A Framework for COVID-19 Pandemic Intervention Modelling and Analysis for Policy Formation Support in Botswana

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***Abstract* — The purpose of this research was to develop a methodological framework that could be applied for policy formation in situations having a high level of uncertainty and heterogeneity of existing opinions among involved stakeholders about risk mitigation and management such as COVID-19 pandemic risk. In this paper, we present such a framework and its application for policy decision-making in Botswana for mitigating the COVID-19 pandemic. The purpose of the proposed model is twofold: firstly, to supply decision-makers with reliable and usable epidemiologic modelling since measures to contain the spread of the COVID-19 virus were initially to a large extent based on various epidemiologic risk assessments. Secondly, given that some sets of measures adopted in other parts of the world were progressively imposing high or even very high social and economic costs on the countries which adopted these measures, we provided a multi-criteria decision support model which could be used in order to weigh different policy approaches to combat the virus spread taking into consideration local impact assessments across a variety of societal areas. We describe how the formulation of a national COVID-19 strategy and policy in Botswana in 2020 was aided by using ICT decision support models as a vital information source. Then we present the virus spread simulation model and its results which are connected to a multi-criteria decision support model. Finally, we discuss how the framework can be further developed for the needs of Botswana to optimise hazard management options in the case of handling COVID-19 and other pandemic scenarios. The significant research contribution is on advancing the research frontier regarding a methodology of including the heterogeneity of views and identification of compromise solutions in policy-relevant discourses under a high degree of uncertainty.**

***Keywords* — COVID-19; intervention modelling; simulation; multiple criteria decision analysis**

I. Introduction

Even though the first COVID-19 vaccines have been approved for emergency use since early 2021 in the developed world, and were approved for regular use in late 2021, there are still no clear predictions of how long the pandemic will last (with new mutations, such as the current, as of July 2022, dominating Omicron BA.4 and BA.5, emerging continuously) and when updated vaccines will be approved and available on markets globally. The short-, medium-, and long-term costs associated with extreme mitigation measures have become a matter of debate and discussion. Nowadays, such discussions constantly put pressure on countries and governments to relax their measures, regardless of the number of new COVID-19 cases.

These costs are enormous and associated with unemployment, low productivity in affected industries, limited trade and mobility, rising inequality, and increased risk of poverty as well as threats to food security and risk of hunger in a number of developing countries. For example, the closing of schools alone had adverse consequences including interrupted learning, gaps in childcare, high economic costs, and the risk of increasing dropout rates, among others.

For supporting the national policy formation in Botswana, a two-stage ICT model was employed. The first stage consisted of a virus spread model based on the available evidence on COVID-19 epidemiological factors, as well as some mitigation measures' impacts. The response measures to the pandemic had to be analysed at specific local levels, to be seen in relation to the demographic, social, and economic conditions and practices, healthcare systems capacity, and stakeholders 'needs. There are various possibilities to combine measures into strategies to see their different effects in reducing the rate of virus transmissibility which is discussed in Section 4. The second stage was a multi-criteria decision analysis model applied to the scenarios and mitigations generated during the first stage. These two stages combined made up the decision support model for policy formation.

The entire COVID-19 pandemic situation shows that mankind has been largely unprepared for it [1]. Quite obviously, there was no vaccine readily available at the onset, nor was there any real preparedness in terms of research as is done regularly for the seasonal flu [2]. Also, we did not have reliable information about critical measures to protect people from the virus and society from its spread or at least to reduce its exposure and vulnerability. Decision-makers had to operate under conditions of severe uncertainty about the case fatality rate, the spreading of the virus, the timing of infectiousness, and the number of asymptomatic cases – just to mention a few uncertainties [3]. A critical problem in assessing the risk is that the evidence about the case fatality rate is still contradictory because we do not know precisely the number of people who are infected, which is the denominator [4]. As a result of this and many other "known and unknown" factors in the COVID-19 outbreak [5], public

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authorities had to make decisions based on "quantitative evidence" and expert scientific advice. These include advice on possible future scenarios, on assessment of the sanitary system carrying capacity (especially of intensive care units), on expected public adoption of more or less restrictive measures, and on the evolution of national public debates about the issue [6].

Under conditions of large uncertainty connected with the handling of the COVID-19 pandemic, several cognitive and behavioural biases might have played a role in the decision-making processes. These biases are connected with risk perceptions under conditions of ambiguity [7]. Behavioural economics count more than 180 various biases. We assume that the following biases might have been relevant regarding the perception of the pandemic emergency situations such as the availability cascade [8], i.e., individuals adopt a new insight since other people have adopted it, and then there is also the availability heuristic, the mixture of frequency and the ease with which examples come to mind [9]. There are bandwagon effects and information cascades, where the individual adoption is strongly correlated to the proportion of people who have already adopted an idea, combined with an enormous amount of available information [10], base rate fallacy [11], probability neglects [12], exaggerated expectations, framing [13], group thinking in general [14], and many others. An obvious component is also the problem with bounded rationality in which individuals are restricted regarding their willingness to collect information and are unable to identify a perceived optimal solution. As a response, they make decisions only after they have significantly simplified the decision space, and must therefore be content with a certain (again perceived) acceptable level of performance. They search in this sense for a satisfactory solution, but they focus only on a limited set of options from available alternatives [15–16]. In case of this bias, there is still a perceived rational claim that the benefits of time-saving will overshadow the costs of any potential reduction in the quality of the decision. While comparing actions of disaster risk reduction, there is also the issue of representativeness heuristics, when representativeness is defined as the degree to which an event is similar in essential characteristics to its parent population. and reflects the salient features of the process by which it is generated [17].

An example of how biases influence the decision-making processes could be the difference in perceptions of the Asian and Western disaster risk reduction authorities. Previous experiences, such as the SARS endemic or seasonal flu, influenced perceptions of COVID-19 as being lethal. Many Asians perceived the COVID-19 risk as being deadlier because of the SARS epidemic, which the region experienced recently. At the same time, the EU disaster risk reduction authorities first perceived COVID-19 as less deadly because of the frequent experiences with the seasonal flu. This shows the influence of representativeness and availability heuristics, as well as of anchoring bias, which is known mainly in relation to negotiation processes. Then there is an unavoidable component of dread risk [18] (compare, e.g., with hazardous technologies) connected with the judgments of people about unknown risks and their "*perceived lack of control, dread, catastrophic potential, fatal consequences, and the inequitable distribution of risks and benefits*" [19].

Risk perceptions, influenced by biases, affect decisions regarding risk mitigation and management, including precautionary measures. The types of precautionary measures that can be enacted by countries at different points in time, depending on the severity of a situation, include: advice to adopt individual hygienic/precautionary measures, limiting large events/mass gatherings, limiting medium events, closing/reducing the opening time of economic activities (restaurants, bars), closing schools and/or universities, adopting border restrictions, adopting travel restrictions, domestic lockdowns, and compulsory quarantine controlled by the military. These measures are progressively limiting more and more of the individual freedoms and have progressively higher economic and societal costs, undertaken with the aim of preserving citizen health.

In their decisions on which measures to enact, many countries acted in an apparently uncoordinated manner, at least at the beginning of the pandemic spread. Even if it is clear that COVID-19 does not respect national borders, the measures undertaken by bordering countries have been partially inconsistent. For example, the decision to close or not to close children's primary care facilities (e.g. kindergarten) has been justified with completely different logic and rationalities. As of March 13, 2020, Switzerland activated a "state of necessity" and Italy was already in a "state of emergency". This means that Italy was at a higher level on the risk evaluation ladder. Notably, the two countries share a border and the Region Lombardy (the most affected area in Italy) is bordering with the Swiss Canton Ticino. On March 13, 2020, Switzerland [20] decided not to close kindergartens to protect the most vulnerable groups of the population (namely the elderly/grandparents), who would otherwise be in charge of taking care of the children. A few kilometres away in Northern Italy, the kindergartens were closed, for the exact same reason: to protect the most vulnerable [21]. Austria and Switzerland also share borders and have a similar population size (8.8 million in Austria and 8.5 million in Switzerland). On Sunday, March 15, 2020, Austria activated a state of emergency and decided on domestic lockdown, with 800 confirmed COVID-19 cases. On the same day, Switzerland had 2,300 confirmed cases but much lower levels of restrictions [22]. In (non-neighbouring) Albania, a lockdown was decided on the same day, with 40 confirmed cases and one death in Tirana. Decisions on whether or not to impose lockdowns were not taken only based on the number of confirmed cases, and the effects of these inconsistencies in decision-making are to a large extent unforeseeable.

The analysis of public responses is a difficult topic for multiple reasons including constant changes in national policy measures over time and a lack of clarity about the drivers of those changes. In other words, rationalities and justifications have been clearly changing, moving, e.g., from "no panic" to "balancing health and economic aspects" to "health first" depending on the number of cases and several other factors (most of them unknown). When do countries decide to enact the aforementioned progressive measures? How do they take into consideration the economic side-effects of mortality, for instance [23], given that the pandemic economic situation is comparable to or even worse than the 2008 financial crisis [24]? For how long can countries sustain skyrocketing levels of unemployment? There are large sacrifices in direct and indirect capital and GDP per life saved (and especially life-years saved) which could lead to unbearable financial consequences for a long time to come.

