(EMCDDA, 2016) - 2 studies performed at 4°C for 24 hours.
	THCCOOH : neglected			(Been, Bijlsma, et al., 2015; Senta et al., 2014)
Other source of the target compound	Morphine charges from therapeutic Morphine Vaud 21 gr / jour (2014) 35 gr / jour (2015) 50 gr / jour (2016) Geneva 124 gr / jour (2017) 121 gr / jour (2018)	 1.83 3.19 4.69 6.33 6.18	Normal (µ, S.E.)	Morphine: Swissmedic Codeine : (Been, Benaglia, et al., 2015) SE: calculated assuming a 95% confidence interval distribution of 10% below 10% above the mean
	Benzoylecgonine: neglected	na	na	(Jones et al., 2014)
	MDMA: neglected	na	na	Assumed for this study
	Amphetamine charges from methamphetamine use and Lisdexamphetamine (Elvanse® medicine) Vaud 0.28 gr / jour (2014) 0.72 gr / jour (2015) 1.02 gr / jour (2016) Geneva 2.38 gr / jour (2017) 3.25 gr / jour (2018)	 0.03 0.07 0.1 0.12 0.17	Normal (µ, S.E.)	Methamphetamine : Wastewater analysis Elvanse®: Swissmedic, MESA Excretion rates : (Baselt, 2011; Béen et al., 2016)
	Methamphetamine: neglected	na	na	Assumed for this study
	THCCOOH charges from Sativex® medicine and CBD (legal cannabis) Vaud 0.0022 gr/jour (2015) 0.004 gr/jour (2017) 0.1316 gr/jour (2018) Idem 2018 (2019)	 0.0001 0.0002 0.007 0.007	Normal (µ, S.E.)	Sativex® : Swissmedic, MESA CBD : Swiss federal customs administration

	µ	S.E.	Distribution	Source
Purity	Heroin Vaud: 14.1% Geneva: 16.81%	$\frac{SD}{\sqrt{n}}$	Normal (µ, S.E.)	ESC, UNIL, VD+GE seizures (2014-2016), n = 79 ESC, UNIL, saisies GE (2017), N= 213
	Cocaine Vaud: 44.5% Geneva 54.0%	$\frac{SD}{\sqrt{n}}$	Normal (µ, S.E.)	ESC, UNIL, VD seizures (2014-2016), n = 734 ESC, UNIL, GE seizures (2017-2019), n = 289
	MDMA Vaud: Pills: 107.7 mg Crystal: 70.2% Geneva: Pills: 107.5 mg Crystal : 71.95%	$\frac{SD}{\sqrt{n}}$	Normal (µ, S.E.)	Vaud: SSML (2014-2016), Geneva: SSML (2017-2019)
	Amphetamine Vaud: 22.7% Geneva: 20.4%	$\frac{SD}{\sqrt{n}}$	Normal (µ, S.E.)	Vaud: SSML (2014-2016) Geneva: SSML (2017-2018)
	Methamphetamine: Thaï pills: 13.7 mg Crystal meth: 70.2%	$\frac{SD}{\sqrt{n}}$	Normal (µ, S.E.)	SSML seizures (2014-2016), n = 145, powder form, n=67 pills
	Cannabis Vaud 2015: Herb: 13.3% Resin: 28.2% 2017: Herb: 13.5% Resin: 28.2% 2018: Herb: 13.3% Resin: 28.2% 2019 idem 2018	2015: Herb: 0.3% Resin: 0.6% 2017: Herb: 0.2%, Resin: 0.6% 2018: Herb: 0.2%, Resin: 0.6% 2019 idem 2018	Normal (µ, S.E.)	Herb: SSML without samples under 2% THC Resin: ESC, UNIL, 2019

	μ	S.E.	Distribution	Source
Factor of correction to infer the canton Vaud	Heroin 2.12	na	na	Methadone users, statistics Vaud IUMSP, CHUV
	Cocaine 1.86	na	na	Last 12 months prevalence differences between WWTP areas and rest of the Canton GPS study CoRolAR (2011-2016)
	MDMA, Amphetmaine, Methamphetamine 1.86 (idem cocaine)	na	na	Idem Cocaine
	Cannabis 2.27	na	na	Last 12 months prevalence differences between WWTP areas and rest of the Canton GPS study CoRolAR (2011-2016)
Factor of correction to infer the canton Geneva	Geneva: All substances 1.12	na	na	Population ratio between canton and WWTP-connected area. OCSTAT Cantonal population statistics and WW operating report