Quantifying Melbourne’s ‘Foodprint’

A scenario modelling methodology to determine the environmental impact of feeding a city

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Abstract

As cities grow and climate change intensifies, challenges related to the sustainable supply of food to urban areas are increasing. This is a particular issue for Melbourne, one of the fastest growing cities in Australia. Although food consumption accounts for a significant proportion of environmental impact, there is little or no data quantifying what it takes to feed a city to help city governments plan for the future. This paper presents the methodology and findings of an investigation into the environmental impact of feeding Greater Melbourne by quantifying it’s ‘foodprint’ – the land and water required, and food waste and greenhouse gas (GHG) emissions generated. It forms part of a larger project, Foodprint Melbourne, investigating the sustainability and resilience of Melbourne’s foodbowl. The foodprint was calculated for 2014 and 2050, using the Australian Stocks and Flows Framework (ASFF). It was found that it takes 758 GL/yr of water and 16.3 Mha/yr of land to feed Melbourne, with over 907,537 t/yr of edible food waste and 4.1 Mt/yr of GHG emissions generated. With no change to consumption patterns or production methods, in 2050 1598 GL/yr of water and 32.3 Mha/yr will be required, with 7.4 Mt/yr of GHG emissions generated.

Keywords: urban, food security, systems, sustainability, food waste

1. Introduction

It has been widely documented that food can be linked to all seventeen Sustainable Development Goals (SDGs) (Rockström and Sukhdev, 2016) highlighting the importance of sustainable food systems for positive global change. Historically, the challenges of the global food system have centred around feeding the world’s growing population (Godfray et al., 2010). More recently, however, due to increasing urban populations (UN, 2014) and environmentally intensive urban food consumption (Popkin, 2006), there has been a reframing of the issue of future food security (and achieving the SDGs) as an urban problem (Hoornweg et al., 2016; Jennings et al., 2015; Satterthwaite et al., 2010).

Melbourne is a city of around 4.5 million people in the state of Victoria in south-east Australia. It is experiencing rapid population growth and predicted to overtake Sydney to become Australia’s largest city within the next two decades. Much of this growth is occurring on the city fringe at relatively low rates of urban density on areas of former farmland. The city is situated in a water-scarce region of the world that is predicted to experience further warming and drying as a result of climate change. As supplies of the natural resources underpinning food production become more constrained, the city will need to explore new approaches to increase the sustainability and resilience of its food supply, and will require an evidence base to support policy and decision making. Although previous studies have assessed the environmental impacts of food consumption at a state level (EPA Victoria, 2008) and national level (ACF, 2007), no such investigation has been undertaken at a city level for Melbourne.

Previous studies in the US and the UK have established the concept and quantitative calculation of a city ‘foodprint’ (Curtis et al., 2013; Peters et al., 2007), drawing on the idea of an environmental footprint (EPA Victoria, 2008). This is a consumption-based systems approach that calculates the environmental impact of feeding a city. So far, not such attempt has been made to undertake this kind of analysis for an Australian city.
The aim of this investigation is to develop and test a methodology to quantify Melbourne’s ‘foodprint’ – how much land and water it takes to feed the city’s population, and the food waste and GHG emissions that are generated. Using a diet profile developed by Turner et al. (2017), and food waste fractions for the North America and Oceania region determined by the Food and Agriculture Organisation (FAO) (Gustavsson et al., 2011), the overall food consumption and food waste generated by the city is estimated by food type. These figures are then used to establish a city consumption factor that is the integrated with the Australian Stocks and Flows Framework (ASFF), to determine the resources used and environmental impacts.

2. Methods

The methods used to calculate Melbourne’s foodprint (both now and in 2050) have been developed to work alongside the Australian Stocks and Flows Framework (ASFF) and draw on its existing database and scenario modelling functions. ASFF is a scenario modelling platform developed to comprehensively assess environmental sustainability challenges in Australia and model potential solutions (Turner et al., 2011). It was designed as a scientific and policy tool to study the interplay between factors such as population, technology, lifestyles and the environment (Poldy and Conroy, 2000). It models the physical processes (often involving the flows in and out of stocks, e.g., additions and demolitions of the building stock) that underlie activity across all sectors of the economy. Essentially a mass and energy accounting system, it is employed to track land, water, energy, labour and materials required for economic activity to actually occur.