Instead of making decisions in a state of panic, a rational analysis should be employed which takes into consideration the actual risks compared with each other. If the risks are indeed high and underestimated by some public authorities, then the typical first priority considered when deciding is moral justice. The obligation, in this case, would be to protect the elderly, the most vulnerable, and the only way to do that is to limit other people's exposure as much as possible. However, without a clear estimation of the risk associated with the SARS-CoV-2 outbreak, there is no indication that this would be the best measure to be adopted by public authorities in their respective countries, not the least because the consequences are unknown and public reactions to unanticipated costs can appear. Measures need to adequately estimate how much it would cost to reduce the risk and to what extent they can reduce it. Measures need to take into consideration the individual perception and behaviour in the wake of risk, the factors which can influence the said perception including media reports and framing, as well as the emotions stirred by representations and by the level of uncertainty.

II. Background to Botswana's response to the COVID-19 pandemic

There are various population and health systems issues that are specific to Sub-Saharan Africa concerning COVID-19. First, the demographic structure is different from the rest of the world. The median age of the population is 19.7 years compared to 38.4 in China and 43.1 in Europe. Early experiences from Asia and Europe showed that people over 60 years of age and those with significant health problems were the most vulnerable to COVID-19. Although Africa's relative youth may have been considered a protective factor, the precise trajectory of how the epidemic would evolve was unclear at the time of modelling. The second factor that had to be taken into consideration was the high prevalence of HIV, TB, malnutrition, and anaemia. There were some indications that last year's peak of malaria and COVID-19 could have coincided. HIV, TB, Malaria, malnutrition, and anaemia are likely to increase the severity when contracting COVID-19. Thirdly, the measures of social distancing may not be easy to impose in Africa. Weekly attendance of religious services among adults is over 80% in some African countries. For example, Senegal had protests when visits to mosques were banned while conversely, Tanzania came under scrutiny when it was announced that places of worship would not be closed.

Another important fact that reflects the response to COVID-19 is that in addition to the burden of infectious diseases like HIV, TB, and malaria, Africa is facing the burden of non-communicable diseases such as diabetes, hypertension, cardiovascular and renal diseases as well as cancer and severe accidents. As a result, already stretched health systems did not have the possibility to handle the burden of COVID-19 as well. The capacity of both medical personnel and material is the lowest in the world. The ratio of medical doctors and nurses per 10,000 inhabitants is less than five in the majority of African countries, which is far below the ratio in developed countries. The capacity to treat critically ill patients with multi-organ failures has posed a challenge to many developed countries. The number of ICU beds and ventilators, as well as the possibilities for renal replacement therapy, is among the major challenges for most of the countries affected by the SARS-CoV-2 virus. Ongoing issues with insufficient numbers of health workers who in the midst of the fight with COVID-19 were exposed to the infection and eventually became victims of the virus, together with a lack of adequate PPE, have made headlines all over the world.

A. COVID-19 impact on Sub-Saharan Africa – with a focus on Botswana

There is a need to reorganise and prioritise health systems in order to increase the critical care capacity focusing on good triage and keeping scarce ICU beds only for critical cases. Most Sub-Saharan countries are having the same challenges when it comes to health systems. Botswana, despite being among the fastest-growing African economies, is sharing the same problems as other countries in the region. Ever since it gained independence in 1966, Botswana has had exponential growth mainly based on revenue from the mining industry but also from tourism and meat production. In the past few years, it became clear that there is a great need to diversify the economy and stimulate local production in order to create more jobs and reduce dependence on its neighbours, mainly South Africa. Another challenge Botswana has is a scarce population of just over 2 million and a huge territory the size of France or Texas. Some parts of Botswana that belong to the Kgalagadi desert have a very low population density, less than 10 per km^2.

Since the early nineties, Botswana has been fighting the HIV/AIDS epidemic. In 2000, it has been officially declared that Botswana is among the countries that have the highest prevalence of HIV in the world. Life expectancy has dropped from 57 to 36 years. This has forced the government to virtually declare war on the epidemic and start offering ARV treatment to all citizens and non-citizens in need. Ever since the government got involved in ARV treatment, it became a success story for the whole continent. The burden of the HIV epidemic has mobilised a lot of human and material resources.

The early onset of the COVID-19 epidemic did not bypass Botswana entirely. The first three cases were detected at the end of March 2020 and consisted of citizens who had travelled to UK and Thailand. Immediately after the detection of the first cases, vigorous contact tracing started which resulted in further detection of new cases with local transmission. One month later, on April 27, 2020, there were 22 cases with one case of death of an elderly lady with other comorbidities.

Closely following the situation in neighbouring countries like South Africa, where at the beginning of March 2020 there were several hundreds of patients including local transmissions, the Botswana government decided to take similar radical steps and locked down the country on April 2, 2020 (using constitutional emergency powers). The borders were closed and people coming from outside were quarantined. Strict measures of social distancing, restriction of movements, hand hygiene, and sanitising were introduced. Only essential services were functioning.

The situation in the late spring of 2020 was as follows: Facing a prolonged period of isolation, the inability to travel and to live a social life for people who have many ties with families in rural areas, would have been taking its toll and causing serious psycho-social problems. The economy would have been deeply affected with most of the businesses closed down and many workers being retrenched. The government introduced measures of social support and food baskets for families in need. Banks had given breaks for loan repayments and owners eased on lease agreements. Despite all these measures, the economy had been affected and there was rising concern about what would happen in the long run. In this situation, a decision was made to try to model the virus spread and societal effects from various mitigation strategies.

In essence, Botswana, like other Sub-Saharan countries, has had its own fair share of pre-existing socio-economic and health system issues that have been straining an already stretched health system. However, keeping in mind a lack of ICU beds, skilled personnel, and resources, there was and still is a fear that things can get out of hand. The inability to treat very sick patients with multi-organ failures remains a large problem that is common even in developed countries. Like in other developing countries, the consensus is that the focus should be on prevention through social distancing, hand hygiene, and restriction of movement.

Initially, it seemed that the measures of lockdown were working. However, the government, through the Taskforce team formed by the President, immediately started working on public health measures that were meant to control and curb the epidemic. Up until June 24, 2020, there were fewer than 100 confirmed cases and only one confirmed death. The first pandemic wave was essentially bypassed by Botswana. During the autumn of 2020, the numbers started to rise with 14,025 confirmed cases at the end of the year and 40 reported deaths. Fear was expressed that the epidemic would go out of hand, especially looking at the experience of other countries. Other diseases like HIV, TB, and malaria have been flaring especially in the North-East part of the country and have been straining the health system. A lack of ICU beds, ventilators, and machines for renal replacement has been worrisome for all sectors of society. In 2021, especially the third pandemic wave has taken its toll on Botswana. The sharpest rise in reported cases was between mid-July and mid-August with over 50,000 new cases reported during that 30-day period and with a sharp rise in reported virus-related deaths following the period. In November 2021, there was a plateau after the third wave with a total of around 190,000 reported cases and 2,400 deaths. This is in relation to a total population of 2.35 million in the country.

B. Assessing COVID-19 impact in Botswana

A proportionate response to the risk situation needs to take into consideration the social and economic impacts as well, which may be unprecedented, as estimated by the Southern African Development Community (SADC), due to financial and healthcare system limitations. Multiple factors and stakeholders need to be included in opting for a set of measures.

The Africa Center for Strategic Studies had estimated for Botswana a risk factor of 18 for the spread of COVID-19, which was among the lowest on the continent (the factor ranged from 37 for South Sudan down to 13–16 for some island nations) [25]. This risk factor resulted from mapping the relative levels of vulnerability considering a country's international exposure, its public health system, the density and total population of urban areas, the population age, the level of government transparency, press freedom, conflict magnitude, and forced displacement, concluding that *"with early identification and isolation of cases, [it] may be better able to minimise the worst effects of this pandemic"*. Elsewhere [26], it was estimated that Botswana was among the countries with a non-negligible risk, exposed exclusively to the potential risk from airports in the Fujian province; since then, however, in April 2020, the first community transmitted cases were registered. Furthermore, the World Health Organization estimated the country's readiness status in February 2020 as being "adequate" [27] and in a situation update for the WHO African Region, it was recommended for countries with under 100 confirmed infections that *"measures to contain or at least delay the spread of the outbreak need to be intensified; including active case finding, testing and isolation of cases, contact tracing, physical distancing and promotion of good personal hygiene practices"* [28]. For other African countries, other analyses have suggested more severe measures, such as for instance the London School of Hygiene & Tropical Medicine (LSHTM) recommending for Nigeria a strategy that would combine the above WHO measures *with "lockdowns of two months' duration, where socio-economically feasible"* [29] to delay the epidemic and gain time for planning and resource mobilisation.

