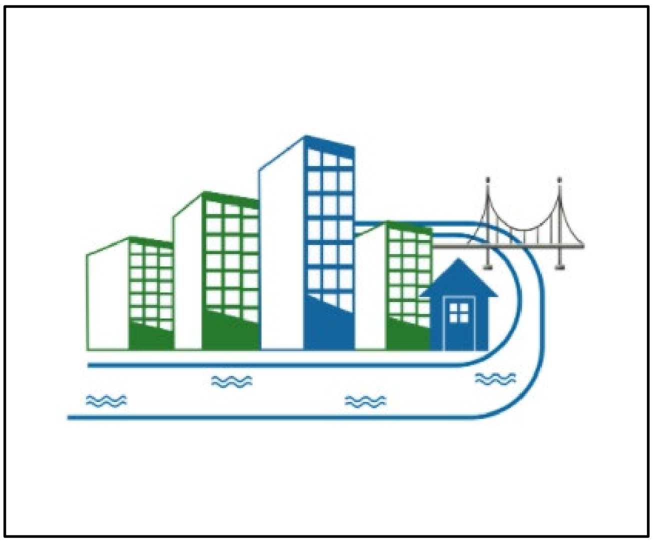
NIST Special Publication 1261

Economic Decision Guide Software (EDGe$) Online Tutorial:

University Pandemic Planning Analysis Use Case



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Abstract

The Coronavirus 2019 (COVID-19) global pandemic has raised concerns as to how to best host fall semesters at universities and colleges across the U.S. in the face of high transmission rates. College campuses have a communal structure that may allow for an infectious disease to become a serious issue to students and staff. College campuses are in need of resilience planning that deals with the presence of a pandemic. In this report, four alternatives are evaluated that might assist colleges in mitigating some of the negative economic effects of an infectious disease. The use case presented in this report is fictious and is meant to reflect a public four-year higher-education institution; however, the values used are based on real-life estimates, when available.

Costs and benefits were configured for four alternatives and analyzed with the Economic Decision Guide Software (EDGe$) Online Tool to determine the relative net present value of these resilience strategies via a benefit-cost analysis (BCA). Though designed to evaluate investments into built infrastructure, EDGe$ is demonstrated to be applicable to questions of resilience planning more broadly.

The results of this use case show that an outdoor facility would be the best alternative for the college campus modeled, given various parameters and assumptions. The outdoor facility allows for the alleviation of all fatalities and has various benefits that include positive externalities and net co-benefits. This use case demonstrates a basic BCA using EDGe$ Online to determine a community's course of action in planning for pandemics, especially when some alternatives relate to built infrastructure resilience and/or sustainability, e.g., through indirect valuation or co-benefits.

Key words

Benefit-cost analysis; community resilience; economic analysis; economic decision tool; online application; pandemic; resilience; resilience dividend; university campus.

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Glossary

BCA	benefit-cost analysis
BCR	benefit-cost ratio
COVID-19	Coronavirus 2019
EDGe$	Economic Decisions Guide Software
HVAC	heating, ventilation, and air conditioning
LCC	lifecycle cost
MCA	multi-criteria analysis
OMR	Operations, Maintenance and Repairs
ROI	return-on-investment
SBS	Sick Building symptoms
WHO	World Health Organization

1. Economic Decision Guide Software (EDGe$) Tool Online – Overview

The Economic Decision Guide Software (EDGe$) Online Tool Version 1.0 establishes a rational, systemic methodology for selecting cost-effective community resilience alternative strategies. The tool can be used to assist community planners. The EDGe$ methodology, which is based on the methodology developed in the *NIST Community Resilience Economic Decision Guide for Buildings and Infrastructure Systems* (Gilbert et al., 2016), was developed with community-level decision-making for resilient buildings and infrastructure planning in mind. To date, EDGe$ has primarily been applied to community resilience planning specific to natural hazards. However, as demonstrated by this use case, EDGe$ is relevant to resilience planning more generally, especially when at least one of the alternatives has values related to built infrastructure resilience and/or sustainability.

EDGe$ Online offers a platform for community leaders and planners to analyze different alternatives relevant to dealing with mitigation towards and recovery from a disaster event through a benefit-cost analysis (BCA). These disasters span natural-, human-made, or a combination of these two types. Pandemics are often classified as natural disasters that are exacerbated by human decision-making (Jamison et al., 2018).

The BCA presented herein is performed by taking the inputs (i.e., costs, benefits, co-costs, co-benefits and externalities) of various parameters and comparing the present and future cost/ benefits associated with each alternative over a period of time, given the possibility of a pandemic reoccurrence at a university campus.

The output of EDGe$ Online guides community-level decision-making by establishing analysis indicators. These include the benefit-cost ratio (BCR) for each alternative, return-on-investment (ROI), and the non-disaster ROI, among others. There are screenshots of selected EDGe$ Online input screens throughout. For a full set of screenshots and a full walkthrough of EDGe$ Online see Helgeson and Zhang (2020).

Section 2 of this report introduces the COVID-19 pandemic in the context of a college campus. Sections 3-6 provide a detailed overview of this fictious demonstrative use case and associated alternatives. Section 7 provides EDGe$ BCA output. Section 8 concludes.

2. Use case Context and Background

In December 2019 a new infectious respiratory disease emerged in Wuhan, Hubei province, China. The World Health Organization (WHO) recognized the emergence of the disease and named it Coronavirus 2019 (COVID-19). COVID-19 is characterized as a highly contagious virus and has become the source of a global pandemic (Indranil and Prasenjit, 2020). COVID-19 is the sixth global pandemic to occur since 2000; it is preceded by H1N1 in 2009, polio in 2014, Ebola in 2014, Zika in 2016 and Ebola 2019 (ibid.).

Pandemics – an epidemic occurring over a very wide area, crossing international boundaries and usually affecting many people—cause large numbers of fatalities, morbidities, and can cost the world billions of dollars (Indranil and Prasenjit, 2020). Given the effects a pandemic can have on a society, global pandemics are seen to have major public health implications, global pandemics have large social and economic implications. The cost associated with the outbreak of a global infectious disease can include increased health system costs, worker productivity disruptions (e.g., from social distancing requirements), and a temporary loss of employment all together in various sectors. A social cost is also accrued with increased anxiety from pandemic-related fears and a lack of human interaction from schools and work being shut down (Bloom, 2018).

The implications mentioned have occurred to some extent with all of the previous global pandemics; however, the global spread of COVID-19 and its transmission rate make it possible that the health and economic cost associated will be more severe (Indranil and Prasenjit, 2020).

Mitigation policies and strategies are key components in diminishing the negative effects of COVID-19. Literature addresses possible pandemic mitigation strategies; Azar et al. (2011) create a simulation model to assess the effects of policy decisions on a pandemic situation with a primary focus on an influenza outbreak. The paper states that "the development of an appropriate vaccine requires a significant amount of time thus communities must focus on non-pharmaceutical interventions" (ibid., p. 89). The non-pharmaceutical mitigation interventions mentioned in the article include social distancing and isolation of those infected (i.e., quarantining) (ibid.). Illness testing, contact tracing, and universal mask wearing are also addressed in pandemic literature as mitigation strategies for virus contraction (Gressman and Peck, 2020).

Global pandemics are associated with devastating costs around the globe and given there have been six already in the current century, it is evident that community resilience plans may benefit from considering virus mitigation strategies that have proven useful in reducing the spread of disease .

In the use case presented herein, the community considered is a fictious public college campus. Various alternatives are put forth that call for social distancing, quarantining, universal mask wearing and illness testing that could help mitigate virus contraction; thus, reducing the extent of the potential health and economic burden on communities in the presence of a pandemic. It should be noted that uncertainty around the extent to which students will adhere to the suggested guidelines is not considered. Given the community structure of a college campus and various social interaction among students and staff, it is crucial to have majority participation amount the population in adhering to guidelines set forth by campus officials. All assumed input values (e.g., costs, benefits, co-benefits etc.) are entered into the EDGe$ Online Tool to conduct a BCA of different mitigation strategies relative to the status quo (i.e., business-as-usual) alternative.