The foodprint assessment draws on data about Australian diets and the impacts of environmental challenges to Australia’s food supply from a previous study of Australia’s national food security by Turner et al (2017) that used the same underlying modelling framework. One of the aims of this study is to develop a methodology and evaluate the use of the ASFF framework for modelling challenges to food supply at city region scale. General and national food system specific limitations to modeling with the ASFF have already been documented by Turner et al. (2011) and Turner et al. (2017) respectively. City region scale limitations specific to this study will be discussed in Section 2.4.

2.1 Diet profile for Melbourne

It was assumed that food consumption in Melbourne followed national consumption patterns. The amount of food eaten per capita was calculated based on a diet profile developed by Turner et al. (2017). It was derived from a combination of data collected as part of the Australian Health Survey’s 2011-12 National Nutrition and Physical Activity Survey (NNPAS) (ABS, 2013a) with ingredient proportions from the Australian Food, Supplement and Nutrition Database (AUSNUT) (FSANZ, 2015) to determine an average Australian diet profile in terms of food commodity types suitable for use in ASFF (Figure 3). Foods are grouped in this way in ASFF due to the commonalities of physical resources (e.g. water, land, energy, fertiliser) required to produce them as well as suitable trade categories. Since Australian food preferences are constantly changing, current trends in dietary patterns, such as increasing chicken consumption and decreasing red meat consumption, were taken into account in estimating the food needs of Melbourne’s future population in 2050. Projected increases in consumption due to rising obesity (Walls et al., 2012) were not taken into consideration in the 2050 calculation, therefore the results are likely to be an underestimate of Melbourne’s future food consumption.
The profiles were multiplied by the number of people in Greater Melbourne to determine the actual food eaten for the city by food type. For the purposes of calculating population numbers, it was assumed that ‘Greater Melbourne’ was made up of all the Local Government Areas within the Urban Growth Boundary, including the urban and ‘interface’ councils, as defined by Sheridan et al (2015).

2.2 Food production and food waste for Melbourne

To determine the amount of food that would need to be produced to feed Melbourne, which would then be used to determine environmental impacts, the actual food eaten for each food type were multiplied by processing, refining and waste factors throughout the food chain. Figure 2 shows the volume reduction of food throughout the supply system. The overall amount of food produced is decreased first by losses or wastage on farms (pre-farm gate). In the ‘farm gate to checkout’ part of the food system, reductions in the overall amounts occur both due to the refining of food and wastage during processing. For some foods there are substantial volume reductions during refining - when raw sugar is converted into refined sugar for example, oil seeds into oil, or raw milk into dairy products, such as cheese and butter. After the food has been purchased, further losses then occur in households and restaurants (post-consumer waste).

The ASFF framework models food amounts from the farm gate, via processing to households, with the potential to incorporate waste and refining factors during processing and at a consumer level (represented by the dark blue section of Figure 2). Because there is little available data on food waste fractions through the food supply chain in Australia, with the exception of household waste (Sustainability Victoria, 2014), food waste fractions for the North America/Oceania region (which includes Australia) from a recent report from the United Nations Food and Agriculture Organisation (FAO) (Gustavsson et al., 2011) have been used in ASFF. Since the food categories for the FAO fractions (Figure 2) did not match the ASFF food categories (and those
in the diet profile) exactly, the FAO waste fractions were applied to the ASFF categories according to where they most closely matched (Table 1). The refining factors used in the ASFF framework were derived from historical data used to calibrate the ASFF framework.