The effects of a lockdown compared to other mitigation measures were unclear; in South Africa, for instance, it was noticeable that its epidemic trajectory had started to flatten before the lockdown effects came into place, but it was to be determined whether the slowed rate of infections was due to lower testing, missing cases in poorer communities or travel and public gatherings restrictions put in place before the lockdown. It has been argued [30] that given the lack of certainty about the effectiveness of a lockdown at specific local levels, direct involvement of the local communities in African countries in the decision over measures would be desirable, as they can provide the needed contextual knowledge and specific issues which must be included so as to preserve basic livelihoods through the chosen local strategy.

The measures initially taken in Botswana were implementing a suppression strategy, in a fashion similar to other countries. On April 2, 2020, the President declared a state of emergency and a national lockdown. This was described as a *"mass quarantine strategy for suppressing or mitigating"* the epidemic, with extreme social distancing imposed, including closing borders, closing schools and universities, suspension of public gatherings of more than 10 people, suspension of public transport services including long-distance buses and trains, and restricted movement. As complementary measures, the government also announced plans for both enhancing community testing and introducing an electronic permit application for contact tracing. There were a few immediately visible effects of the lockdown, aside from the epidemiological ones. On the downside, industry sectors were affected to an extent that was difficult to estimate, for instance, triggering a COVID-19 Pandemic Relief Fund with a capitalisation of two billion Pula from the government [31]. This was to be distributed according to four strategic objectives: for wage subsidies for business sectors with a few exceptions for the industries which continue their activity, for stabilising businesses by offering, for instance, government loan guarantees and making tax concessions, then for ensuring strategic reserves and for promoting opportunities for the sectors which can upscale their local production. The educational system was also highly affected, as the Ministry of Basic Education signalled. It was estimated that learners might find themselves in the situation of repeating their classes in 2021–2022. The closure of schools is making the duration of the current school year insufficient to meet the minimum requirements for the number of school days in a school year.

Botswana could have had possible advantages in the local demographics and population distribution, as mentioned above. The population of the country is relatively young. As evidence from other countries shows, the most severe COVID-19 cases are among the elderly groups of the population. Due to the demographic situation in Botswana, the total mortality rate in this country could be lower than in China or Western Europe. The population density in Botswana is also lower than in Europe or China. But the healthcare system was insufficiently prepared to provide the necessary equipment and care. It was estimated that Botswana has approximately 100 ICU fully equipped beds and 2,000 overall available hospital beds. There are also associated comorbidities such as malaria, HIV/AIDS, and tuberculosis which can influence the number of potentially severe cases.

Each alternative of a set of COVID-19 risk mitigation measures has implications for socioeconomic development in the country. Therefore, the needs of various social groups and stakeholders should be considered while drafting policy measures and action plans for future pandemic risk mitigation and management. As the evidence on current pandemic risk management shows, there has been an astonishing lack of coordinated actions. Also, no vision was developed for handling a similar or even a more serious event in the future. There are no entirely value-neutral policy plans. Opting for the most popular vision and choosing a seemingly reasonable path ultimately requires tackling medical and financial considerations, as well as differing societal preferences together, rather than as separate issues. Understanding of preferences from various stakeholder groups such as policymakers, industry, young community, civil society, and academia, contributes significantly to social acceptance of risk mitigation measures. Guided by the hypothesis that contributions to such a development and preferences amongst societal stakeholders are just as important as medical or regulatory issues, a complete decision support model should address benefits and costs, perceptions and preferences, potentially arising conflicts between stakeholder groups and political requirements of different mitigation pathways.

III. Available measures

The measures to contain the spread of the COVID-19 virus have been largely based on various epidemiologic risk assessments, which were made primarily by centres of disease control and prevention in Europe and the US, and by the World Health Organization. These assessments established scenarios starting from the number of confirmed infections in a country, with every scenario having a series of recommendations on containment measures to use in order to limit the spread of the virus. Aside from the increased healthcare and treatment efficiency efforts, these non-pharmaceutical interventions are layered progressively, starting from more low-cost measures to isolating individuals confirmed positive with the virus to, eventually, more invasive and costly social distancing measures. Countries have taken different approaches as to which set of measures to introduce and when. Some countries, such as Japan, did initially mainly focus on contact tracing and testing, recommending people restrict their travels and teach and work from home. Sweden chose to cancel public events and restrict public transport but did not close primary schools or workplaces while recommending people to keep a social distance. South Korea had a similar approach, but with a more intensive contact tracing using digital systems. Interestingly, Taiwan, in spite of its proximity to China, had one of the lowest stringency levels [32] since they did not close down schools, workplaces, or public transport, and did mostly focus on tracing and isolating measures. Taiwan's experience with the 2003 SARS epidemic could account for a series of quick decisions involving traveller screening, wide distribution of masks, hand sanitizers, and thermometers [33], as well as investing approx. USD 6.8 million into the manufacturing sector to create 60 new mask production lines.

However, there was a dominant approach that seems to have been preferred by several countries including Romania, Austria, Denmark, Norway, Germany, Italy, and many others. This approach adopted extreme social distancing measures going from case quarantine and public gathering bans to partial lockdowns. Furthermore, the approach included closing schools, public transport, and many workplaces, only allowing people to leave their homes for specific purposes, with a tighter curfew imposed on the elderly. These measures have been defended for their short-term capacity to reduce the rate of transmissibility and to flatten the epidemic curve as much as possible in order to primarily keep the hospital systems from getting overburdened.

There are several challenges with modelling the effects of risk mitigation measures. One challenge is connected with epidemiologic models which do not take into consideration demographics, distribution of population, age groups, and their interaction patterns, such as the classic SEIR model. Furthermore, there is limited evidence included in currently used models [6] on how each measure reduces the rate of transmissibility.

It has already been argued that *"the incremental effect of adding another restrictive measure is only minimal and must be contrasted with the unintended negative effects that accompany it"* [34]. We begin to know more about some measures' effectiveness. For instance, combining case quarantine with other public health measures is shown to be more effective than only relying on case quarantine. There is also some evidence that wearing masks [35] reduces transmissibility and is most effective when compliance is high, at the same time substantially reducing both the death toll and the economic impact. Wearing them at a rate of 96% could alone flatten an epidemic growing at a rate of 0.3/day by bringing down the R factor (virus reproduction) from an original value of 3.68 to 1.00 or less. When combined with contact tracing, the two effects multiply positively [36]. But what about other measures? How effective is it to close schools or borders, or to restrict certain workplace activities? How much can a country build up its healthcare system during the restriction period? There is no meaning in restricting businesses if corresponding measures are not taken. In this case, the costs of lockdowns could be much higher than the costs of taking less extreme suppression measures.

Since there are no clear predictions of how long the pandemic will last and when vaccines will be approved and available on markets globally. The societal costs associated with these extreme measures have become a matter of debate and discussion. These costs are enormous, associated with unemployment, low productivity in affected industries, limited trade and mobility, rising inequality, and increased risk of poverty as well as threats to food security and risk of hunger in a number of developing countries. However, few countries base their decisions to adopt a set of measures on adequate economic simulations, and the macro-level projections made by the IMF [37] and OECD [38] estimate that the lockdowns will affect one-third of the developed countries' GDPs. This makes economic mitigation approximate at best and vulnerable to the many unknown side-effects which might not be possible to model at a country level.

The response measures to the pandemic have to be analysed at specific local levels, to be seen in relation to the demographic, social, and economic conditions and practices, healthcare systems capacity, and stakeholder needs. Botswana's early suppression was an advantage from this point of view, as its low numbers of infections and deaths make way for a variety of pandemic hazard scenarios that can be considered for the future. There are various possibilities to combine measures so as to see their different effects in reducing the rate of transmissibility, while also looking at their different consequences under other criteria, including indirect deaths in different groups, inhibited work capacity in the short and long term, social costs, fear, democracy, and human rights aspects.

IV. Framework description

Initially, the prognoses used estimation-prediction methods such as spread models. Then time calibration was done using the observed number of case fatalities and estimates of the time between infection to death and infection fatality risk. The assumptions which serve as a basis for predictions are that there is no change in behaviour and that preventive measures were put in place at one specific point in time. It is also assumed that the overall effect of preventive measures is known. The effects are estimated from the observed increased doubling time after preventive measures are put in place. The predictions are highly sensitive to the doubling times without and with preventive measures, sensitive to the basic reproduction number R0 but less sensitive to the estimates used for time-calibration: observed number of case fatalities, the typical time between infection and death, and the infection fatality risk [39].

A more complete framework could include more phases than the scenario generation using strategies that will constitute the basis for an initial analysis, which was the focus of the work discussed in this paper, where we applied varieties of the SEIR model for modelling the effects of various risk mitigation measures. Other activities could consider other criteria and a more complete multi-criteria decision analysis (MCDA) methodology to identify the preferences of various stakeholder groups. The stakeholders' preferences should then be collected with the help of focus group discussions and decision-making experiments.