3. Pandemic Planning Use case Overview

3.1 Use case Overview

At the time of writing, colleges and universities around the U.S. faced the decision as to whether and how to safely open for the 2020/21 academic year in the face of the ongoing COVID-19 pandemic. In autumn 2020, about 17 million students planned to return to college campuses; and with the intensity of the COVID-19 pandemic, colleges faced new interconnected issues, including a public health concern, revenue shortages, and logistical challenges (Gressman and Peck, 2020). College campuses function as their own diverse and inclusive community. Rajiv et al. (2020) describes a college campus as having a quintessential congregate environment. The NIST definition of community resilience and the EDGe$ Tool Online envisions a *community* to be defined by two unifying characteristics: 1. a defined geographic boundary and 2. a leadership structure (NIST, 2015). Thus, a college campus constitutes a *community*.

The collegiate environment of most residential four-year college campuses and the influx of students and staff from all different regions, causes a campus community to be more susceptible to viruses during a pandemic than other community types. This increased susceptibility caused many academic institutions to move to online learning during the Spring 2020 semester and has reduced the college attendance rate for the Fall 2020 semester. A survey of 2020 high school seniors found that their decision to rethink college alternatives revolved around not wanting to lose tuition money (28.8 %) and being in fear of potentially contracting the virus at college (21.9 %) (Muholland, 2020). Colleges are faced with the crucial decision as to how best to alleviate some of the uncertainty for the following semester and to ensure student safety to the greatest extent possible, all while maintaining attendance rates and garnering critical funds that come from tuition.

Colleges started opening for the Fall 2020 semester in early- to mid-August 2020. During the first weeks of August 2020, COVID-19 already spread rapidly within some of these communities. In fact, the University of North Carolina-Chapel Hill experienced 130 positive cases among students in the first week alone causing all undergraduate classes to be moved to remote learning and a reduction of campus activities (Treisman, 2020). The composition of many college campuses has led to a large increase in cases. For example, by mid-August, clusters of positive COVID-19 increases were observed at sorority and fraternity housing across the country, including California, North Carolina and Mississippi (Nierenberg and Pasick, 2020). This has led to entire dormitories being quarantined and has increased fear and vulnerability for university students, staff, and the larger communities that often surround colleges. Some universities, such as the University of Notre Dame and the University of North Carolina at Chapel Hill, decided to rescind decisions that were made to hold in-person classes in favor of remote learning (ibid.). The first few weeks of the fall semester demonstrated that universities need to consider comprehensive strategies in the presence of public health crises.

A pandemic resilience plan can include various options available to the college, depending on the details of the situation faced, budget constraints, and expressed desires of the students and staff.

This use case focuses on four different generic alternatives that may be applicable in general terms to many four-year higher education institutions. Three of the alternatives are not mutually exclusive, that is, dependent upon universities budget constraints, various parts of each alternative can be combined. The three alternatives are: 1. **increased building air filtration**, 2. **isolation housing,** and 3. **an outdoor facility.** The fourth alternative explored is mutually exclusive and addresses the alternative of the college switching to **full online learning**.[1]

[1] Not that it is assumed that in a full online learning scenario students are not housed on campus. Otherwise this option is not truly mutual exclusive of the other alternatives.

During development of this use case, various assumptions were made around input data and analysis parameters. While the college used in this case study is a fictitious public four-year higher education institution, some parameters and assumption from the case study are based on population, housing and weather characteristics that are collected from the University of North Carolina-Wilmington. The data gathered from the University of North Carolina-Wilmington .was garnered from publicly available sources. The analysis for many of the costs and benefits were calculated using their student population of 17 500 and staff population of 2 200 (total of 19 600) and assuming the possibility of a dual disaster during hurricane season ("about UNCW," n.d.).

3.2 Analysis Parameters

All alternatives in this use case are analyzed over four time horizons: 5, 10, 20, and 50 years. The EDGe$ analysis is run for each of these planning horizons to provide a basis for comparison. The use of various time horizons is based on the assumption that colleges typically want to have long-term capital planning, but also are interested in the near-term repayment on alternatives, especially during such an uncertain period.

The recurrence rate of a pandemic is assumed to be 50 years.[2] The infection rate of COVID-19 on college campus is assumed to be 3.8, meaning one person infected will infect an average of 3.8 people (Gressman and Peck, 2020). The value of a statistical life for those between 15 and 24 years of age is set at $12.64 M (Robinson et al., 2020). The alternatives of increasing air filtration, isolation housing and an outdoor facility all have co-benefits that are included in the resilience planning analysis. Tanner et al. (2018) defines a co-benefit as "benefits or uses of a disaster risk management investment or action, in addition to the primary disaster risk management objective of reducing disaster losses" (p. 11). When analyzing this case study, it is important to assess co-benefits and define the various resilience dividends associated with each alternative. Fung and Helgeson (2017) define the resilience dividend as the net co-benefit (or co-cost) of investing in enhanced resilience, in the absence of a disruptive incident which accrues on the "day-to-day." The possible co-benefits included in this case study are important for longer-term valuation of alternatives as these tend to materialize even in the absence of a disaster. Thus, the co-benefits can accrue over the life of the plan adopted.

4. Alternatives: Descriptions

The alternatives listed below likely allow for some level of COVID-19 virus transmission mitigation. These strategies include: social distancing, quarantining, universal mask wearing and illness testing.

Upgrading the air filtration system was chosen because it encapsulates a method that decreases the way in which transmission of the virus occurs (i.e., though air borne particles). The

[2] Pandemic research suggest that the reoccurrence rate of an infectious disease is difficult to define due to the high uncertainty surrounding pandemics (Morens and Taubenberger, 2011). In order to conduct a full BCA of this scale, a sensitivity analysis must be conducted for fluctuations of the reoccurrence rate.

assumption of universal mask wearing, illness testing, quarantining and contact tracing strategies are also applied.

Isolation housing was chosen as a way to have an effective quarantine alternative, and is considered necessary with a large population of students living on campus. Mass testing, contact tracing, quarantining and universal mask wearing are implemented though this alternative as well.

The outdoor facility is chosen because it allows for a safer place for students to attend classes and gain internet access while maintaining social distancing requirements. Mass testing, contact tracing, quarantining and universal mask wearing are implemented though this alternative along with social distancing.

A full online-learning alternative is analyzed because this was the strategy chosen by a majority of universities for the Spring 2020 semester. This alternative does not need to address the mitigation strategies of social distancing, quarantining, universal mask wearing and illness testing, because no staff or students would be present on campus given this alternative. This alternative does alleviate all possible fatalities of a pandemic that could occur from on-campus interaction between students, as well as staff.

4.1 Alternative 1: Air filtration system upgrade (Retrofitting with an economizer)

COVID-19 is generally thought to be spread through close contact with people. The EPA has extended the longevity of the disease transition criteria to include air borne particles that can remain in the air even after an infected individual is not within the required social distancing parameter. Evidence shows that air borne particles of the virus are lasting longer and traveling farther than originally thought (Indoor Air and Coronavirus, 2020). The design of the heating, ventilation, and air conditioning (HVAC) systems at the university can affect the transmission of the virus. This suggests that improving air quality can decrease infection rates (Indoor Air and Coronavirus, 2020). This alternative calls for an economizer to be added to an already existing HVAC system. An economizer is a part of the outdoor components, most often mounted on the roof, of an HVAC system for commercial buildings. The economizer evaluates outside air temperature and humidity levels. When the exterior air levels are appropriate, it uses the outside air to cool the building. HVAC economizers use logic controllers and sensors to get an accurate determination of the outside air quality. As the economizer detects the right level of outside air to bring in, it utilizes internal dampers to control the amount of air that gets pulled in, recirculated and exhausted from the building (East, 2019). The economizer brings outdoor air in, thereby increasing air quality and helping to filter out virus particulates present in the building.