<table>
<thead>
<tr>
<th>Food type</th>
<th>Pre-farm gate</th>
<th>Farm gate to checkout</th>
<th>Post-consumer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereal grain</td>
<td>0.02</td>
<td>0.09</td>
<td>0.27</td>
</tr>
<tr>
<td>Rice</td>
<td>0.02</td>
<td>0.09</td>
<td>0.27</td>
</tr>
<tr>
<td>Legume grain</td>
<td>0.12</td>
<td>0.06</td>
<td>0.04</td>
</tr>
<tr>
<td>Sugar cane</td>
<td>0.12</td>
<td>0.06</td>
<td>0.03</td>
</tr>
<tr>
<td>Nuts</td>
<td>0.12</td>
<td>0.06</td>
<td>0.03</td>
</tr>
<tr>
<td>Oil crops</td>
<td>0.12</td>
<td>0.06</td>
<td>0.03</td>
</tr>
<tr>
<td>Fruit</td>
<td>0.20</td>
<td>0.25</td>
<td>0.14</td>
</tr>
<tr>
<td>Vegetables</td>
<td>0.20</td>
<td>0.17</td>
<td>0.17</td>
</tr>
<tr>
<td>Beef &amp; Veal</td>
<td>0.03</td>
<td>0.10</td>
<td>0.11</td>
</tr>
<tr>
<td>Mutton &amp; Lamb</td>
<td>0.03</td>
<td>0.09</td>
<td>0.10</td>
</tr>
<tr>
<td>Pigmeat</td>
<td>0.03</td>
<td>0.09</td>
<td>0.10</td>
</tr>
<tr>
<td>Poultry</td>
<td>0.03</td>
<td>0.01</td>
<td>0.10</td>
</tr>
<tr>
<td>Eggs</td>
<td>0.03</td>
<td>0.09</td>
<td>0.10</td>
</tr>
<tr>
<td>Milk</td>
<td>0.03</td>
<td>0.03</td>
<td>0.15</td>
</tr>
<tr>
<td>Freshwater Fish</td>
<td>0.12</td>
<td>0.16</td>
<td>0.25</td>
</tr>
<tr>
<td>Tunas</td>
<td>0.12</td>
<td>0.16</td>
<td>0.25</td>
</tr>
<tr>
<td>Other Marine Fish</td>
<td>0.12</td>
<td>0.16</td>
<td>0.25</td>
</tr>
<tr>
<td>Crustaceans</td>
<td>0.12</td>
<td>0.16</td>
<td>0.25</td>
</tr>
<tr>
<td>Mollusces</td>
<td>0.12</td>
<td>0.16</td>
<td>0.25</td>
</tr>
</tbody>
</table>

It was possible to use the FAO food waste fractions (entered into the model framework) to work backwards from the amount of food eaten to determine the food produced to feed Melbourne at the farm-gate and subsequently, calculate the amount of post-consumer and processing food waste. Because the production module of the ASFF framework is based on data recorded at the farm-gate for both food production and resource use, the farm-gate food production amount could then be used to determine land and resource use and GHG emissions generated through food production (see Section 2.3). ASFF does not, however, include data or structure to directly calculate pre-farm gate losses, which is important not just to get an accurate estimation of total food waste, but also to determine the associated GHG emissions related to disposal of the waste.

For this reason, additional code was developed to work alongside the main ASFF framework to calculate an estimate of the edible portion of pre-farm gate waste. Since this study was concerned with quantifying only avoidable or edible food waste, the losses during refining are not intended to be included. Food amount data by food type was extracted from the model at the post-refined, pre-processed point (Figure 3). This data was then used with the FAO pre-farm gate waste fractions to calculate and estimate edible pre-farm gate waste according to the following equation:

\[ W_{PF} = W_{PF} \frac{P_{PFG}}{1 - W_{PF}} \]

where:

- \( W_{PF} \) = pre-farm gate waste amount (tonnes)
- \( W_{PF} \) = pre-farm gate waste fraction
- \( P_{PFG} \) = Edible food production at the farm gate (refined but not processed)
The amount of pre-farm gate waste calculated was added to the amounts of processing and post-consumer waste calculated previously to determine the overall amount of food waste generated to feed Melbourne.

2.3 Calculating environmental impacts of food consumption

As Australia is largely self-sufficient in food (PMSEIC, 2010), we assumed for the purposes of modelling environmental impacts that Melbourne’s food was sourced from within Australia. To determine the environmental impacts of food consumption now and in the future, this study used an existing ASFF scenario developed and documented by Turner et al. (2017) to simulate the impacts of climate change and land degradation on agricultural production. The core model of the ASFF calculates the total resources used by commodity for the agricultural sector at a national scale, including those required to produce exports. To determine the land, water and greenhouse gas emissions attributable to Melbourne’s food waste, it was necessary to calculate the proportion of overall agricultural production represented by food consumed in the city.

