Effective digital contact-tracing in the wake of the COVID-19 pandemic

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1. Introduction

Governments have increasingly been using contact-tracing applications (apps) to keep COVID-19 under control. These apps are a big part of existing government policies to combat COVID-19. According to the literature, traditional means of contact-tracing have been highly effective in the challenge to combat COVID-19 (Wang et al. 2021; Acemoglu et al. 2020). Contact-tracing apps, - or digital contact tracing, complements these traditional means. Contact-tracing apps use Bluetooth or location data to ‘predict’ COVID-19 exposures. When an infected individual comes in near proximity of another individual for some predetermined amount of time, the exposed individual receives a notification that recommends him or her to stay at home or to get tested.

Governments put a lot of attention on the implementation of these apps in their press conferences, policy briefs, public announcements, and campaigns. These apps are prone to criticism, due to arising issues with Big Data ethics (such as privacy) and the question if these apps are even effective at all (Parker et al. 2020; Cho et al. 2020). The introduction of contact-tracing apps is part of a broader digitalization of the public sector: questions of privacy, security, and digitization are on the mind of many Public Administration scholars. However, clear ethical and practical frameworks for digitization are often still lacking (Janowski 2015; Sarker 2018; Royakkers 2018).

It is interesting that the success of contact-tracing apps vastly differs among countries. For example, adoption rates (the percentage of people that downloaded the app) in some countries are much higher than in others. The contact-tracing app of Ireland has an adoption rate of almost 51%. In contrast, in Spain, only 15.5% of citizens have downloaded the app. Moreover, there have been countries where the contact-tracing apps have been canceled or suspended entirely (European Data Protection Board 2020; Sato 2020). What determines the success or failure of contact-tracing apps?

Defining the success of contact-tracing apps can be complex. Existing literature names several factors that are important for the success of contact-tracing apps, such as adoption rates (Kleinman & Merkel 2020) and the accuracy of predictions (Hinch et al. 2020; Kleinman & Merkel 2020). Also, some contact-tracing apps have been suspended or canceled, which implies that these apps are a failure (European Data Protection Board 2020; Sato 2020). Therefore, the success of contact-tracing apps cannot be attributed to only one factor. Since the concept is quite complex, this thesis will extensively discuss how success is defined and measured.

When the complex nature of success has been defined, what are then sufficient or necessary conditions for a contact-tracing app to be successful? The analysis in this thesis will look at multiple conditions. First of all, an ethical implementation of contact-tracing apps is hypothesized to be a condition for success, since it could directly impact the success of contact-tracing apps (Parker et al. 2020). Secondly, an effective underlying technology and follow-up are expected to be necessary or sufficient for successful contact-tracing apps (Braithwaite et al. 2020; Hinch et al. 2020). Next, it is hypothesized that promotion from the government and trust in the government increases adoption, and thus success (Parker et al. 2020; Riemer et al. 2020). Finally, a high willingness of citizens to adopt new technologies is expected to be a condition for successful contact-tracing apps.

These conditions are expected to influence the success of contact-tracing apps and will be assessed in this thesis. However, since 'success' is multifaceted and complex in nature, it can be expected that the conditions influencing success are equifinal. While existing literature suggests how individual conditions could influence the outcome, no literature exists on how these conditions are interacting with each other: it could be that multiple conditions are needed for success, or that there are multiple 'paths' to success, - the so-called equifinality of the concept.

There seems to be a research gap on the effectiveness and success of contact-tracing apps. Existing literature on the topic of COVID-19 and contact-tracing is expanding rapidly. However, no worthwhile efforts to assess the necessary or sufficient conditions of contact-tracing apps have been published. Most existent literature focuses on the question *if* contact-tracing apps are effective at all, but does not focus on the comparison between apps: no comparative and configurative research has been done to assess the relationship between the existence or non-existence of various conditions and the resulting success or non-success of contact-tracing apps. Such research could identify why countries failed or succeeded in implementing digital contact-tracing. In the future, research of this kind could help in the development of contact-tracing apps during this, - or future pandemics. This thesis shows which conditions are *necessary* or *sufficient* for contact-tracing apps. When governments are creating these apps, these factors are of utmost importance for success.