4.2 Alternative 2: Isolation housing

Social distancing and quarantine of those who are infected are crucial steps to slowing transmission rates and saving lives (Gressman and Peck, 2020). Having these alternatives available is important and the university may consider renting rooms at a local hotel to maintain flexibility through increased lodging space. Students may live in these rooms to help alleviate dormitory crowding as needed to address social distancing needs. Additionally, the college can use these rooms to place students in the case that a dormitory on campus is needed as a place to quarantine anyone who becomes infected.[3] This alternative assumes that 5 % of student housing will need to be moved to hotels. Given UNCW campus housing capacity, 200 rooms will be rented.[4] The University has a standing discount of 20 % for students at local hotels; thus, this discount is applied to the assumed hotel room fees.

4.3 Alternative 3: Outdoor Facility

Aside from housing, dining facilities and libraries are potential areas of major concern to higher education institutions due to the lack of social distancing in these types of indoor facilities. An outdoor facility alternative can not only alleviate some of the dining and library service issues, it can also increase exposure to outdoor air for students and staff. The proposed outdoor facility is a 10 000 sq/ft (929.03 sq/m) area. The area is covered by an aluminum pergola with an extensive green roof. Laptops are available for rent by students to ensure all students have access to the internet while outside.

4.4 Alternative 4: Complete online learning

The alternative of going completely online is a straight-forward alternative during a pandemic.[5] During the 2020 spring semester, many colleges chose this alternative in the wake of COVID-19 pandemic. This alternative transfers all classes online and halts any college campus functions. This includes no on-campus living arrangements for most students.

5. Assumptions

The following values are assumed for all four alternatives:

Planning Horizons: 5, 10, 20, 50 years

Discount Rate: 3 % (Haacker et al., 2020)

Pandemic rate: Every 50 years

Statistical Value of a Life : $12.64 M (Robinson et al., 2020)

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[3] For hotels, these types of partnerships help bring back business during a time when decreased bookings have meant furloughed workers. This type of arrangement has emerged at universities across the country. For example, Emerson College in Boston has taken over eight floors of the nearby W Hotel to house 192 students after partially reserving sections of one residence hall, the Paramount Center, for quarantine rooms (McMahon, 2020).

[4] The assumption of 200 rooms comes from a proposed quarantine planning option at Boston University (BU). BU is planning enough hotels rooms to cover 5 % of their total housing capacity (Pirog and Lui, 2020). UNCW has 4 000 rooms thus given the 5 % of housing capacity assumption, 200 rooms are to be rented.

[5] There are associated issues for some students who may not have a place to live outside of campus housing or inherently miss the community aspects of "college life." These costs are not captured in this analysis.

Other key assumptions have been made to simplify this example analysis. These are not necessarily realistic and should not be considered prescriptive for an actual BCA or Life- cycle cost (LCC) analysis.

Assumptions that apply to all four alternatives:

- There is no dependence between distributions, for instance for distributions of cost and distributions of indirect cost. EDGe$ currently does not implement such considerations, although for some distributions such dependencies would exist.
- There is no uncertainty related to the return rate of the pandemic.
- The assumed infection rate at a university is 3.8.
- The statistical value of a life is for students aged 15 to 24 thus fatalities averted is only relevant to the 17 500-student population.
- The analysis compares all values relative to the implicit alternative of "doing nothing."

Assumptions related to specific values derived for the analysis are mentioned as they arise from the narrative, below.

6. Data Inputs

6.1 Cost Data

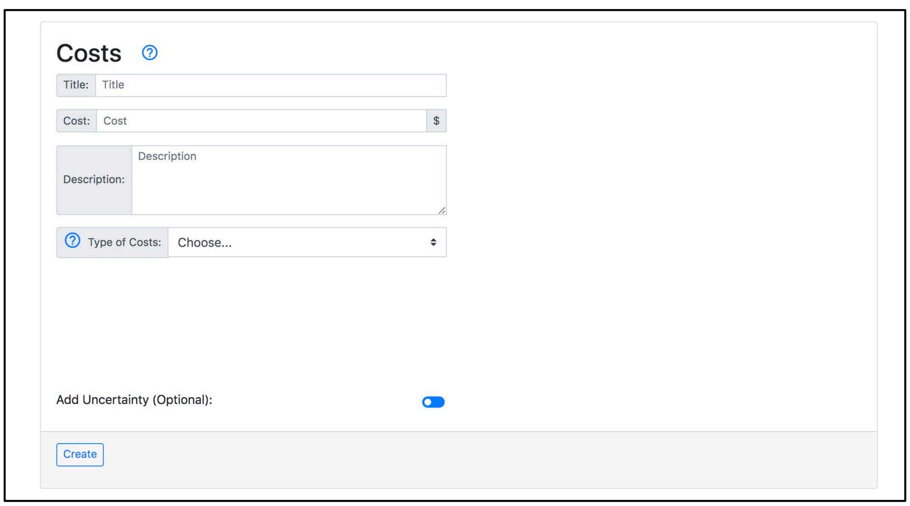

Figure 1. EDGe$ cost data screen

6.1.1 Alternative 1: Air filtration system upgrade (Retrofitting with an economizer)

The alternative of retrofitting an economizer to an existing HVAC system has associated direct costs and one reoccurring maintenance cost. The direct cost for retrofitting an economizer includes the cost of the economizer infrastructure itself. This alternative assumes that four economizers are required. Furthermore, COVID-19 prevention/cleaning supplies are used; the assumed costs are $ 33 per person for cleaning materials and $133/per person for face masks (assuming a third of the campus population will need a mask). COVID-19 testing is also a necessary cost at $100 per test and a limit of one test per person. Yearly maintenance must be done to keep the economizer functioning properly. The annual cost of maintenance is assumed to be $ 1500.

Table 1. Cost inputs for alternative 1 (Air filtration system upgrade)

Cost Category	Description	Cost
Direct	Cost of retrofitting an economizer to a university's already existing HVAC system. $96 000 per economizer while assuming 4 are necessary. (Koenigshofer et al., 2018)	$384 000 (Koenigshofer et al., 2018)
Direct	Sanitizer, cleaning materials, thermometers, etc. $33 per person with a population of 19 600 individuals	$646 800 ("Reopening Schools During a Time of Triple Crisis: Financial Implications," 2020)
Direct	The cost of disposable masks, assuming 1/3 of population need masks each day at $ 133 per person. (based on a 224 day academic year)	$868 899 ("Reopening Schools During a Time of Triple Crisis: Financial Implications," 2020)
Direct	COVID-19 test Assuming $ 00 per test and one test per person	$1 960 000 ("Reopening Schools During a Time of Triple Crisis: Financial Implications," 2020)
Operations, Maintenance and Repairs (OMR)	Cost of yearly maintenance on the upgraded system	$ 1500 annually (Koenigshofer et al., 2018)