Another important issue is to validate the results and develop policy recommendations through various methods of participatory governance. This could include key informant interviews (face-to-face or telephone), in collaboration with local actors, to collect a set of narratives from relevant stakeholders (developers, public, and public authorities at a local scale, local experts, NGOs, as well as enterprises). Using qualitative data analysis software, such as NVivo and Atlas.ti, we could analyse the narratives to identify dominant and oppressed discourses in both sectors. Applying the lens of the theory of plural rationalities, we could identify differences in view about the COVID-19 issues in Botswana, as well as areas of conflict. The interviews and a literature review help to adjust the weights and the valuations and to have a more thorough discussion regarding the preferences and input data in the model.

A. A SEIR model for Botswana

In epidemiology, so-called SEIR (or SIR) models are very commonly used to represent the spread of disease in a population. Based on our review of comparative studies of various simulation models [63], and our conclusions of the available measures within the Botswana context described in section III, we opted to use the SEIR model. The SEIR model provided the necessary flexibility to assess spread including the selection bias in testing, which can contribute towards a better accuracy on unreported cases that in turn established the necessary projections for measures on the untested infectious part of the population. Furthermore, the SEIR model with its visualisation and modelling extensions has been used in several countries and states that have similar socio-economic environments and health care systems to Botswana.

The population is divided into three (or four) compartments; susceptible (S), exposed (E), infected (I), and recovered (R), and in some models also dead (D). In these models, a system of coupled differential equations governs the flows between the different compartments over time, people becoming infected move from S to I and people who recover (or die) move from I to R. System Dynamics is a natural choice for implementing models simulating transmission processes, since the methodology presupposes a holistic approach and focuses on how the parts in the system affect each other with reinforcing or balancing feedback loops [40–41]). A common SEIR model operates on the following parameters: individual mortality; disease spread rate; recovery rate and the mean infection time, rate of movement from the exposed class to the infectious class and the mean latency period, and the basic reproduction R0 [42].

To model an age-specific spread of COVID-19 in the population, the four compartments (S, E, I, and R) are divided into three age groups 0–14 year old, 15–64 year old, and 65+ year old. These age groups are then further divided into a non-risk group and a risk group.

The transmission rate of the virus is governed by a time-dependent infectiousness (seasonality), age-group specific infectivity, a severity-specific reduction (undetected, mild, severe, and critical) of infectivity, an age-group specific 3x3 contact matrix, and two physical distancing measures: quarantine and contact reduction. The seasonality of the virus reflects that the virus is more infectious during a specified period. The seasonality is based on three parameters: the period, peak day (the day of the year with the highest infectiousness), and the amplitude of the seasonality. See Fig. 1 for an overview of the model and its parameters.

During planning for intervention measures against outbreaks of pandemics, various computer-based support tools are commonly used. For instance, in Sweden, the National Board of Health and Welfare has supported research and development of a decision support tool to complement the individual-based, total population model MicroSim [43]. The primary requirements for tools of this kind were that they should support scenario analysis, i.e. to run "what-if" experiments and that the tools should be implemented quickly and be easy to adapt. During the latter decade, various simulation environments have emerged, such as AnyLogic, enabling swift usage of generic SEIR modelling which has been employed in some recent studies, including studies of the Corona SARS-CoV-2, MERS, and the Zika virus [44–45].

There are several studies investigating specific performance aspects of interventions against pandemics but they are most often limited to a single scenario, as well as seldom being designed to explicitly acknowledge the inherent uncertainties in both simulation results and scenario likelihoods. We have previously applied a dynamic multi-criteria decision analysis approach to synthesise outcome predictions from multiple models and explicitly elicit and imbed stakeholder preferences into decision recommendations [46]. Utilising such an approach, dynamic, comprehensive, and transparent decision-making is supported.

For the epidemiologic model adjusted to Botswana's case, the input data requires the following country-specific information:

1. Population size in country/region/city divided into age groups.
2. Households, age distribution, health sector capacity.
3. Morbidity in the population per age group (for instance presence of risk factors in each age group).
4. Number of confirmed cases per day, divided per age group and case severity (like intensive care and hospitalisation).
5. Number of tested people, number of positive cases, and deaths from COVID-19.
6. For increased granularity, number of average contacts (with other people) per day for each age group and with other age groups (for instance, school kids mostly interact with other school kids).
7. Current medical system capacity (no. of ICU beds, ventilators, medication, testing capacity) and estimated ability to increase it (how much and in what timeframe).
8. Population access to personal hygiene, including water, soap, disinfectants, and face masks.

We could, e.g., consider one of three alternative sets of measures to contain the spread of the SARS-CoV-2 virus, as they had at the time of this modelling been (1) already implemented by countries, as described above in the Available measures section and monitored by the Oxford COVID-19 Government Response Tracker (OxCGRT) [47] (2) modelled by the Imperial College London team of Ferguson et al. [6] and (3) modelled in other African countries. After the data collection phase, it should be established which set of measures could be applied, considering the available level of specificity for each set, as well as Botswana's characteristics and capacity. For instance, a measure aiming to reduce the elders' social contact might not be effective in protecting the vulnerable categories in Botswana, as the population is generally younger than in the UK or Italy. A measure relying on the extensive use of face masks again depends on the availability of such on the market and on the country's capacity to invest in their rapid production, as well as on their affordability once they are on the market. A realistic set of measures should of course be chosen for an integrated model.

Therefore, the alternative sets of measures considered are the following:

Measure set (1):

- **Level 1**: Only pharmaceutical measures and case isolation
- **Level 2**: Measures from level 1 and personal protective measures (stay home when sick, wash hands, observe prudent respiratory etiquette, clean frequently touched surfaces daily, use face masks), mild social distancing measures (large public gatherings banned, work from home where possible, social distancing recommended, possible social network-based distancing strategies [48])
- **Level 3**: Measures from level 2, but with social distancing imposed, including a partial lockdown – schools, universities, restaurants and large shopping centres are closed. People can still go out for their basic necessities, work, use public transport – partial lockdown (based on Austrian and Romanian models) [49]
- **Level 4**: Full lockdown, when everything is closed and people are not allowed to go out or are not allowed to go out after a certain time of the day, such as having a curfew after 6 pm (based on models from some cities in Romania and Russia as well as in Jordan)

Measure set (2) [50]*:*

- **Level 1**: An unmitigated epidemic – a scenario in which no action is taken.
- **Level 2**: Mitigation including population-level social distancing –aiming at a uniform reduction in the rate at which individuals contact one another, short of complete suppression.
- **Level 3**: Mitigation including enhanced social distancing of the elderly – as Level 2 but with individuals aged 70 years old and above reducing their social contact rates by 60%.
- **Level 4**: Suppression – exploring different epidemiological triggers (deaths per 100,000 inhabitants) for the implementation of wide-scale intensive social distancing (modelled as a 75% reduction in interpersonal contact rates) with the aim to rapidly suppress transmission and minimise near-term cases and deaths.

Measure set (3):

- **Level 1**: *Sectors permitted*: all sectors open. Transport restrictions: all modes of transport allowed, with stringent hygiene conditions in place. *Movement restrictions:* interprovincial movement allowed, with restrictions on international travel.
- **Level 2**: *Sectors permitted*: construction, all other retail, all other manufacturing, mining, all other government services, installation, repairs and maintenance, domestic work and cleaning services, and informal waste-pickers. *Transport restrictions*: domestic air travel restored, car rental services restored. *Movement restrictions*: movement between provinces at Level 1 restrictions.

- **Level 3**: *Sectors permitted*: licensing and permitting services, deeds offices and other government services designated by the Minister of Public Service and Administration, take-away restaurants and online food delivery, retail within restricted hours, clothing retail, hardware stores, stationery, personal electronics, and office equipment production and retail, books, and educational products, e-commerce and delivery services, clothing and textiles manufacturing (at 50% capacity), automotive manufacturing, chemicals, bottling, cement and steel, machinery and equipment, Global Business Services, construction, and maintenance. *Transport restrictions*: Bus services, taxi services, e-hailing, and private motor vehicles may operate at all times of the day, with limitations on vehicle capacity and stringent hygiene requirements, Limited passenger rail restored, with stringent hygiene conditions in place, Limited domestic air travel, with a restriction on the number of flights per day and authorisation based on the reason for travel. *Movement restrictions*: No inter-provincial movement of people, except for transportation of goods under exceptional circumstances (e.g. funerals).
- **Level 4**: *Sectors permitted*: all essential services, plus Food retail stores already permitted to be open permitted may sell a full line of products within the existing stock, All agriculture (horticulture, export agriculture including wool and wine, floriculture and horticulture, and related processing), Forestry, Pulp and Paper, Mining (open cast mines at 100% capacity, all other mines at 50%), All financial and professional services, Global business services for export markets, Postal and telecommunications services, Fibre optic and IT services, Formal waste recycling (glass, plastic, paper and metal). *Transport restrictions*: Bus services, taxi services, e-hailing and private motor vehicles may operate at all times of the day, with limitations on vehicle capacity and stringent hygiene requirements. *Movement restrictions*: No inter-provincial movement of people, except for transportation of goods under exceptional circumstances (e.g. funerals).
- **Level 5**: *Sectors permitted*: Only essential services. *Transport restrictions*: Bus services, taxi services, e-hailing and private motor vehicles may operate at restricted times, with limitations on vehicle capacity and stringent hygiene requirements. *Movement restrictions*: No inter-provincial movement of people, except for transportation of goods under exceptional circumstances (such as funerals).