Substantive literature does exist on contact-tracing itself, which can be used to hypothesize the conditions needed for a contact-tracing app to be successful. Moreover, literature on Big Data ethics can be used to determine which principles should be in place for ethical implementations of contact-tracing apps.

This thesis will attempt to answer the following research question: *'Which conditions are sufficient or necessary for contact-tracing apps to be successful'*?

To answer the research question, a *Crisp-set Qualitative Comparative Analysis* (csQCA) will be executed. This method is chosen since it allows the researcher to qualitatively assess multiple cases on several conditions. Moreover, the research design is well-suited to deal with equifinality and the interaction of multiple conditions. Cases will be selected within Europe, in an iterative process based on the availability of the data and language barriers. The csQCA will determine which conditions are sufficient or necessary for the outcome variable 'success of the contact-tracing app'.

This thesis will be structured as followed. In the theory section, it will be theorized which conditions should be included to determine if a contact-tracing app is successful. For this purpose, several papers on Big Data ethics and contact-tracing will be discussed. Moreover, it will be assessed when the conditions are 'present' or 'absent', as necessitated by the crisp-set approach of QCA. For the outcome variable, it will be determined, - using theory, when a contact-tracing app is successful. In the methods section, the csQCA method will be extensively discussed. This section will go into the iterative process of csQCA. Afterward, the analysis and results chapter will assess the cases on the hypothesized conditions and execute the csQCA analysis. This will result in the minimal formula's that show which conditions are necessary or sufficient for successful digital contact-tracing. Then, some limitations of the research will be discussed. The thesis will end in a conclusion and discussion, answering the research question.

2. Theoretical framework

Policymakers today live in a vastly different landscape than two decades ago. The digitization of the public sector has been studied by Public Administration scholars extensively. However, the digitization of governance is still moving forward rapidly (Janowski 2015). Questions of digitization, privacy, and security are on the mind of many Public Administration scholars, however, clear ethical or practical frameworks are often lacking due to the speed of digital transformations (Sarker 2018). Contact-tracing apps are a new challenge for Public Administration. How can these apps be successfully implemented by governments in existing COVID-19 policies? Are the infringements on ethical principles justified in the light of the COVID-19 pandemic? How should these apps be implemented effectively? These are all questions that come to mind when thinking about contact-tracing apps in relation to Public Administration.

In this chapter of the thesis, existing literature will be used to theorize both *when a contact-tracing app is successful* and some *conditions that could, either individually or in combination with other conditions, be necessary or sufficient* for a contact-tracing app to be successful. In the first part of this chapter, it will be defined what makes a contact-tracing app successful. In the second part of the chapter, some conditions for the success of contact-tracing apps will be discussed. It is important to stress the difference between the 'success of a contact-tracing app' and the hypothesized conditions for a contact-tracing app to be successful. The success of a contact-tracing app is the actual outcome of the implementation of contact-tracing apps for different countries. For example: did the Dutch CoronaMelder app manage to indicate a high number of COVID infections? Did many people download the app in the Netherlands? Is the app canceled or continued? These are actual outcomes. In contrast, the hypothesized relevant conditions show individual characteristics of the contact-tracing apps and countries, such as an ethical implementation of the app, the underlying technology that was used, and the amount of government promotion that the app received.

2.1 Success of contact-tracing apps

To answer the research question, the 'success' of contact-tracing apps needs to be defined. What makes a contact-tracing app successful? Success is not a one-sided concept, and therefore not easy to define. Success is not measured by one scale or criterion, but is 'complex'. The existing literature seems to imply that three general points indicate a successful implementation of contact-tracing apps. First of all, both access to phones and download rates determine the success of contact-tracing apps (Rowe 2020). This can be summarized in a general 'adoption rate', which indicates the percentage of all people of a country that downloaded a contact-tracing app. Second, the actual accuracy and effectiveness of the contact-tracing apps are important for success (Hinch et al. 2020). Is the app generally seen as successful in identifying COVID-19 cases? Did the app manage to get infected individuals in quarantine? This determinant shows if the app managed to uncover a significant amount of infections. Finally, the continuation, cancellation, or suspension of contact-tracing apps could identify their success. In this part of the theoretical framework, these determinants of successful contact-tracing are detailed further.