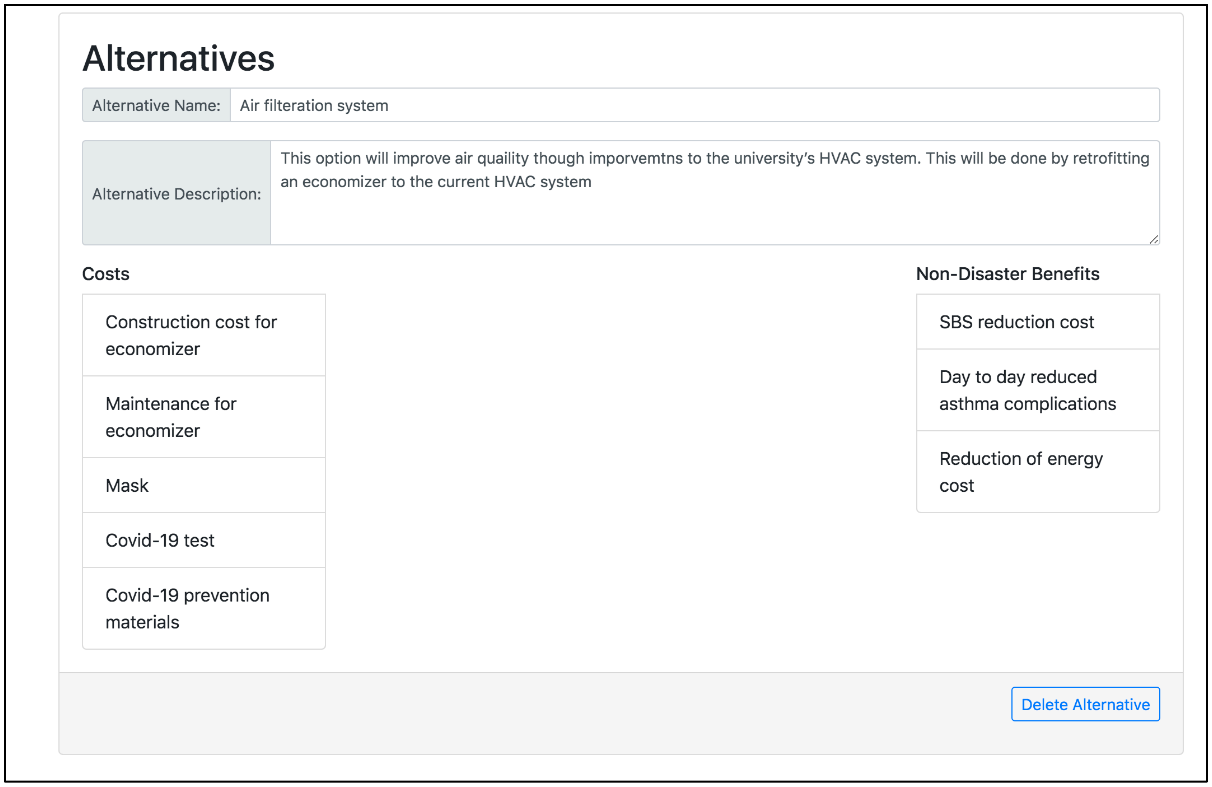

Figure 2. EDGe$ inputs for Air filtration alternative

6.1.2 Alternative 2: Isolation housing

The isolation housing alternative includes a number of direct cost, reoccurring maintenance costs, and a co-cost. The direct cost includes the cost of renting 200 hotel rooms at a charge of $100 per day, before adding a university discount of 20 %. Each room must have an air purifier system with an assumed cost of $ 185 per air purifier. An additional shuttle bus must be purchased due to extra travel needs from off-campus housing to campus. This additional cost is $500 000. COVID-19 prevention/cleaning supplies are necessary at a cost of $ 33 per person for cleaning materials and a $ 133/per person disposable mask cost assuming a third of the population will need a mask daily. COVID-19 testing is also a necessary cost at $ 100 per test and a limit of one per person. Maintenance costs must also be considered. A yearly maintenance cost for the air purifiers are necessary in keeping them functioning efficiently. The cost of each filter is $ 175 per/ filter. The addition of a shuttle bus also accrues a yearly maintenance cost of $ 90 000. The air filtration alternative has two co-costs associated with it. The loss of housing revenue for the 200 students on-campus dorms must be considered given each room has an average yearly revenue of $ 6000. The air purifiers also have a co-cost considering the use of them is expected to increase energy cost at the hotel. This cost is assumed to be $56/per year per air purifier and the cost burden is put on the university.

Table 2. Cost inputs for alternative 2 (Isolation housing)

Cost Category	Description	Cost
Direct	Hotel rental cost Assuming $100 per room then an additional 20% discount. ($80). 200 rooms will need to be rented for the entire academic year (224 days[6])	$3 584 000 ("Best Western Plus Wilmington / Carolina Beach",n.d.)
Direct	Air purifier cost Each isolation room must have an air purifier: 200 purifiers with an assumed cost of $185 each	$ 37 000 (Santanachote, 2019)
Direct	One additional shuttle bus	$ 500 000 (*Transit Facts and Figures ,n.d.)*
Direct	Sanitizer, cleaning materials, thermometers etc. $ 33 per person with a population of 19 600 individuals	$646 800 ("Reopening Schools During a Time of Triple Crisis: Financial Implications," 2020)
Direct	The cost of disposable mask, assuming 1/3 of population need mask each day at $133 per person (based on a 224 day academic year)	$ 868 899 ("Reopening Schools During a Time of Triple Crisis: Financial Implications," 2020)
Direct	COVID-19 test Assuming $100 per test and one test per person	$ 1 960 000 ("Reopening Schools During a Time of Triple Crisis: Financial Implications", 2020)
Indirect cost	Loss of housing revenue for 200 dorms Assuming an average cost of $6,000 per academic year	$ 1 200 000 ("Housing & Residence Life." ,n.d.)
Indirect cost (Co-cost)	Energy increases from air purifiers paid by university Assuming $ 56/per year per purifier	$ 11 200 000 (Santanachote, 2019)
OMR	Air purifier filter cost The yearly cost of replacing the filter in each air purifier assuming a filter cost of $ 175	$ 35 000 annually (Santanachote, 2019)
OMR	Yearly service cost for bus	$ 90 000 (Transit Facts and Figures, n.d.)

[6] 224 days for the hotel calculations in reference to a college academic year (i.e., 7 days for 32 weeks)