First a domestic consumption factor was calculated. Per capita food consumption, according to the diet profiles developed by Turner et al (2017) and including waste, was multiplied by the national population to get the total domestic food consumption by food type. This was then divided by the total production by food type to determine the domestic consumption factor. The domestic consumption factor was then multiplied by the proportion of the national population living in Melbourne for that year to determine a specific consumption factor for the city. The overall national agricultural resource-use quantities from ASFF were multiplied by the Melbourne consumption factor to determine the environmental impacts of food consumed in Melbourne.

The calculated environmental impacts of food consumption include the resources required and emissions generated in food production (including livestock farming, livestock feed and crops). Water figures take into account only irrigation water that is used to grow crops and animal feed as well as drinking water for animals, commonly referred to as ‘blue’ water. ‘Green’ water - the water that falls directly onto crops as rain - is not included because it is not tracked in Australia’s water accounts. Land figures include amount of land needed to grow the fruit, vegetables, grains and pulses that Melbourne eats, as well as the land on which livestock are raised for meat, dairy and eggs. It also includes the land used to grow feed for these animals.

GHG emissions figures include emissions associated with food production on farm only and emissions from food waste. Specifically, these are the emissions from enteric fermentation, cropping and fertilizer application, soil carbon loss due to grazing, and emissions from the use of farm machinery. An additional calculation was performed to determine the emissions generated from the disposal of food waste in landfill as this is not included in the ASFF framework but represents a significant proportion of food-related emissions. The total amount of food waste (in tonnes) was multiplied by a factor of 1.6, the emissions factor for food waste determined by the Department of Environment using the Australian Greenhouse Emissions Information System (AGEIS) (Department of the Environment, 2014).

They do not include the resources used in other parts of the food system such as food processing, distribution and household
preparation, because it is difficult to separate the proportion of resource use in the manufacturing and transport sectors that is attributable to food. For water and land this is not expected to have a considerable impact on the results, since these activities have a relatively small environmental impact. Food processing has a very small land footprint and other research indicates that water use in food processing in Australia represents less than 2% of the water used in agricultural production (Wallis et al., 2007). For these reasons and those mentioned earlier, the figures calculated in this study should be considered as a conservative estimate.

Along with the historical calibration process undertaken whenever the ASFF database is updated (see Turner et al. 2011 for more details), figures generated with ASFF about Melbourne’s foodprint in the scenario period were validated against external sources of data, such as industry and government reports, and data sets from the Australian Bureau of Statistics. Findings were also validated through expert consultation. This process was used to make further changes to modelling assumptions in ASFF.

2.4 Challenges and limitations of modelling methods

ASFF is a framework for evaluating environmental sustainability challenges in Australia and for modelling potential solutions. It was designed to explore these issues at a national scale, and over the long term. Care was required to adapt the model for use at a smaller geographic scale, or for exploring issues over the short to medium term. For example, as ASFF is designed to model trends over the long term, the effects of recent changes in trends (such as a recent slowing or acceleration of a trend) can be masked.

Although ASFF has considerable spatial detail, different types of data are modeled over different spatial regions. For example, agriculture is modeled over 58 statistical divisions across Australia, while water resources are modelled over 74 water regions and population across 217 sub-statistical divisions. At a national scale, these differences have little or no impact on the results of modelling. However, at a city region scale, considerable additional work is required to validate the results of the modelling.

ASFF is also a complex physical model, built for a high level of user input i.e. for a large team of researchers who can check and adjust input data across a wide range of areas. Considerable resources are required to ensure that key information pertaining to food systems is accurate and up-to-date. There are a number of areas where inputs required manipulation or where assumptions needed to be made in order to interface with ASFF. In other areas, data in the model was inappropriate for analysis at the city-region scale and required adjustments e.g. grazing areas for livestock are larger on average across Australia than they are in Melbourne’s foodbowl. At times, workarounds were developed outside ASFF to address data gaps or constraints related to the capacity of the framework. The resources required to use ASFF to its potential could make it difficult for small teams to use at a regional level.