B. *Results from the SEIR model*

It should be emphasised that the model we have used in this framework is quite simple despite there being a large number of models around. There are nevertheless strong reasons to keep as much as possible as simple as possible. The more input parameters we have, the more diffuse everything becomes if we cannot make them local due to the already enormous state space. The big challenge here is rather to get the input data realistic since there are still many critical uncertainties with COVID-19 and models with higher complexity than the training and validation data should be used very sparingly as decision bases. In the example simulation (in AnyLogic 8) below, the input parameters were the following (see Fig. 1):

- Infected (days): Number of days an individual is infected and infectious.
- Exposed (days): Number of days between an individual gets infected and becomes infectious.
- Infectivity 0–14: A parameter used to calibrate the risk of people in age group 0–14 getting infected.
- Infectivity 15–64: A parameter used to calibrate the risk of people in age group 15–64 getting infected.
- Infectivity 65+: A parameter used to calibrate the risk of people in age group 65+ getting infected.
- Amplitude: The amplitude of the seasonality.
- Peak day: The day with the highest infectiousness during the year (in days from January 1) [51].
- Infectivity (% of infectiousness)
- The reduction in % of infectiousness for undetected, mild, severe, and critical cases.
- Population: The total population.
- % of the total population
- 0–14: Age group 0–14's share of the total population.
- 15–64: Age group 15–64's share of the total population.
- 65+: Age group 65+'s share of the total population.
- 0–14 RG: The share of people in the age group 0–14 who belong to a risk group.
- 15–64 RG: The share of people in the age group 15–64 who belong to a risk group.
- 65+ RG: The share of people in the age group 65+ who belong to a risk group.
- Quarantine (% of days infected)
- The % of the infected period for undetected, mild, severe, or a critical case in quarantine.
- Severity profile
  - The share of each age group who are undetected, mild, severe, or critically infected. Period (1 or 2): Checkbox used to enable the policy.
  - Year (2020 or 2021): The year the policy should be enabled. Start day: The start day of the policy (day of the year).
  - End day: The end day of the policy (day of the year).

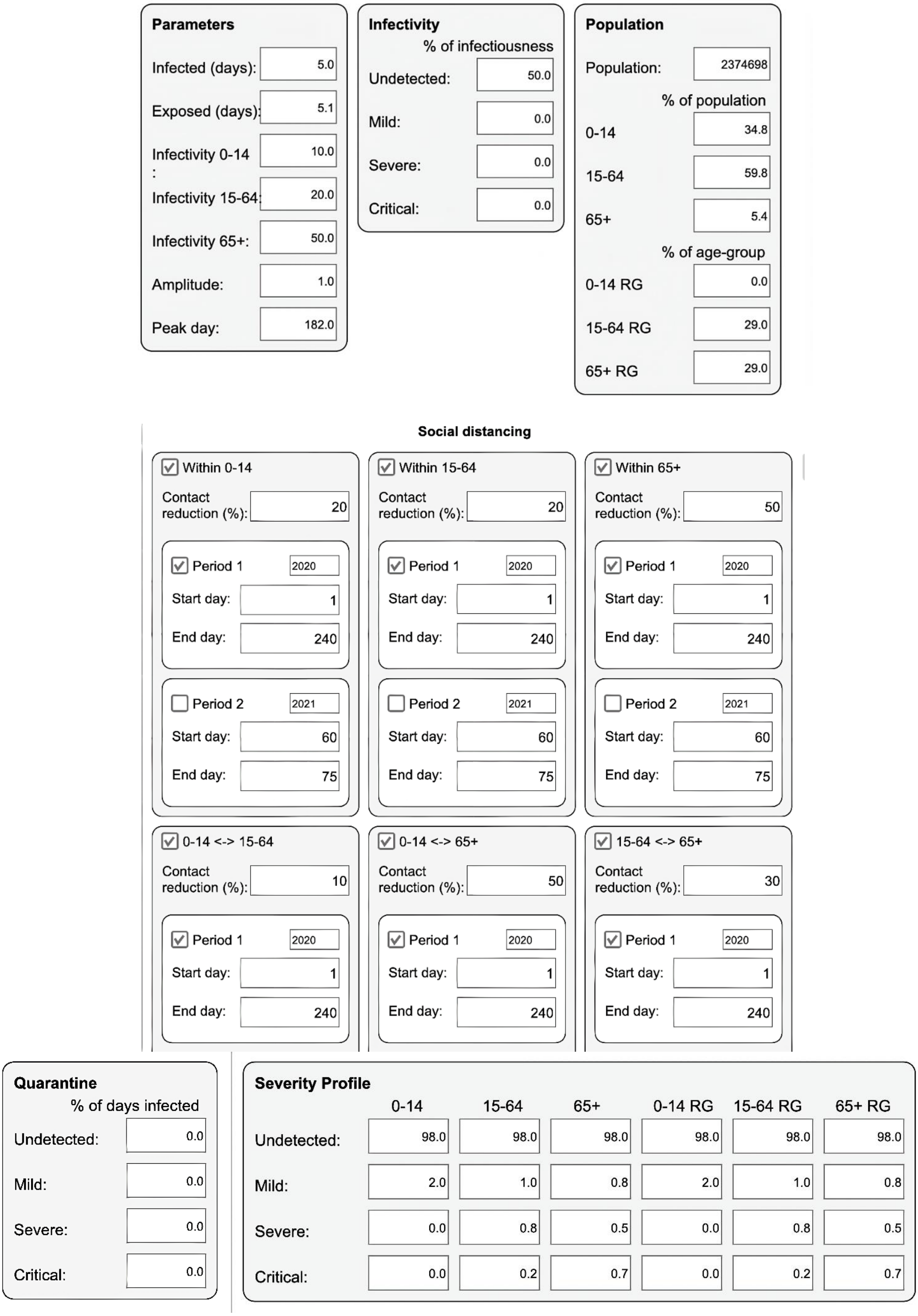

Fig. 1 Input values to the SEIR simulation model: general parameters, infectivity, demographics and risk groups, social distancing, quarantine days and severity profiles

The results from the basic assumptions are provided in Fig. 2 below. This is, however, based on an incomplete data set that must be adjusted and adapted to different regions, in particular since SARS-CoV-2 does not seem to behave like, e.g., seasonal influenza, but is acting more local in comparison. The particular conditions in Botswana cannot really be compared in a simple way, and the micro and meso perspectives must play an important role.