A combination of these three determinants would imply a successful implementation of contact-tracing apps. When a contact-tracing app is canceled or suspended early, the app would directly become a failure, since it would fail to effectively predict COVID-19 transmissions. When only a combination of a high adoption rate with a continuation of the app, or a high adoption rate with accurate predictions is present, an individual assessment must determine the success of the app.

The findings are summarized in table 1.

Determinants for successful contact-tracing apps
1. Adoption rate
2. General effectiveness in identifying / quarantining / testing cases
3. The contact-tracing app has been canceled, suspended, or continued.

Table 1: Determinants for successful contact-tracing apps

2.1.1 Adoption rate

According to Rowe (2020), a critical determinant of the success of a contact-tracing app is access to smartphones and high adoption rates. High adoption rates and access to smartphones would increase the chance that when a contagious person comes near another person, contact-tracing apps could identify these potential exposures. Kleinman & Merkel (2020) underline this point: widespread adoption and general effectiveness of contact-tracing apps are dependent on widespread adoption of such apps.

Hinch et al. (2020) published a paper that further validate the need for high adoption rates: they write that *"low rates of app use will result in resurgence of the epidemic and the need for further* *lockdown. With low rates of uptake, digital contact tracing at least delays the interval between lockdowns"* (Hinch et al. 2020: p. 17). They find that an adoption rate of 56% of the population of a country will lead to a suppression of the epidemic. This does not mean that adoption rates lower than 56% are useless. The app has an effect on all levels of adoption (Hinch et al. 2020). Media outlets have often misinterpreted this point, suggesting that contact-tracing apps will only work at an adoption rate of 56% or higher (O'Neill 2020). However, Parker et al. (2020) confirm that adoption rates lower than 50% are still effective in suppressing the pandemic. Like the effectiveness in predicting COVID-19 transmissions, there is no simple threshold for success here: the higher the adoption rate, the more effective the contact-tracing app can be. This raises challenges for the operationalization for Qualitative Comparative Analysis, which will be discussed in the methods chapter.

2.1.2 Effectiveness in predicting and notifying COVID-19 exposures

Hinch et al. (2020) write that the most important measure of success is the extent to which an app reduces transmissions and the number of people that unnecessarily go into quarantine. A successful app should accurately predict COVID-19 transmissions and get the infected people in quarantine (Hinch et al. 2020). The more accurately COVID-19 transmissions are predicted, the higher the effectiveness of the app.

Rowe (2020) writes that the ability of the population to be tested and that these tests are not prone to errors is a key determinant for the effectiveness in predicting COVID-19 exposures. Morerover, Kleinman & Merkel (2020) further develop the need for access to diagnostic testing: the success of contact-tracing apps is fully dependent on it. This seems to imply that not only factors of contact-tracing apps themselves are important, but the follow-up on the initial detection of exposure is important as well. Parker et al. (2020) stress this point: successful contact-tracing should be able to quickly identify cases, gather information about the contacts the infected individual had, and notify and quarantine those contacts (Parker et al. 2020).

2.1.3 Continuation, cancellation, or suspension of contact-tracing apps

Empirical findings show that some contact-tracing apps are either suspended or canceled. For example, the Norwegian contact-tracing app has been canceled due to privacy concerns (European Data Protection Board 2020), and Iran's contact-tracing app has been canceled due to the developers spying on its users (Sato 2020). These indicate instant failures of such apps.

2.2 Conditions for success of contact-tracing apps

Now that it is clear what defines a 'successful' contact-tracing app, some relevant conditions for contact-tracing apps to be successful need to be theorized. As discussed above, these are individual characteristics of the different contact-tracing apps and countries. First, the ethical considerations will be extensively discussed, since widespread adoption and the continuation of the app could be dependent on an ethical implementation (Trivedi & Vashsiht 2020). This leads to some requirements that need to be fulfilled for an ethical contact-tracing app. Afterward, the important requirements for the underlying technologies of contact-tracing apps need to be discussed, since it can be hypothesized that the type of underlying technology affects the effectiveness of contact-tracing apps (Hinch et al. 2020). Next, the follow-up will be discussed: what happens once you have been close to someone that has been infected? The type of follow-up could be an important condition for contact-tracing apps to be successful (Braithwaite et al. 2020). Then, the conditions 'government promotion' and 'trust in the government' will be discussed, since it can be expected that these conditions can lead to successful digital contact tracing (Kleinman & Merkel 2020; Riemer et al. 2020; López et al. 2021). Finally, the condition 'willingness of citizens to adopt new technologies' will be discussed.