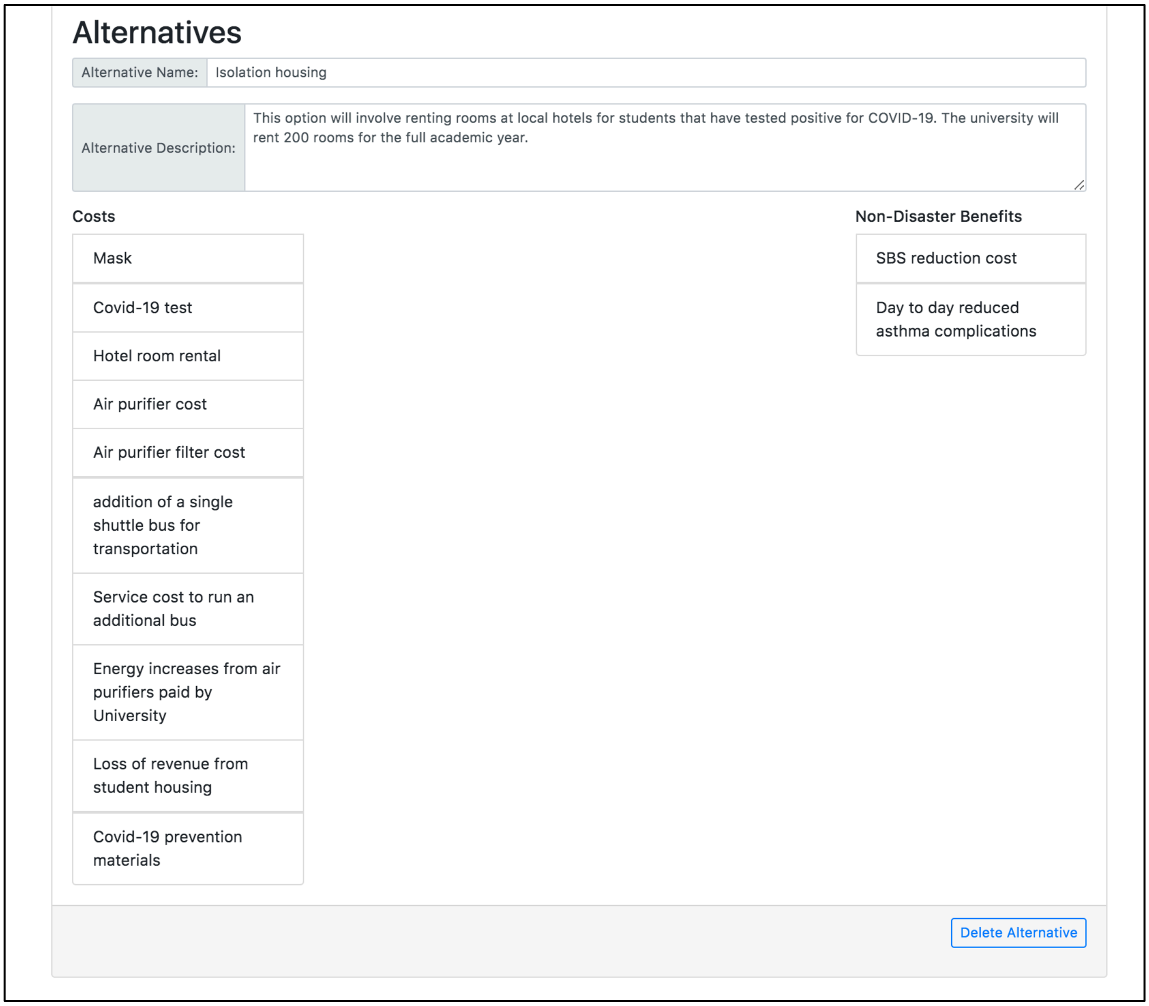

Figure 3. EDGe$ inputs for isolation housing

6.1.3 Alternative 3: Outdoor facility

The alternative of an outdoor facility includes a number of direct costs, as well as one re-occurring maintenance cost.[7] The direct costs include: a WiFi expansion over a large area with a cost of $ 462 000; the cost of offering of 100 rentable laptops with a cost of $ 735 per laptop; a 10 000 sq/ft (929.0304 sq/m) aluminum pergola assuming a material cost of $ 25 per sq/ft (0.09 sq/m) and a labor cost of $ 18.50 per sq/ft (0.09 sq/m); an extensive green roof for the 10 000 sq/ft (929.03 sq/m) pergola assuming a cost of $ 172 per sq/ft (0.09 sq/m) (COVID-19 prevention/cleaning supplies at a cost of $ 33 per person for cleaning materials; $ 133 per person disposable mask cost assuming a third of the population will need mask; and, COVID-19 testing is also a necessary cost at $ 100 per test and a limit of one per person. The extensive green roof has a yearly maintenance cost of $ 11.11 per sq/meter (0.09 sq/m).

[7] The proposed outdoor facility is a study area akin to an outdoor library. If such an outdoor facility was replacing indoor classrooms, energy savings from not having to use indoor classrooms could be considered a non-disaster benefit.

Table 3. Cost inputs for alternative 3 (Outdoor Facility)

Cost Category	**Description**	**Cost**
Direct	WiFi coverage expansion over a large outdoor area	$ 462 000 ("Project Funding and Cost." n.d.)
Direct	Rentable Laptops 100 laptops for students to use in outdoor area, assuming a cost of $ 735 per laptop	$ 73 500 (Leda, 2020)
Direct	Aluminum Pergola 10 000 sq/ft (929.03 sq/m) Assuming materials are $25 per sq/ft (0.09 sq/m) and labor is $18.30 per sq/ft (0.09 sq/m)	$ 433 000 ("How Much Does It Cost to Build a Pergola?" 2017; "Homewyse Calculator: Cost to Install Wood Pergola," n.d.)
Direct	Extensive green roof for pergola (Installation) Assuming $172 per sq/meter (0.09 sq/m)	$ 159 788 (United States General Services Administration, 2011)
Direct	Sanitizer, cleaning materials, thermometers, etc. $ 33 per person with a population of 19 600 individuals	$ 646 800 ("Reopening Schools During a Time of Triple Crisis: Financial Implications," 2020)
Direct	The cost of disposable mask, assuming 1/3 of population need mask each day at $ 133 per person based on a 224 day academic year)	$ 868 899 ("Reopening Schools During a Time of Triple Crisis: Financial Implications," 2020)
Direct	COVID-19 test Assuming $100 per test and one test per person	$ 1 960 000 ("Reopening Schools During a Time of Triple Crisis: Financial Implications," 2020)
OMR	Extensive green roof for pergola (Maintenance) Assuming a yearly cost of $11.11 sq/ft (0.09 sq/m);	$ 2694.10 yearly (United States General Services Administration, 2011)

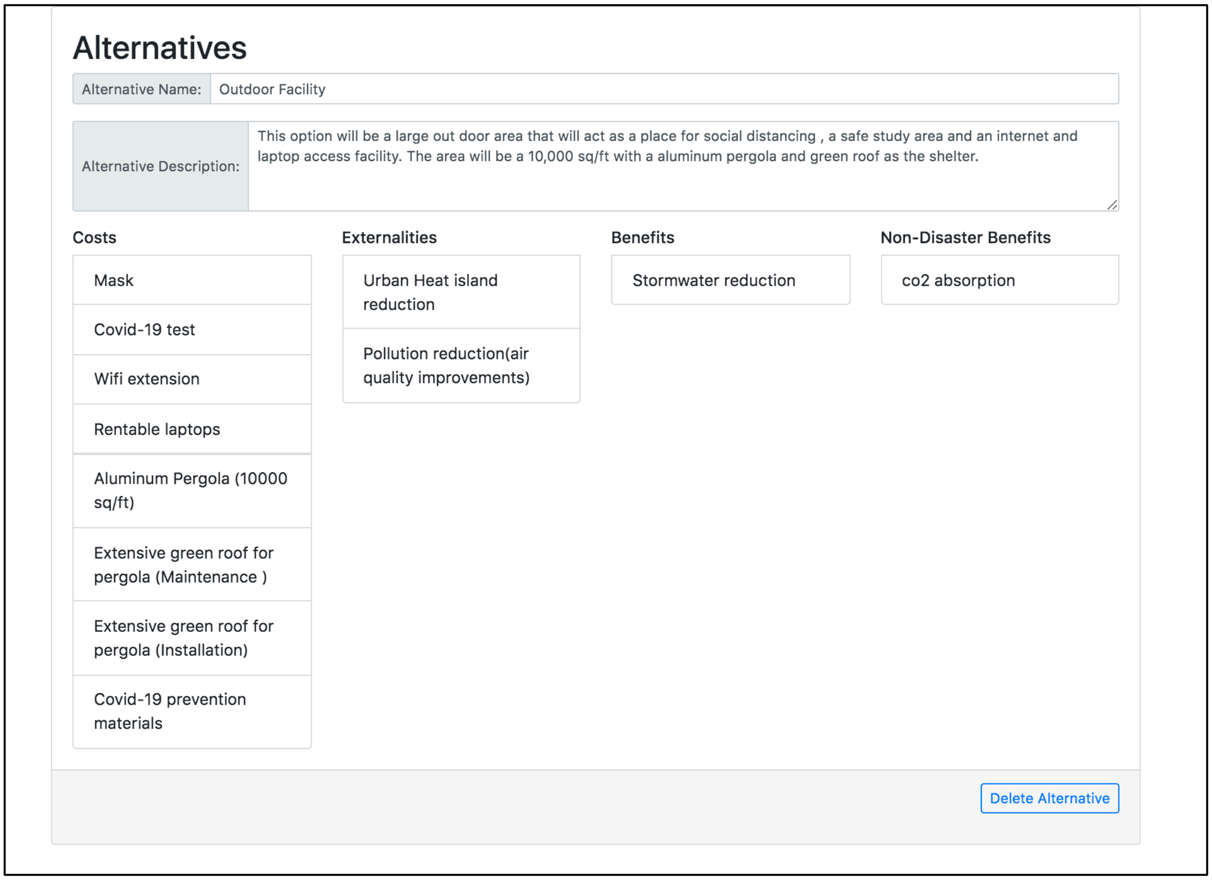

Figure 4. EDGe$ inputs for an outdoor facility

6.1.4 Alternative 4: Complete Online Learning

The alternative of going completely online has a number of direct cost and one indirect cost. The direct cost for this alternative includes a WiFi expansion over a large area with a cost of $ 462 000. The offering of 100 rentable laptops with a cost of $ 735 per laptop and an online meeting platform subscription for remote student/professor interaction. The online platform cost is $ 1999 for 100 hosts (i.e., each class or professor that will use web conferencing would count as one host).[8] In this analysis a 100 hosts are assumed, but the numbers can vary and additional hosting access might a necessary purchase. The complete loss of student housing must be considered as an indirect cost. The loss for all on-campus housing revenue is $31 470 641.

Table 4. Cost inputs for alternative 4 (Online learning)

Cost Category	Description	Cost
Direct	WiFi coverage expansion over a large outdoor area	$ 462 000 (“Project Funding and Cost.” n.d.)

[8] This value is derived from the cost for a Zoom™ enterprise account.