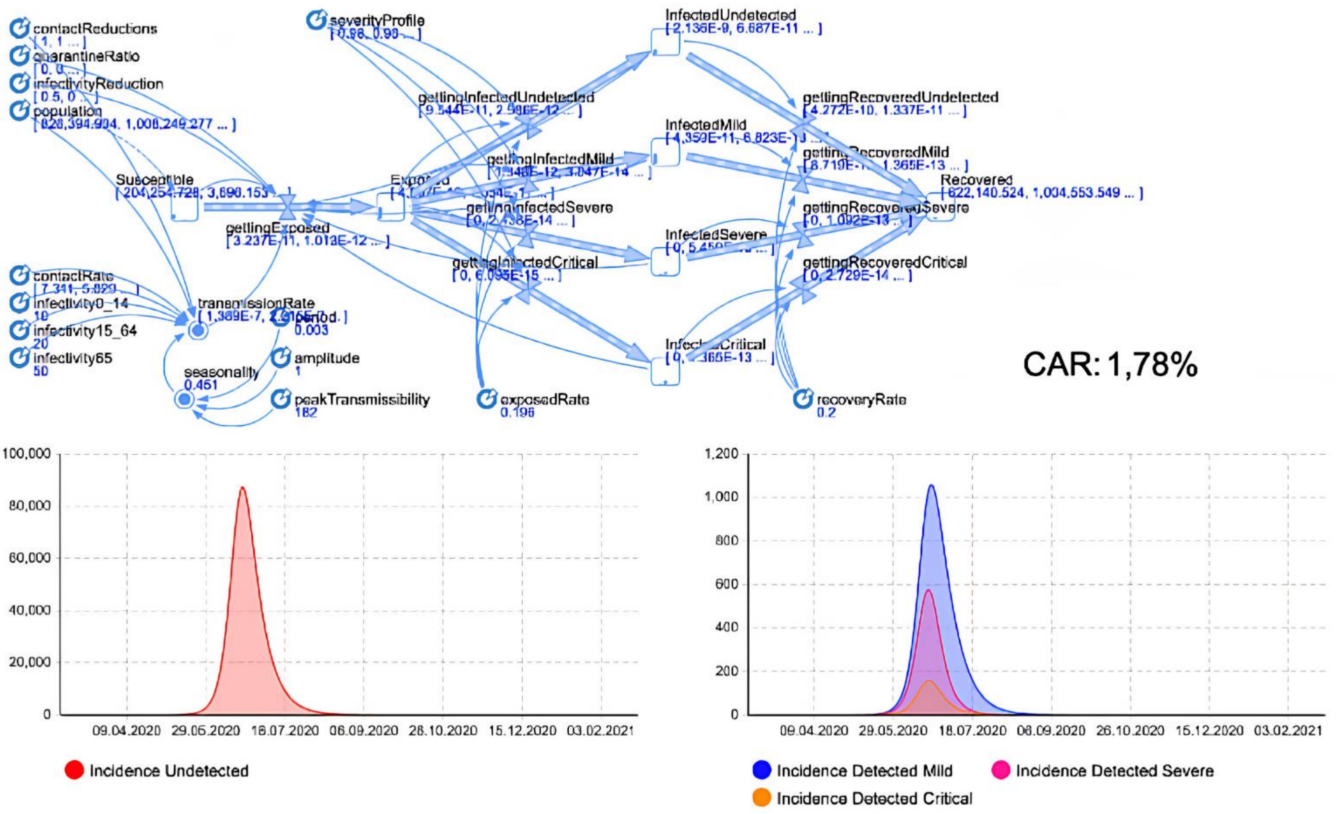

Fig. 2 Output from the SEIR simulation model for Botswana: Covid-19 undetected and detected incidences

C. Further socioeconomic modelling aspects

For the socioeconomic analysis information about households, age distribution, health sector capacity and other input factors are needed:

1. A complete economic input-output table (should be in a format similar to tables from Eurostat) for the economy of Botswana. The sector classification can be different.
2. National accounting data (including sector accounts with non-financial balance sheets and government statistics).
3. Some data that can be used as a proxy for the sectorial demand shock due to COVID-19 (the number of unemployed due to the lockdown as a proxy).
4. Population access to the Internet, divided into age groups and occupation if possible (to see where and if remote work can be used).
5. Educational system data, including lost school time, test score outcomes, how many are affected, what kinds of long-term effects and what the mitigation plans are and known effects.
6. Population at risk of poverty and informal economy size.
7. Baseline criminality rates (thefts and domestic violence in particular).
8. Mitigation measures that have been in effect and others that are being considered.
9. Communication strategy for COVID-19 information.

Additionally, business demographics data would be useful but is not absolutely essential. An initial rough evaluation of the number of fatalities, costs and effects of 3–4 categories of mitigation scenarios could be a starting point. This can be an initial step to produce an estimate of how many lives in Botswana can be saved and what will be the direct short- and long-term costs of risk mitigation measures.

A multi-criteria decision analysis should include collected data following a criteria setup that is subject to refinement when gathering more available evidence:

10. Epidemiological and healthcare systems: direct fatalities, indirect fatalities;
11. Economic aspects: short-term costs, unemployment, taxes, specific industries affected, growing industries;
12. Social and behavioural aspects: criminality rates, domestic violence, mental health, education and training, social division, trust in government;
13. Environmental: climate change, pollution;
14. Long-term resilience: remote work and education, improving prevention and hazard response, social inclusion and coping with loneliness;
15. Political: Risk of short- and long-term abuses, citizen dissatisfaction.

D. Multi-criteria decision modelling and analysis

A multi-criteria decision analysis (MCDA) framework should be supported by elaborated decision analytical tools and processes: a framework for elicitation of stakeholder preferences, a decision engine for strategy evaluation, a set of processes for negotiation, a set of decision rule mechanisms, processes for combining these items and various types of implementations of the above. These components apply to decision components, such as: agenda settings and overall processes, stakeholders, goals, strategies/policies/sub-strategies/part-policies, etc., consequences/effects, qualifications and sometimes quantifications of the components, negotiation protocols and decision rules and processes.

A multitude of methods for analysing and solving decision problems with multiple criteria and stakeholders have been suggested during the last decades. A common approach is to make preference assessments by specifying a set of attributes that represents the relevant aspects of the possible outcomes of a decision. Value functions are then defined over the alternatives for each attribute and a weight function is defined over the attribute set. One option is to simply define a weight function by fixed numbers on a normalised scale and then define value functions over the alternatives, where these are mapped onto fixed values as well, after which these values are aggregated and the overall score of each alternative is calculated. One of the problems with the additive model as well as other standard multiple criteria models is that numerically precise information is seldom available, and most decision-makers experience difficulties in entering realistic/real-life information when analysing decision problems, as they are faced with the elicitation of exact weights that demand an unreasonable exactness which does not exist. The common lack of reasonably complete information increases this problem significantly. Several attempts have been made to resolve this issue. Methods allowing for less demanding ways of ordering the criteria, such as rank orderings or interval approaches for determining criteria weights and values of alternatives, have been suggested, but the evaluation of these models is sometimes quite complicated and difficult for decision-makers to understand and accept. Some main categories of approaches to remedy the precision problem are based on capacities, sets of probability measures, upper and lower probabilities, interval probabilities (and sometimes utilities), evidence and possibility theories, as well as fuzzy measures. The latter category seems to be used only to a limited extent in real-life decision analyses since it usually requires a significant mathematical background on the part of the decision-maker. Another reason is that computational complexity can be problematic if the fuzzy aggregation mechanisms are not significantly simplified.

For the evaluations in the decision support model, a method and software for integrated multi-attribute evaluation under risk, subject to incomplete or imperfect information should be used. The software used for our purposes originates from earlier work on evaluating decision situations using imprecise utilities, probabilities, and weights, as well as qualitative estimates between these components derived from convex sets of weight, utility and probability measures. To avoid some aggregation problems when handling set membership functions and similar, we introduced higher-order distributions for better discrimination between the possible outcomes [52]. For the decision structure, we use a common decision tree formalism but refrain from using precise numbers. To alleviate the problem of overlapping results, we suggest a new evaluation method based on the resulting belief mass over the output intervals, but without trying to introduce further complicating aspects into the decision situation. During the process, we consider the entire range of values as the alternatives presented across all criteria as well as how plausible it is that an alternative outranked the remaining ones, and thus provided a robustness measure. Because of the complexity of these calculations, we use the state-of-the-art multi-criteria software tool *Decide*IT 3.0 for the analysis, which allows for imprecision of the kinds that exist in this case. *Decide*IT is based on patented algorithms [53] and several versions have been successfully used in a variety of decision situations, such as large-scale energy planning [54], allocation planning [55], demining [56], financial risks [57], gold mining [58] and many others [59].

As mentioned above, a problem with most models for criteria rank ordering is that numerically precise information is seldom available. We have solved this in part by introducing surrogate weights [60]. This, however, is only a part of the solution since the elicitation can still be uncertain and the surrogate weights might not be a fully adequate representation of the preferences involved, which of course, is a risk with all kinds of aggregations. To allow for analyses of how robust the problem is to changes of the input data, we also introduced intervals around the surrogate weights as well as around the values of the options. Thus, in this elicitation problem, the possibly incomplete information was handled by allowing the use of intervals [61], where ranges of possible values are represented by intervals in combination with a surrogate.

Using the weighted aggregation principle, we combined the multiple criteria and stakeholder preferences with the valuation of the different options under the criteria surrogate weights.

The results of the process were (i) a detailed analysis of each option's performance compared with the others, and (ii) a sensitivity analysis to assess the robustness of the result. During the process, we considered the entire range of values as the alternatives presented across all criteria as well as how plausible it was that an alternative would outrank the remaining ones, and this provided a robustness measure.

E. Multi-criteria decision modelling and analysis

With a co-creation process, we mean an adaptive and inclusive approach to participatory governance, based on the engagement and involvement of various stakeholder groups. It recognises human factors such as individual patterns of decision-making processes as well as cognitive and behavioural biases, institutional structures, perceptions of risks, benefits, and costs of various policy interventions as well as a need for compromise-oriented solutions to bring heterogeneity of views and a variety of voices. The involvement of stakeholders in decision-making processes and model development is essential for conforming to stakeholder requirements.

For this, a number of techniques may be employed providing a value-oriented prioritisation to meet the demands and the environment of the stakeholders better than other techniques. We could then employ a preference-based approach, relying on techniques and models from the decision-analytic field aimed to elicit users' values through studying their preferences and gathering preferential data from several stakeholders or prospective users in order to reach a selection of features providing maximum value while within the resources available [62].

V. Conclusions

Our approach is situated within the wider field of the social shaping of technology, a basic premise being that the transformation of technologies and technical systems is not determined by any scientific, technological or economic rationality. Rather there is a wide range of social, political and institutional factors that interact in a systemic fashion to influence their development changing them into socially transformed information systems that assist us in making precise decisions.