2.2.1 Condition 1: An ethical implementation

This thesis will now go into an ethical assessment of contact-tracing apps, to assess the ethicality of different types of contact-tracing apps. This assessment will lead to several determinants of 'ethical' contact-tracing apps. As stated above, widespread adoption of contact-tracing apps stands or falls with people's perception. The use of contact-tracings apps introduces some ethical dilemmas which can influence these perceptions (Parker et al. 2020). Moreover, an unethical implementation could lead to the cancellation of a contact-tracing app due to the app not following legal rules. An example of this in practice is the anti-fraud system 'SyRI', which was canceled since it was in breach with the European Convention on Human Rights (Court of Justice The Hague 2020).

Ethical issues are related to how data is collected, stored, and used by national governments. The problems are thoroughly analyzed in the literature on Big Data ethics. According to Zwitter (2014), the main ethical issue that people have with the use of Big Data is captured by the following citation*: "The more our lives become mirrored in a cyber-reality and recorded, the more our present and past become almost completely transparent for actors with the right skills* *and access"* (Zwitter 2014: pp. 3-4). This shows why citizens could think digital contact-tracing is problematic: they often do not fully know what data is collected, how it is used and stored, and which actors can have access to that data (Zwitter 2014).

First of all, the concepts of privacy, confidentiality, and transparency will be discussed. Afterward, it will be assessed how a balance can be struck between these concepts and effective digital contact-tracing. Finally, several determinants of ethical implementations will be discussed using existing literature.

2.2.1.1 Privacy, confidentiality, and transparency

Richard & King (2014) call for the development of an ethical framework for Big Data ethics. To do so, they stress the importance of three ethical principles that must be in place for the ethical implementation of Big Data: *privacy*, *confidentiality,* and *transparency.*

In the modern-day, privacy entails the rules for the flow of data. It describes what legal and social rules are in place to govern the use and disclosure of our data (Richard & King 2014). Privacy shows to what extent people have control over their data. How is it collected, used, and disclosed? According to Herschel & Miori (2017), the collection and analysis of data can be a problem for ethical theory due to violations of privacy. They write: *"(…) no one has the ability to determine how their data is actually shared and used, because the Big Data space is too big and there is no mechanism affording the individual the ability to actively monitor and control their private information"* (Herschel & Miori 2017: p. 34). Citizens become simple data points to reach the desired goal. The authors raise the argument that you can never fully know what happens with your data. In essence, the privacy of citizens is sacrificed for the sake of reaching a goal (Herschel & Miori 2017).

On the other hand, confidentiality entails how the data is handled. For this, rules need to be in place. Who has access to the data? How is the data protected? In other words, confidentiality concerns itself with how data is kept secret from third parties. Moreover, it means that data shall not be used by other actors than the ones the citizens agreed with (Richard & King 2014; Donner et al. 2008).

For this purpose, the final ethical principle must be in place: *transparency.* The citizen must be able to see how their data is used, stored, and disclosed. Transparency can introduce checks & balances. *"Transparency can help prevent abuses of institutional power while also encouraging individuals to feel safe in sharing more relevant data to make better big data predictions for* *our society"* (Richard & King 2014: p. 96). For contact-tracing apps, transparency could entail extensive privacy statements and information on the official websites.

When applied to the context of contact-tracing apps, privacy, confidentiality, and transparency should be maximized. Citizens should know how their data will be used and should give consent for the use of their data. Extensive information should be given about how the data will be collected, stored, and used. Data should be handled safely, with clear rules and openness. However, some infringements on these concepts are necessary when implementing contact-tracing apps. How should a balance be struck?