3. Results and Discussion

3.1 Food produced for Melbourne

Greater Melbourne’s population of around 4.37 million requires around 15,080 tonnes of food to be produced each day (Figure 4), approximately 3.45 kilograms per person. This 3.45 kilograms is significantly more than the 1.2 kilograms of food physically eaten by the average Melbournian each day, as food is wasted throughout the food chain, and inedible parts are discarded.
By 2050, Melbourne’s population is likely to grow by at least an additional 2.63 million people to reach a population of around 7 million (Sheridan et al., 2015). If Melbournians eat the same diet as they currently consume, this population of 7 million will require around 24,132 tonnes of food per day.

3.2 Food Waste

Modelling results show that Melbourne currently generates a total of 907,537 tonnes of edible food waste each year, around 32% of edible food produced for the city. This is equivalent to 568 grams of food waste per capita per day, or 207 kg per person per year.

Around 41% (370,974 tonnes) is ‘post-consumer’ food waste generated by households and in restaurants and cafes, 24% is pre-farm gate waste (that occurs before food leaves the farm), and 35% occurs during food processing and distribution. The amounts of edible waste that occur at different stages in the food supply system are summarised in Table 2.

<table>
<thead>
<tr>
<th>Stage of food system</th>
<th>Food waste generated (tonnes/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-farm gate</td>
<td>217,287</td>
</tr>
<tr>
<td>Farm gate to checkout</td>
<td>319,276</td>
</tr>
<tr>
<td>Post-consumer</td>
<td>370,974</td>
</tr>
<tr>
<td>Total</td>
<td>907,537</td>
</tr>
</tbody>
</table>

Different types of food incur waste to differing degrees along the food chain. Figure 5 shows food waste distribution throughout the food system for each food type.
By 2050, with no change in consumption patterns or waste fractions, the volume of wasted food will rise to 1.4 million tonnes each year.

3.3 Land

Feeding Melbourne’s population of around 4.37 million people for one year takes around 16.3 million hectares of agricultural land. This area is equivalent in size to almost three-quarters of the area of the surrounding state of Victoria (ABS, 2012), but represents just 4% of Australia’s agricultural land (ABS, 2013b).

Different food groups have different land requirements (Figure 6). Vegetable production for Melbourne is responsible for just 0.1% of the city’s land foodprint, although vegetables make up 15% of Melburnians’ food needs. The vast majority of Melbourne’s land foodprint – around 90% - is related to beef and lamb consumption, although beef consumption makes up just 4% of the city’s diet. This is due to beef and lamb production systems in Australia, in which most animals graze on pasture over large areas of land at low stocking densities. Much of this land is unsuitable for other types of food production (Wiedemann et al., 2016).

![Figure 6 – Proportion of the land footprint attributed to different food groups in the typical Australian diet](image)

By 2050, when Melbourne has a population of around 7 million people, the land required to feed the city will have almost doubled to 32.3 million hectares (Figure 7). The city’s per capita land foodprint is likely to have increased from 3.8 hectares to around 4.6 hectares.

This 24% increase in the city’s per capita land foodprint is due primarily to land degradation and the impacts of climate change, so that more land will be required by 2050 to produce the same amount of food. When land is used intensively, the soil degrades (Turner et al., 2016). Raising more animals on a piece of land than it can naturally support also requires the use of fertilisers and other inputs to maintain productivity, and this increases over time.

![Figure 7 – Land required to feed Melbourne now and with a population of 7 million](image)
3.4 Water

To grow food for Melbourne’s population takes over 758,000 million litres of water per year (758 gigalitres). This is around double Melbourne’s household usage, which is approximately 376 gigalitres per year (Melbourne Water, 2015). It is equivalent to 475 litres per person per day or 173,375 litres per person per year.

As with land, different types of food require different amounts of water. For example, 18% of the average Melbournian’s diet is fruit (see Figure 1), but only 0.5% of the water used to grow their food is attributed to fruit (Figure 8). Three quarters of the typical Melbournian’s water foodprint is attributed to livestock products - 26.3% to beef and lamb and 53% to dairy products. More water is used to produce dairy products than red meat, because dairy production in Australia typically takes place on irrigated pastures, while most beef and lamb production takes place on dryland ranges and is rainfed (this ‘green water’ has not been included in our estimate of the water used to feed Melbourne).

![Figure 8](image1.png) – Proportion of water used to feed Melbourne by food group

When Melbourne grows to a population of around 7 million by 2050, approximately 1598 gigalitres of water will be needed per year to grow food for the city (Figure 9). This is around 627 L per person per day, a 32% increase on the amount of water currently required per capita to grow Melbourne’s food.