Compared to other research of the pre-covid era our research advances the methodology of risk governance in conditions of severe uncertainty by including a multidisciplinary aspect and developing compromise-oriented solutions which applied inputs from various sciences. The previous pre-covid studies were based either on epidemiological background or on social or policy studies. Our methodological framework allows for unifying both of these areas. It also addresses the long-term long-lasting risks on which scientifically available evidence is seldom as the majority of disaster risk reduction works focus on risks with immediate impacts.

The result of an extended governmental project would define a blueprint on how decisions are made, implemented and scaled up and how data become information and their underlying technologies lead to novel delivery of the right decisions for the public. This approach is by default respecting the culture and new knowledge on how hybrid decision-related services can be introduced to a wider Private-Public Partnership ecosystem. The social impact of a more innovative project could provide a more harmonised, mutually efficient interaction between administration and the greater public via the proposed technical means while addressing:

- Real needs from real users addressed
- A better fit between problem and solution
- Larger support for the proposed measure and more sustainable adoption
- New ideas and opportunities spotted, debated, and created

Such a project would garner insight into how to optimise hazard management options in relation to COVID-19-induced hazards. Stakeholders would become more aware of the availability of different management options regarding each of the pertinent hazards to their communities, as well as the impact of their preferences on risk management and on the broader society. This would probably facilitate improvements in the resilience also regarding future extreme hazard events, particularly in a multi-hazard context deliver effective solutions for a multi-stakeholder planning approach and strengthen policy coherence by identifying management options, thereby contributing to a more resilient region. The management options can be communicated with stakeholders that could also be used to gather feedback about how they recognise these options and determine the possible opportunities and constraints from their viewpoint. The participatory approach of engaging different stakeholders would help to ensure the buy-in of stakeholders and encourage them to take on board the final results.

Societal actors at all levels can acquire rich and deep insights into how their actions and the actions of others contribute to the escalation or mitigation of extreme hazards. A common understanding of future challenges should be shared among different stakeholders. Recommendations on how to develop optimal hazard management can help shed light on similar challenges faced now and in the future.

A limitation of our model is that it does not support adequate calculations of trade-offs between different criteria. Transparency furthermore must be considered when handling critical situations. Should there be other types of mitigation measures and even social constructs so that underprivileged groups could be better protected? Furthermore, when imposing hard mitigations, countries suffer from the socioeconomic effects of pandemics, increasing poverty and inequality. This must be discussed in advance among broader populations. We have already started to develop such trade-off support features if which some have been implemented in the tool Helision [1], providing graphical support for such analyses.[i] Further research includes developing automatized and interactive questionnaires so that respondents more directly will be able to see the results of their answers so they can be refined in real-time. Another line of research will be to further develop interactive support for users to state preference structures in a way that is even better aligned to their “real” preferences, something that they might not even be aware of in advance. This might be done by sequences of questions for internal consistency checks.

References

1. World Health Organization, “Virtual press conference on COVID-19 - 11 March 2020, URL: https://www.who.int/docs/default-source/coronaviruse/transcripts/who-audio-emergencies-coronavirus-press-conference-full-and-final-11mar2020.pdf?sfvrsn=cb432bb3_2
2. F. Amanant and F. Krammer, “SARS-CoV-2 Vaccines: Status Report”, Immunity, volume 52, issue 4, pp. 583-589, 2020
3. K. G. Andersen, A. Rambaut, W. I. Lipkin, E. C. Holmes and R. F. Garry, “The proximal origin of SARS-CoV-2” Nature medicine, 25, pp. 450-452, 2020.
4. The Research Blog of IIASA Nexus, “Explaining the COVID-19 outbreak and mitigation measures” Mar 10 2020, URL: https://blog.iiasa.ac.at/2020/03/10/explaining-the-covid-19-outbreak-and-mitigation-measures/
5. S. Roberts, “Embracing the Uncertainties”, The New York Times, April 7 2020, URL: https://www.nytimes.com/2020/04/07/science/coronavirus-uncertainty-scientific-trust.html
6. N. M. Ferguson, D. Laydon, G. Nedjati-Gilani et al., “Report 9: Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demand“, Imperial College London (16-03-2020), URL: https://www.imperial.ac.uk/media/imperial-college/medicine/sph/ide/gida-fellowships/Imperial-College-COVID19-NPI-modelling-16-03-2020.pdf
7. D. Ellsberg, “Risk, Ambiguity, and the Savage Axioms”, Quarterly Journal of Economics. 75 (4): 643–669, 1961
8. K. Timur, and C. Sunstein, “Availability Cascades and Risk Regulation”, Stanford Law Review, Vol. 51, No. 4 (1999).
9. A. Tversky, and D. Kahneman, “Availability: A heuristic for judging frequency and probability”, Cognitive Psychology, Volume 5, Issue 2, Pages 207-232, 1973
10. R. B. Morton, D. Mueller, L. Page, B. Torgler (2015). "Exit polls, turnout, and bandwagon voting: Evidence from a natural experiment". European Economic Review. 77: 65–81. doi:10.1016/j.euroecorev.2015.03.012.