2.2.1.2 Striking a balance: Utilitarianism & proportionality

For the assessment of the ethics of contact-tracing apps, a utilitarian approach is taken. Utilitarianists examine the outcome of an action or policy: *"The right act is one that produces the greatest happiness for a community or society"* (Herschel & Miori 2017: p. 33). This simply means that a utilitarian approach looks at the *net effects* of an action. Only actions that have a *net positive* effect on happiness can be seen as just actions. When applied to the realm of Big Data ethics, infringements on ethical implementations should be offset by positive effects on society, such as safety or security. This is related to the concept of proportionality, which will be discussed below. This 'balancing act' is quite a common thing to do by governments. According to the European Data Protection Supervisor (2021), **"***Proportionality is a general principle of EU law. It restricts authorities in the exercise of their powers by requiring them to strike a balance between the means used and the intended aim. In the context of fundamental rights, such as the right to the protection of personal data, proportionality is key for any limitation on these rights".* The existence of proportionality within Big Data ethics is utilitarian in nature, since with both concepts the net effects of an action are measured.

This would mean that if contact-tracing apps do infringe some of the ethical principles, but this is balanced out by any negative effects on the number of infections from COVID-19, the app could still be seen as 'just'. This Utilitarian way of thinking can be seen in statements from the Council of Europe as well: *"It is important to recall that data protection can in no manner be an obstacle to saving lives and that the applicable principles always allow for a balancing of the interests at stake"* (Council of Europe 2020a: p. 2). This shows the *proportionality principle*: any infringements on data protection must stand in proportion with increases in health, safety, or security. A joint statement was also released on the concept of proportionality and digital contact tracing directly, stating that *"It is crucial, therefore, to ensure that the* *measures and related data processing are necessary and proportionate in relation to the legitimate purpose pursued and that they reflect, at all stages, a fair balance between all interests concerned, and the rights and freedoms at stake, as the European Convention on Human Rights (Article 8) and Convention 108 + (Articles 5 and 11) prescribe"* (Council of Europe 2020b: p. 2).

The net consequences of an action need to be determined, which is simply done by weighing the positives and negatives (Herschel & Miori 2017). With this view in mind, you could argue that any negative effects on privacy, confidentiality, or transparency could be offset by how the app helps in fighting the COVID-19 pandemic.

A final consideration has to do with the 'privacy paradox' (Rowe 2020). This paradox essentially boils down to this question: how much privacy are people willing to sacrifice to assure their security, or in this case, health? You can see how this paradox relates to the proportionality principle, since both are about effectiveness versus privacy, confidentiality, and transparency. The COVID-19 pandemic changed the global context of security. For example, instead of assessing the already difficult ethical dilemma of privacy versus government surveillance against criminals, the dilemma now concerns itself directly with people's health. According to Rowe (2020), *"(...), the smartphone app against covid pandemics appears as an extreme case of the privacy paradox where the government plays on the immediate benefits and downplays long-term concerns while inducing a technology of self"* (Rowe 2020: p. 1). Parker et al. (2020) argue that some restrictions on privacy may be allowed in the context of the COVID-19 pandemic: *"The scale of the suffering caused by the COVID-19 pandemic means that if a case can be made that some degree of privacy infringement will save significant numbers of lives and reduce suffering, the intervention may be justified"* (Parker et al. 2020: p. 428). This seems to imply a utilitarian approach: some sacrifices on privacy must be made if this means that the net result will be positive.

Now that these concepts are clear, some determinants for ethical implementations of contact-tracing apps can be defined.

2.2.1.3 Determinants for an ethical implementation

There are two important questions related to the privacy paradox and proportionality principle of this utilitarian approach (Parker et al. 2020). First of all, how extensive are the infringements on privacy? Secondly, can these issues be justified in our current context? Parker et al. (2020) argue that there is some justification for these ethical issues in the context of COVID-19.

However, the authors argue that this does not mean that Big Data ethics should not play a role at all. Any justifications for ethical infringements should depend on both their necessity and their effectiveness compared to more ethical alternatives (Parker et al. 2020). Some privacy may be sacrificed under four conditions: First, privacy issues need to be minimized as much as possible. Second, high standards of data security are guaranteed through protection and oversight. Third, the way the data is used needs to be transparent to citizens. Finally, other protections such as non-discrimination need to be in place (Parker et al. 2020). These principles complement the necessity of not only privacy standards, but confidentiality and transparency standards as well.