![Figure 9](image2.png) – Water required to feed Melbourne now and at a population of 7 million

More water is likely to be needed to grow each person’s food as a result of land degradation and the impacts of climate change. Due to land degradation, more land is likely to be required to produce the same amount of food (see section 3.4), and more water will need to be applied to irrigate that land. More irrigation water is also likely to need to be applied as the climate dries due to the impacts of climate change (Turral et al., 2011).
3.5 GHG emissions

Melbourne’s food consumption accounts for over 0.9 tonnes of GHG emissions per capita per year, which is 4.1 million tonnes in total for Melbourne. Around 58% of the GHG emissions associated with Melbourne’s food production are due to red meat production (beef and lamb), and a further 21% of emissions are associated with dairy production (Figure 10). This is mostly due to enteric emissions from ruminant livestock, the vast majority from cattle rather than sheep. This is a conservative estimate of emissions due to meat consumption. It assumes 14 kg per capita beef consumption per year. This figure was determined using the beef consumption estimate of 17.5 kg per capita in 2011, based on data from the aforementioned Australian Health Survey (ABS 2014), and a declining trend in beef consumption based on historical data in ASFF. However, industry sources estimate per capita beef consumption to be considerably higher (Meat and Livestock Australia, 2015). Other sources of emissions related to food production come from cropping and fertilizer application, soil carbon loss due to grazing, and emissions from the use of farm machinery.

![Figure 10](image1.png)

**Figure 10 – GHG emissions from Melbourne’s food consumption by food group**

As Melbourne’s population grows, GHG emissions due to food production will increase. By 2050, when Melbourne reaches a population of around 7 million, the city’s total GHG emissions due to food production are likely to increase to around 7.4 megatonnes (Figure 11). Per capita GHG emissions are also likely to increase around 13% to 1.1 tonnes. This projected increase in per capita emissions is due to an increase in the amount of land required to produce food, as a result of land degradation, and an increase in the number of livestock required to meet Melbourne’s meat needs, due to the impacts of climate change, including the effects of heat stress on livestock (Brown et al., 2016).

![Figure 11](image2.png)

**Figure 11 – GHG emissions from feeding Melbourne now and at a population of 7 million**

Melbourne’s food consumption also has a high energy footprint. This energy footprint considers only on farm fuel use. On farm fuel use to produce Melbourne’s total food consumption is around 114 megalitres per year. Most of this fuel use is associated with beef consumption, as a result of the fuel required to produce animal feed, primarily from the use of farm
machinery. Overall though, agriculture is responsible for a relatively small proportion of Australia’s energy use, accounting for just 1.7% of the nation’s industrial energy consumption (BREE, 2014).

4. Conclusions
A methodology was developed using the Australian Stocks and Flows Framework to estimate the environmental footprint – ‘foodprint’ – associated with feeding the city of Melbourne. The results showed that the resources required and waste and emissions generated were significant. Over 16.3 million hectares of land is required, an area equivalent to 72% of the state of Victoria, and 758 gigalitres of water, double Melbourne’s household usage. Around 907,537 tonnes of edible food waste is generated, equivalent to 32% of edible food produced for the city, showing that a sizeable portion of Melbourne’s environmental footprint is also due to food waste.

Around 4.1 million tonnes of GHG emissions are emitted in producing the city’s food, and a further 2.5 million tonnes from food waste (1.5 million from landfill and 1 million from producing the wasted food) The majority of the land, water, and energy required to feed Melbourne is due to meat and dairy consumption, as well as the majority of the GHG emissions generated from producing the city’s food.

Melbourne is likely to grow rapidly between now and 2050. Its population is predicted to increase by at least 60% to become a city of over 7 million people, with a significantly larger environmental footprint. This larger footprint is not only due to increased population, but also due to larger per capita foodprint based on impacts from land degradation and climate change. Supplies of the natural resources that underpin Melbourne’s food supply – including land, water, fossil fuels and phosphorous – will become more constrained in future. There is also likely to be increased pressure to reduce GHG emissions associated with food production and consumption. This suggests that changes to both food production methods and food consumption patterns will be required to ensure the security and sustainability of Melbourne’s food supply in the future.

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