Direct	Rentable Laptops 100 laptops for students to rent within the outdoor area. Assuming a cost of $ 735 per laptop	$ 73 500 (Leda, 2020)
Direct	Online Platform account $ 1999 for 100 hosts (assuming 100 hosts as a maximum)	$ 1999 ("Video Conferencing, Web Conferencing, Webinars, Screen Sharing," n.d.)
Indirect	Loss of all on-campus housing revenue	$ 31 470 641 (Hudson, 2017)

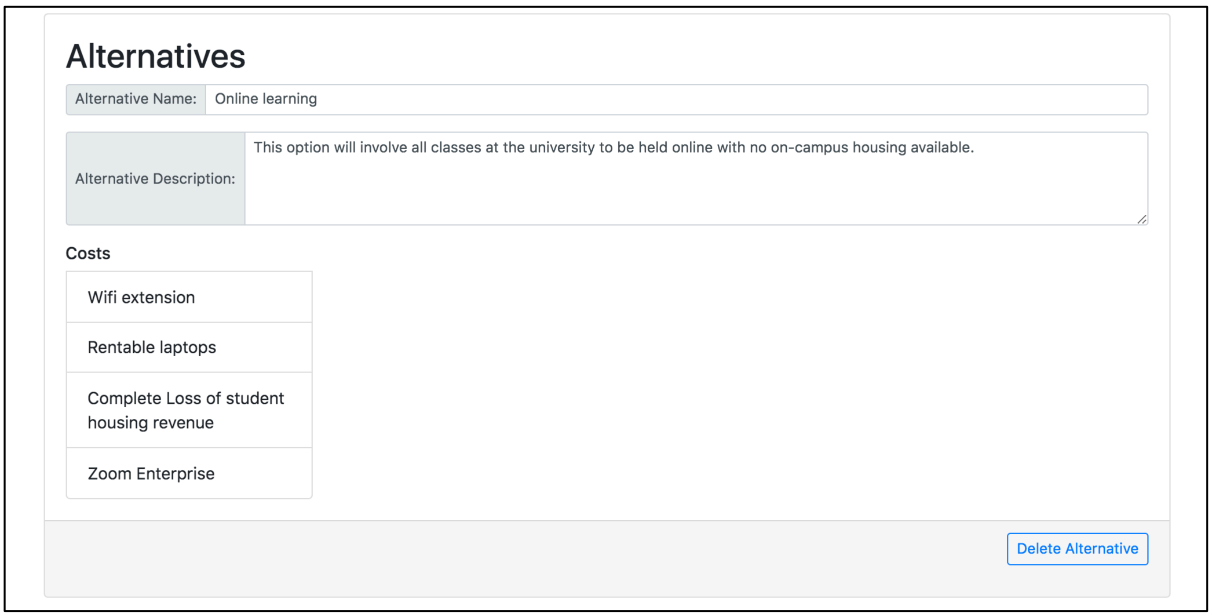

Figure 5. EDGe$ inputs for online learning

6.2 Benefit Data

6.2.1 Alternative 1: Air filtration system upgrade (Retrofitting with an economizer)

The alternative associated with retrofit of an economizer to an existing HVAC system has no direct benefits. This alternative has various non-disaster related benefits. The first co-benefit is the reduction of Sick Building symptoms (SBS). This benefit occurs from better air quality and is assumed to be $222/year per person[9] with an assumption that 16 % of the population suffers

[9] The original health cost estimate of SBS was $182 in 2008 dollars. This value was adjusted for inflation using the Consumer Price Index and brought to the inflation-adjusted 2020 dollar amount, as used here.

from SBS. The second co-benefit occurs from a reduction in asthma complications from improved air quality. This benefit is found to be $ 64 / year per person with an assumption that 7.7 % of the population suffers from asthma. The last co-benefit is a reduction of energy cost that accrues from a decrease in heating and cooling cost with the new addition to the HVAC system. The fatalities averted from this alternative are assumed to be nine lives, equating to total of $ 113.76 million in the value of a statistical life(s). The assumptions and framework of the fatalities averted calculations are below. No positive or negative externalities were found with this alternative.

Table 5. Non-Disaster related benefits (Resilience dividend) for alternative 1

Description	***Benefit***
SBS (Sick building symptoms) reduction cost This benefit occurs from better air quality Assuming a benefit of $ 222/year per person with 16.8 % of population being susceptible to SBS.	$ 731 001.61 early (Fisk et al., 2011)
Day to day reduced asthma complications This benefit occurs from better air quality. Assuming a benefit of $64/year per person and 7.7 % of the population has asthma	$96 576 ("Most Recent National Asthma Data," 2020; Martenies and Batterman 2018)
Energy cost reduction This benefit occurs from lowered heating and cooling cost arising from use of the economizer.	$ 4 256 yearly (Koenigshofer, 2018)

<u>**Fatalities averted**</u>

The assumed mortality rate is 1 %. ("Do the Benefits of COVID-19 Policies Exceed the Costs? Exploring Uncertainties in the Age–VSL Relationship," 2020)

Value of a statistical life (aged 15 to 24): $ 12.64 million ("Do the Benefits of COVID-19 Policies Exceed the Costs? Exploring Uncertainties in the Age–VSL Relationship." 2020)

No intervention: 83% population is infected in the 100 days (Gressman and Peck, 2020)

University population : 14 624

Total Fatalities: 15

Air filtration alternative: 36 % of community population is infected in 100 days (Gressman and Peck, 2020)

5 712 individuals infected

Total Fatalities: 6

Fatalities averted: 9

Monetized value of lives saved : $ 113.76 million

6.2.2 Alternative 2: Isolation housing

The isolation housing alternative includes no direct benefits. This alternative includes one non-disaster related benefit (co-benefit); this co-benefit is a reduction in asthma complications that occur with better air quality. This benefit is found to be $ 64 / year per person with an assumption that 7.7 % of the population suffers from some level of asthma or allergy resulting in similar breathing issues (Martenies and Batterman, 2018). This benefit accrues due to the air purifiers placed in each hotel room. The fatalities averted from this alternative are assumed to be nine lives and come to a monetary total of $ 113.76 Million. The assumptions and framework of the fatalities averted calculations are below. No positive or negative externalities were found with this alternative.

Table 6. Non- Disaster related benefits (Resilience dividend) for alternative 2

Description	***Benefit***
Day to day reduced asthma complications This benefit occurs from better air quality. Assuming a benefit of $ 64/year per person and 7.7 % of the population has asthma	$ 96 576 ("Most Recent National Asthma Data," 2020; Martenies and Batterman, 2018)
SBS (Sick building symptoms) reduction cost This benefit occurs from better air quality Assuming a benefit of $222 /year per person with 16.8 % of population being susceptible to SBS.	$ 731 001.06 yearly (Fisk, et al., 2011)

<u>Fatalities averted</u>

The assumed mortality rate is 1 % ("Do the Benefits of COVID-19 Policies Exceed the Costs? Exploring Uncertainties in the Age–VSL Relationship," 2020)

Value of a statistical life (aged 15 to 24): $ 12.64 million ("Do the Benefits of COVID-19 Policies Exceed the Costs? Exploring Uncertainties in the Age–VSL Relationship," 2020)

No intervention: 83 % population is infected in the 100 days (Gressman and Peck, 2020)

University Student population : 14 624

Total Fatalities: 15

Air filtration alternative: 36 % population is infected in 100 days (Gressman and Peck, 2020)

5712 infected

Total Fatalities: 6

Fatalities averted: 9

Monetary benefit of lives saved : $ 113.76 million

6.2.3 Alternative 3: Outdoor Facility

The alternative of an outdoor facility includes one direct benefit. This direct benefit is a reduction in storm water that is a nuisance faced by the university in this use case. The benefit accounts for a reduction in storm water damages attributed to having a green roof and assumes a benefit of $13.60 per ft^2 (0.093 m^2) of green roof which accrues every year.

This alternative includes one non-disaster related benefit, the benefit is the absorption of CO_2 from the inclusion of a green roof. The benefit is assumed to be $12.10 per ft^2 (0.093 m^2) a green roof and accrues ever year. The fatalities averted from this alternative are assumed to be 15 lives and come to a monetary total of $189.6 million.

The assumptions and framework of the fatalities averted calculations are provided, below.