[1] https://www.preference.nu/helision/

11. M. Bar-Hillel, "The base-rate fallacy in probability judgments", Acta Psychologica. 44 (3): 211–233, 1980, doi:10.1016/0001-6918(80)90046-3.
12. C. Sunstein, "Probability Neglect: Emotions, Worst Cases, and Law", Chicago Law & Economics, Olin Working Paper No. 138, 2001
13. A. Tversky, D. Kahneman, "The Framing of decisions and the psychology of choice", Science, 211 (4481): 453–58, 1981
14. M. E. Turner, A. R. Pratkanis, "Twenty-five years of groupthink theory and research: lessons from the evaluation of a theory", Organizational Behavior and Human Decision Processes, 73 (2–3): 105–115, 1998
15. L. E. Lindblom, "The handling of norms in policy analysis", in Abramovitz, Moses; et al. (eds.), The allocation of economic resources: essays in honor of Bernard Francis Haley, Stanford, California: Stanford University Press, 1959.
16. H. Simon, "Models of Bounded Rationality Behavioral Economics and Business Organization". Vol. 2, MIT Press, Cambridge, MA, 1982
17. D. Kahneman and A. Tversky, "Prospect theory: An analysis of decision under risk", Econometrica, 47, 263–291, 1979
18. B. Chu, "What is 'dread risk' – and will it be a legacy of coronavirus?" Independent, June 16 2020, URL: https://www.independent.co.uk/news/business/comment/dread-risk-coronavirus-legacy-psychology-probability-economy-a9568696.html
19. P. Slovic, "Perception of risk", Science, 236(4799), 280–285, 1987
20. État De Vaud, "Hotline et Informations sur le Coronavirus", URL: www.vd.ch/coronavirus
21. Gazzetta Ufficiale Della Repubblica Italiana, Anno 161, Numero 62, 9 marzo 2020, URL: https://www.gazzettaufficiale.it/eli/gu/2020/03/09/62/sg/pdf
22. John Hopkins Unversity of Medicine, Coronavirus Resource Center, URL: https://coronavirus.jhu.edu/map.html
23. A. France-Presse, "Financial crisis caused 500,000 extra cancer deaths, according to Lancet study" The Telegraph, 26 May 2016, URL: https://www.telegraph.co.uk/news/2016/05/25/financial-crisis-caused-500000-extra-cancer-death-according-to-l/
24. OECD, "The territorial impact of COVID-19: Managing the crisis and recovery across levels of government", 10 May 2021, URL: https://www.oecd.org/coronavirus/policy-responses/the-territorial-impact-of-covid-19-managing-the-crisis-and-recovery-across-levels-of-government-a2c6abaf/
25. Africa Center for Strategic Studies, "Mapping Risk Factors for the Spread of COVID-19 in Africa", April 3, 2020 (updated May 13, 2020) URL: https://africacenter.org/spotlight/mapping-risk-factors-spread-covid-19-africa/
26. M. Gilbert, G. Pullano, F. Pinotti, E. Valdano, C. Poletto, P-Y. Boëlle, E. D'Ortenzio, Y. Yazdanpanah, S. P. Eholie, M. Altmann, B. Gutierrez, M. U. G. Kraemer, V. Colizza, "Preparedness and vulnerability of African countries against importations of COVID-19: a modelling study", The Lancet, volume 395, issue 10227, March 14, 2020. URL: https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(20)30411-6/fulltext
27. World Health Organization, "COVID-19 in Africa: from readiness to response" URL: http://whotogo-whoafroccmaster.newsweaver.com/JournalEnglishNewsletter/g65c7ca8gui
28. World Health Organization, "COVID-19 Situation update for the WHO African Region: External Situation Report 8, 22 April 2020, URL: https://apps.who.int/iris/bitstream/handle/10665/331840/SITREP_COVID-19_WHOAFRO_20200422-eng.pdf
29. London School of Hygiene & Tropical Medicine, "Strategies combining self-isolation, moderate physical distancing and shielding likely most effective COVID-19 response for African countries", 21 april 2020, URL: https://www.lshtm.ac.uk/newsevents/news/2020/strategies-combining-self-isolation-moderate-physical-distancing-and-shielding
30. BBC, "Coronavirus: Why lockdowns may not be the answer in Africa", 15 April 2020, URL: https://www.bbc.com/news/world-africa-52268320
31. Republic of Botswana, "COVID-19 Relief Fund", URL: https://www.gov.bw/covid-19-relief-fund
32. University of Oxford, "Oxford COVID-19 Government Response Tracker", URL: https://covidtracker.bsg.ox.ac.uk/stringency-scatter
33. I. Scher, "Taiwan has only 77 coronavirus cases. Its response to the crisis shows that swift action and widespread healthcare can prevent an outbreak", Insider, URL: https://www.businessinsider.com/coronavirus-taiwan-case-study-rapid-response-containment-2020-3
34. B. Nussbaumer-Streit, V. Mayr, A. Iulia Dobrescu, A. Chapman, E. Persad. I. Klerings, G. Wagner, U. Siebert, C. Christof, C. Zachariah and G. Gartlehner, Quarantine alone or in combination with other public health measures to control COVID-19: a rapid review, Cochrane Database of Systematic Reviews, 2020 URL: https://www.cochranelibrary.com/cdsr/doi/10.1002/14651858.CD013574/full
35. J. Howard, A. Huang, Z. Li, Z. Tufekci, V. Zdimal, H-M. van der Westhuizen, A. von Delft, A. Price, L. Fridman, L-H. Tang, V. Tang, G. L. Watson, C. E. Bax, R. Shaikh, F. Questier, D. Hernandez, L. F. Chu, C. M. Ramirez and A. W. Rimoin, "Face Masks Against COVID-19: An Evidence Review", Preprints, 10 April 2020, URL: https://www.preprints.org/manuscript/202004.0203/v1?fbclid=IwAR3sy7TFIQwdj87y2W_aRE-9LxVh6qyxan9I05zA9BWRKKu7ArJ1EeaDMQw
36. L. Tian, X. Li, F. Qi, Q-Y. Tang, V. Tang, J. Liu, Z. Li, X. Cheng, X. Li, Y. Shi, H. Liu and L-H. Tang, "Calibrated Intervention and Containment of the COVID-19 Pandemic", arXiv, URL: https://arxiv.org/abs/2003.07353
37. International Monetary Fund, "World Economic Outlook, April 2020: The Great Lockdown", URL: https://www.imf.org/en/Publications/ WEO/Issues/2020/04/14/weo-april-2020
38. OECD, "OECD updates G20 summit on outlook for global economy", 27 Marsh 2020 (updated 15 April 2020), URL: http://www.oecd.org/ newsroom/oecd-updates-g20-summit-on-outlook-for-global-economy.htm
39. T. Britton, "Basic estimation-prediction techniques for Covid-19, and a prediction for Stockholm" medRxiv, 15 April 2020, URL: https://www.medrxiv.org/content/10.1101/2020.04.15.20066050v1.full.pdf
40. J. W. Forrester, "Principles of Systems". Cambridge MA: Productivity Press, 1968
41. J.D. Sterman, "System Dynamics Modeling: Tools for learning in a Complex World". California Management Review. 2001;43(4), 2001
42. M.Y. Li and J.S. Muldowney, "Global Stability for the SEIR Model in Epidemiology", Mathematical Biosciences.Vol.125, pp.155–164, 1995
43. L. Brouwers, M. Camitz, B. Cakici, K. Mäkilä, P. Saretok, "MicroSim: Modeling the Swedish Population", arXiv:0902.0901. URL: http://arxiv.org/abs/0902.0901, 2009
44. P. Shi, Y. Dong, H. Yan, C. Zhao, X. Li, W. Liu, M. He, S. Tang, and S. Xi. "Impact of temperature on the dynamics of the COVID-19 outbreak in China", Science of the Total Environment 728, 2020
45. J. Jang, and I. Ahn, "Simulation of Infectious Disease Spreading based on Agent Based Model in South Korea", Advanced Science and Technology Letters Vol.128, pp.53–58, 2016.
46. T. Fasth, A. Talantsev, L. Brouwers, A. Larsson, "A Dynamic Decision Analysis Process for Evaluating Pandemic Influenza Intervention Strategies", ISPOR Value in Health, Vol. 20(9), 2017
47. University of Oxford, COVID-19 Government Response Tracker, URL: https://www.bsg.ox.ac.uk/research/research-projects/coronavirus-government-response-tracker
48. P. Block, M. Hoffman, I. J. Raabe, J. Beam Dowd, C. Rahal, R. Kashyap, M. C. Mills, "Social network-based distancing strategies to flatten the COVID 19 curve in a post-lockdown world", arXiv:2004:07052, 2020, URL: https://arxiv.org/ftp/arxiv/papers/2004/2 004.07052.pdf
49. Radio România Internațional, "Romania enters total lockdown", 25 March 2020, URL: https://www.rri.ro/en_gb/romania_ enters_total_lockdown-2614312
50. P. GT. Walker, C. Whittaker, O. Watson et al., "The Global Impact of COVID-19 and Strategies for Mitigation and Suppression", Imperial College London, 2020, URL: https://www.imperial.ac.uk/media/ imperial-college/medicine/sph/ide/gida-fellowships/Imperial-College-COVID19-Global-Impact-26-03-2020v2.pdf
51. R. A. Neher, R. Dyrdak, V. Druelle, E. B. Hodcroft, and J. Albert, "Impact of seasonal forcing on a potential SARS-CoV-2 pandemic", medRxiv, 13 Feb. 2020, URL: https://www.medrxiv.org/ content/10.1101/2020.02.13.20022806v1.full.pdf
52. M. Danielson, and L. Ekenberg, "An Improvement to Swing Techniques for Elicitation in MCDM Methods", Knowledge-Based Systems, 2019.
53. M. Danielson and L. Ekenberg, "A support system for decision analysis", Google Patents, WO2005117531A2, URL: https://patents.google.com/patent/WO2005117531A2/en
54. N. Komendantova, L. Ekenberg, L. Marashdeh, A. Al-Salaymeh, M. Danielson, and J, Linnerooth-Bayer, "Are Energy Security Concerns

Dominating Environmental Concerns? Evidence from Stakeholder Participation Processes on Energy Transition in Jordan", Climate, 2018.
55. A. Larsson, T. Fasth, M. Wärnhjelm, L. Ekenberg, and M. Danielson, "Policy Analysis on the Fly with an Online Multi-Criteria Cardinal Ranking Tool", Journal of Multi-Criteria Decision Analysis, 2018:1–12, 2018, https://doi.org/10.1002/mcda.1634.
56. L. Ekenberg, T. Fasth, and A. Larsson, "Hazards and Quality Control in Humanitarian Demining", International Journal of Quality & Reliability Management 35(4), pp. 897–913. 2018, doi:10.1108/IJQRM-01-2016-0012.
57. M. Danielson, M., and L. Ekenberg, "Efficient and Sustainable Risk Management in Large Project Portfolios", proceedings of BIR 2018 (17th International Conference on Perspectives in Business Informatics Research), Springer, 2018.
58. A. Mihai, A. Marincea, and L. Ekenberg, L., "A MCDM Analysis of the Roșia Montană Gold Mining Project", Sustainability Vol. 2015(7), pp. 7261–7288, doi:10.3390/su7067261, 2015.
59. L. Ekenberg, K. Hansson, M. Danielson, G. Cars, "Deliberation, Representation, and Equity: Research Approaches, Tools, and Algorithms for Participatory Processes", 384p, ISBN 978-1-78374-304-9, Open Book Publishers, 2017.
60. M. Danielson, and L. Ekenberg, "An Improvement to Swing Techniques for Elicitation in MCDM Methods", Knowledge-Based Systems, 2019, https://doi.org/10.1016/j.knosys.2019.01.001.
61. M. Danielson, L. Ekenberg, and A. Larsson, "Evaluating Multi-Criteria Decisions under Strong Uncertainty", to appear in A. de Almeida, L. Ekenberg, P. Scarf, E. Zio, M.J. Zuo, Multicriteria Decision Models and Optimization for Risk, Reliability, and Maintenance Decision Analysis - Recent Advances, Springer, 2022.
62. M. Danielson, L. Ekenberg, N. Komendantova, A. Al-Salaymeh and L. Marashdeh (2022) A Participatory MCDA Approach to Energy Transition Policy Formation, to appear in A. de Almeida, L. Ekenberg, P. Scarf, E. Zio, M.J. Zuo, Multicriteria Decision Models and Optimization for Risk, Reliability, and Maintenance Decision Analysis - Recent Advances, Springer, 2022.
63. Soumik Purkayastha, Rupam Bhattacharyya, Ritwik Bhaduri, Ritoban Kundu, Xuelin Gu, Maxwell Salvatore, Debashree Ray, Swapnil Mishra & Bhramar Mukherjee A comparison of five epidemiological models for transmission of SARS-CoV-2 in India, BMC – part of Springer, 2021

[i] https://www.preference.nu/helision/