This alternative includes two positive externalities. The first is reduction in the urban heat island effect that occurs from the inclusion of an extensive green roof. The benefit accrues every year at the rate of $0.23 per ft^2 (0.093 m^2) of green roof. The second positive externality is pollution reduction (i.e., air quality improvements) for the entire college town. This positive externality addresses the pollution reduction of NO_x, SO_2 and PM(10) pollutants attributed by the extensive green roof. The value of NO_x abatement is $29 per ft^2 (0.093 m^2) green roof, SO_2 is $.000002 per ft^2 (0.093 m^2) of green roof and PM(10) is $0.00115 ft^2 (0.093 m^2) of green roof. All greenhouse gas reductions accrue every year during the study period.

Table 7. Direct Benefits (Benefits screen in EDGe$) for Alternative 3

Description	***Benefit***
Storm water reduction This benefit accounts for the reduction in storm water damages attributed to having a green roof assuming $13.6 ft^2 (0.093 m^2) of green roof	$ 136 000 (USGSA, 2011)

Table 8. Non-Disaster related benefits (i.e., resilience dividend) for Alternative 3

Description	***Benefit***
CO_2 absorption This benefit accounts for the CO_2 absorption in the air surrounding the university attributed to the extensive green roof assuming a benefit of \$12.10 per ft^2 (0.093 m^2)	\$ 121 000 yearly (USGSA, 2011)

Fatalities averted

The assumed mortality rate is 1%. *(*“Do the Benefits of COVID-19 Policies Exceed the Costs? Exploring Uncertainties in the Age–VSL Relationship.” 2020)

Value of a statistical life (aged 15-24): \$12.64 million *(*“Do the Benefits of COVID-19 Policies Exceed the Costs? Exploring Uncertainties in the Age–VSL Relationship.” 2020)

No intervention: 83 % population is infected in the 100 days (Gressman and Peck, 2020)

University population: 14 624

Total Fatalities: 15

Outside facility: No deaths given percentage of fatalities in this specific age range

Total Fatalities averted: 15

Monetary benefit of lives saved \$ 189.60 Million

Table 9. Externalities for Alternative 3

Description	***Benefit***
Urban Heat island reduction The reduction of heat in the atmosphere that accompanies the extensive green roof. The benefit is \$0.23 per ft^2 (0.093 m^2)	\$ 2 300 yearly
Pollution reduction (air quality improvements) This positive externality addresses the pollution reduction of NOx, SO_2 and PM(10) pollutants attributed by the extensive green roof. The value of NOx abatement is \$29 per ft^2 (0.093 m^2), SO_2 is \$0.000002 per ft^2 (0.093 m^2) and PM(10) is \$.00115 per ft^2 (0.093 m^2)	\$ 2 911.52 yearly

6.2.4 Alternative 4: Online Learning

The alternative of going completely online has no direct benefits, non-direct benefits (resilience dividend) or externalities. The fatalities averted from this alternative are assumed to be 15 lives and come to a monetary total of $189.6 million. The assumptions and framework of the fatalities averted calculations are below.

Fatalities averted

The assumed mortality rate is 1%. ***(***“Do the Benefits of COVID-19 Policies Exceed the Costs? Exploring Uncertainties in the Age–VSL Relationship.”2020)

Value of a statistical life (aged 15-24): $12.64 million ***(***“Do the Benefits of COVID-19 Policies Exceed the Costs? Exploring Uncertainties in the Age–VSL Relationship.”2020)

No intervention: 83 % population is infected in the 100 days (Gressman and Peck, 2020)

University population: 14 624

Total Fatalities : 15

Outside facility: No deaths given percentage of fatalities in this specific age range

Fatalities averted: 15

Monetary benefit of lives saved $189.60 million

7. Analysis and EDGe$ Output

The EDGe$ Online output for all four alternatives across the four different planning horizons are listed below in Tables 10-13. Red dollar values in parentheses indicate a negative value for all tables in this section. There are two numbers for NPV provided in the output, with and without externalities.[10]

In all four alternative cases, across the four defined planning horizons, the alternative with the highest NPV is the outdoor facility. This is the case for when externalities are included, as well as when they are not. A crucial parameter to analysis when suggesting pandemic resilience plans, is fatalities averted. In looking at the output, loss of lives averted from the various resilience alternatives played a large role in determining the course of action suggested through the BCA.

[10] Present expected values are given for costs and externalities as well.

Table 10. EDGe$ output for Pandemic example at a 5-year horizon

	Air filtration	**Isolation housing**	**Outdoor Facility**	**Online learning**
DISASTER ECONOMIC BENEFITS				
Direct Loss Reduction	$0	$0	$ 12 819.53	$ 0
Disaster Non-Market Benefits				
Value of a statistical lives saved	$ 10 723 157.96	$ 10 723 157.96	$ 17 871 929.93	$ 17 871 929.93
Number of Statistical Lives Saved	.9	.9	1.5	1.5
Non-disaster Related Benefits				
Reoccurring	$ 3 804 615.29	$3 785 149.32	$553 426.13	$0
Costs				
Direct cost	$ 3 859 689	$ 7 596 689	$ 4 602 977	$ 537 499
Indirect cost	$0	$ 1 211 200	$0	$ 31 470 641
OMR cost				
Recurring	$ 6 860.65	$ 571 721.21	$ 12 321.74	$0
EXTERNALITIES				
Positive (reoccurring)	$0	$0	$ 23 836.29	$0
Present Expected Value				
Benefits	$ 14 527 773.24	$ 14 508 307.28	$18 438 175.58	$ 17 871 929.93
Cost	$ 3 866 549.65	$ 9 379 610.21	$ 4 615 298.74	$ 32 008 140
Externalities	$ 0	$ 0	$ 23 836.29	$ 0
With Externalities				
Net (NPV)	$ 10 661 223.59	$ 5 128 697.07	$ 13 846 713.14	($14 136 210.07)
Benefit-to-Cost Ratio with Externalities	3.76	1.55	4.0	.56
Internal Rate of Return with Externalities (%)	No IRR	9.48	No IRR	No IRR

Return on Investment with Externalities (%)	55.15	10.94	60.0	-8.83
Non-Disaster ROI with Externalities (%)	19.68	8.07	2.5	0
Without Externalities				
Net (NPV)	$10 661 223.59	$5 128 697.07	$ 13 846 713.14	($14 136 210.07)
Internal Rate of Return with Externalities (%)	No IIR	9.48	No IIR	No IIR
Benefit-to-Cost Ratio without Externalities	3.76	1.55	4.0	.56
Return on Investment without Externalities (%)	55.15	10.94	59.9	-8.83
Non-Disaster ROI without Externalities (%)	19.68	8.07	2.4	0

Table 11. EDGe$ output for Pandemic example at a 10-year planning horizon

	Air filtration	**Isolation housing**	**Outdoor Facility**	**Online learning**
DISASTER ECONOMIC BENEFITS				
Direct Loss Reduction	$ 0	$0	$ 23 853.40	$ 0
Disaster Non-Market Benefits				
Value of a statistical lives saved	$ 19 952 665.54	$ 19 952 665.54	$ 33 254 442.57	$ 33 254 442.57
Number of Statistical Lives Saved	1.8	1.8	3	3
Non-disaster Related Benefits				
Reoccurring	$ 7 079 278.01	$ 7 043 057.54	$ 1 029 764.41	$0
Costs				
Direct cost	$ 3 859 689	$ 7 596 689	$ 4 602 977	$ 537 499
Indirect cost	$ 0	$ 1 211 200	$ 0	$ 31 470 641
OMR cost				
Recurring	$ 12 765.67	$ 1 063 806.21	$ 22 927.15	$0

EXTERNALITIES				
Positive (reoccurring)	$ 0	$ 0	$ 44 352.38	$ 0
Present Expected Value				
Benefits	$ 27 031 943.55	$ 26 995 723.08	$ 34 308 060.38	$ 33 254 442.57
Cost	$ 3 872 454.67	$ 9 871 695.21	$ 4 625 904.15	$ 32 008 140.00
Externalities	$ 0	$ 0	$ 23 836.29	$ 0
With Externalities				
Net (NPV)	$ 23 159 488.88	$ 17 124 027.86	$ 29 726 508.60	$ 1 246 302.57
Benefit-to-Cost Ratio with Externalities	6.98	2.73	7.43	1.04
Internal Rate of Return with Externalities (%)	No IRR	26.23	No IRR	No IRR
Return on Investment with Externalities (%)	59.81	17.35	64.26	0.39
Non-Disaster ROI with Externalities (%)	18.28	7.13	2.32	0
Without Externalities				
Net (NPV)	$ 23 159 488.88	$ 17 124 027.86	$ 29 682 156.23	$ 1 246 302.57
Internal Rate of Return with Externalities (%)	No IRR	26.23	No IRR	No IRR
Benefit-to-Cost Ratio without Externalities	6.98	2.73	7.42	1.04
Return on Investment without Externalities (%)	59.81	17.35	64.17	0.39
Non-Disaster ROI without Externalities (%)	18.28	7.13	2.23	0

Table 12. EDGe$ output for Pandemic example at a 20-year planning horizon

	Air filtration	**Isolation housing**	**Outdoor Facility**	**Online learning**
DISASTER ECONOMIC BENEFITS				

Direct Loss Reduction	$ 0	$ 0	$ 41 524.43	$ 0
Disaster Non-Market Benefits				
Value of a statistical lives saved	$ 3 473 396.37	$ 3 473 396.37	$ 5 788 993.95	$5 788 993.95
Number of Statistical Lives Saved	3.6	3.6	6.0	6.0
Non-disaster Related Benefits				
Reoccurring	$ 12 323 736.15	$ 12 260 682.89	$ 1 792 632.65	$ 0
Costs				
Direct cost	$ 3 859 689	$ 7 596 689	$ 4 602 977	$ 537 499
Indirect cost	$0	$1 211 200	$0	$ 31 470 641
OMR cost				
Recurring	$ 22 222.72	$ 1 851 893.24	$ 39 912.00	$0
EXTERNALITIES				
Positive (reoccurring)	$0	$0	$ 77 209.43	$0
Present Expected Value				
Benefits	$47 057 699.87	$46 994 646.61	$ 59 724 096.62	$ 57 889 939.54
Cost	$ 3 881 911.72	$ 10 659 782.24	$ 4 642 889.00	$ 32 008 140.00
Externalities	$0	$0	$77,209.43	$0
With Externalities				
Net (NPV)	$ 43 175 788.15	$ 36 334 864.37	$ 55 158 417.05	$ 25 881 799.54
Benefit-to-Cost Ratio with Externalities	12.12	4.41	12.88	1.81
Internal Rate of Return with Externalities (%)	No IRR	28.65	No IRR	No IRR
Return on Investment with Externalities (%)	55.61	17.04	59.4	4.04
Non-Disaster ROI with Externalities (%)	15.87	5.75	2.01	0
Without Externalities				
Net (NPV)	$ 43 175 788.15	$ 36 334 864.37	$ 55 081 207.62	$ 25 881 799.54
Internal Rate of Return with Externalities (%)	No IIR	28.65	No IIR	No IIR

Benefit-to-Cost Ratio without Externalities	12.12	4.41	12.89	1.81
Return on Investment without Externalities (%)	56.61	17.04	59.4	4.04
Non-Disaster ROI without Externalities (%)	15.87	5.75	1.93	0

Table 13. EDGe$ output for Pandemic example at a 50-year planning horizon

	Air filtration	**Isolation housing**	**Outdoor Facility**	**Online learning**
DISASTER ECONOMIC BENEFITS				
Direct Loss Reduction	$0	$0	$ 71 498.02	$0
Disaster Non-Market Benefits				
Value of a statistical lives saved	$ 59 805 994.55	$ 59 805 994.55	$ 99 676 657.59	$ 99 676 657.59
Number of Statistical Lives Saved	9.0	9.0	15.0	15.0
Non-disaster Related Benefits				
Reoccurring	$ 21 219 383.51	$ 21 110 816.49	$ 3 086 609.40	$0
Costs				
Direct cost	$ 3 859 689	$ 7 596 689	$ 4 602 977	$ 535 500.00
Indirect cost	$ 0	$ 1 211 200	$ 0	$ 31 470 640
OMR cost				
Recurring	$ 38 263.75	$ 3 188 646.07	$68,721.70	$ 0
EXTERNALITIES				
Positive (reoccurring)	$ 0	$ 0	$ 132 941.54	$ 0
Present Expected Value				
Benefits	$ 81 025 378.06	$ 80 916 811.04	$ 102 834 765.01	$ 99 676 657.59
Cost	$ 3 897 952.75	$ 11 996 535.07	$ 4 671 698.70	$ 32 008 140.00

Externalities	$ 0	$ 0	$ 132 941.54	$ 0
With Externalities				
Net (NPV)	$ 77 127 425.31	$ 68 920 275.97	$ 98 296 007.85	$ 67 668 517.59
Benefit-to-Cost Ratio with Externalities	20.79	6.75	22.04	3.11
Internal Rate of Return with Externalities (%)	No IRR	28.77	No IRR	No IRR
Return on Investment with Externalities (%)	39.57	11.49	42.08	4.23
Non-Disaster ROI with Externalities (%)	10.89	3.52	1.38	0
Without Externalities				
Net (NPV)	$ 77 127 425.31	$ 68 920 275.97	$ 98 163 066.31	$ 67 668 517.59
Benefit-to-Cost Ratio without Externalities	20.79	6.75	22.01	3.11
Internal Rate of Return with Externalities (%)	No IIR	28.77	No IIR	No IIR
Return on Investment without Externalities (%)	39.57	11.49	42.02	4.23
Non-Disaster ROI without Externalities (%)	10.89	3.52	1.32	0

8. Discussion and Future Research

Resilience modeling for pandemics can be particularly difficult due to evolving health concerns and uncertain details related to transmission rates and processes associated with each new pandemic. As can be concluded from the EDGe$ Online output for this use case, the value of fatalities averted played a crucial role in determining the BCA outcome. The severity of the pandemic and how contagious and fatal it is play a crucial role in resilience planning that relates to pandemic resilience. Since these factors change with every pandemic occurrence, future research on how to mitigate fatalities over a range of possible pandemic parameters is necessary for a more all-encompassing analysis.

It is clear that pandemics are a challenging event to map into a resilience plan due to the high level of uncertainty surrounding severity, along with the rate at which pandemics occur. Morens and Taubenberger (2011), suggest that pandemics, influenza specifically, have uncertainty in the “patterns of pandemic recurrence, the stability of its endemic persistence, its eventual disappearance, and its ability to cause fatalities” (2011, page number?). This use case suggests that sensitivity analysis must be done on the reoccurrence rate due to this level of uncertainty. It would also be wise to do a sensitivity analysis on fatalities averted to account for the changing fatality rates across pandemic diseases. For example, considering influenza in this use case would make a number of assumed values quite different.

Future research on the reoccurrence rate of pandemics, along with research about other pandemic-specific parameters used in this use case may lead to more effective BCA, and ultimately more useful pandemic resilience plans. Additionally, other analysis alternatives could be helpful in fully determining the best plan of action. For example, alongside a BCA, a multi-criteria analysis (MCA) is an option that would be beneficial for a pandemic resilience analysis. Multi-criteria analysis is best used “when goals, in addition to efficiency are relevant, as well as when efficiency is the only goal, but relevant impacts cannot be confidently monetized.” Multi-criteria analysis works though the notion that “ alternatives should be compared in terms of all the relevant goals” (Boardman, 45).

It should also be noted that net co-benefits (i.e., resilience dividend) had a large effect on the outcome of the BCA in this use case. Future research of the different pandemic resilience alternatives that carry co-benefits and on how to properly monetize the resulting resilience dividends would greatly increase the benefits that accrue to the community. Given that COVID-19 is the sixth global pandemic in the last century, pandemics will be a reoccurring issue that is of concern at the community scale. Resilience plans that relate directly to mitigating the effects of a pandemic are highly relevant. Yet, since so many university communities face additional chronic and acute hazards, pandemic planning is ideally included within larger resilience planning efforts that are pertinent to mitigating social and economics losses.

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