According to Morley et al. (2020), four principles need to be considered before implementing contact-tracing apps. First of all, the app should be necessary: if the app would not be there, fewer lives would be saved. In other words, there are no better alternatives. This complements the consideration from Parker et al. (2020) that the app should be necessary and effective compared to alternatives. The second principle is the proportionality principle: the infringements on ethics should be proportionate to the increase in health and safety. Third, the app should be effective, timely, popular, and accurate. Finally, the app should be temporary: there must be an end date where data will not be collected anymore (Morley et al. 2020).

For an ethical implementation, privacy infringements should be kept at an absolute minimum, while transparency and confidentiality should be kept at a maximum. According to a utilitarian framework, net happiness should be as large as possible. What do we value more? Our privacy, or saving lives? When this approach is used, some privacy can be sacrificed when this means that lives can be saved, and confidentiality and transparency standards are in place. The negative effect of reductions in privacy can be offset by any decreases in the number of infections or casualties as a result of contact-tracing apps, and increases in confidentiality and transparency standards. Therefore, the number of privacy infringements should always be in relation to the positive effects of contact-tracing apps, and the standards that are in place for confidentiality and transparency.

To assess the ethics of individual contact-tracing apps, this means that we need to assess privacy, confidentiality, and transparency. For this purpose, the existing literature already shows some principles that can be applied to contact-tracing apps to keep privacy, confidentiality, and transparency at a maximum. According to Kleinman & Merkel (2020), privacy should be maximized by using the privacy laws incorporated in the European Union's General Data Protection Regulation. These laws would translate to guaranteeing *"encryption* *of all personal data, explanations in plain language and user consent for data storage and use, restrictions on use of the data outside the public health responses to COVID-19, automatic deletion of data, and the option to delete data at any time"* (Kleinman & Merkel 2020: p. 655). Moreover, they argue that the app should be voluntary in use. Finally, users should be able to delete or pause the app at any time.

Parker et al. (2020) argue that the app should be voluntary as well, especially since research has shown that an adoption rate of under 50 percent would still be effective. However, they argue that the automatic deletion of data and the option to delete data at any time could have an adverse effect: it limits the possibilities of retrospective feedback to increase effectiveness (Kleinman & Merkel 2020). Parker et al. (2020) underline the important concern citizens have not only about their current privacy but their future privacy as well. Once the pandemic is over, data needs to safely be handled or deleted. This once more stresses the importance of confidentiality. Parker et al. (2020) argue that any discussion on ethical issues surrounding contact-tracing apps should consider the 'scope and duration' of the data collected.

Citizens appear to especially have problems with the fact that location data is seen as personal: *"Existing contact tracing apps typically rely on the collection of personal data such as timestamped locations to determine exposure risk. Location data are highly personal, and the privacy concerns (...) are especially salient for location data"* (Yasaka, Lehrich & Sahyouni 2020: p. 2). Kleinman & Merkel (2020) underline this point by writing that the constant monitoring of location data introduced extensive privacy concerns compared to traditional contact-tracing. Citizens simply do not fully know what happens with their data. Therefore, it can be argued that the use of Bluetooth versus location data (GPS) would be a more ethical option.

Morley et al. (2020) define some requirements for contact-tracing apps to ensure high standards of privacy, confidentiality, and transparency. They underline the requirements discussed above such as the need for contact-tracing apps to be voluntary, encryption of personal data, consent, and the ability to erase data at any time. They stress the importance of clearly defining the purpose of data collection. Moreover, they add the requirement that the purpose of the app should be limited: it should only be used for tracing and tracking the COVID-19 pandemic (Morley et al. 2020). Finally, the app should have a decommissioning process: this means that there should be a defined process for shutting the app down. For example: when the pandemic is over, the defined process should clearly state that data collection will stop, and the app will be shut down (Morley et al. 2020).

2.2.1.4 In summary

The utilitarian approach has shown why privacy, confidentiality, and transparency should be kept at a maximum when implementing contact-tracing apps. Any negative net effect on privacy, confidentiality, and transparency should be offset by a lower number of infections or casualties. In this thesis, it will be researched if any negative net effects on ethical implementations actually impact the success of contact-tracing apps. Are ethical apps less, or more successful? This thesis will show if, and how the notion of proportionality plays a role with contact-tracing apps. The classic way of thinking is that less privacy means a more effective app. However, what if citizens value ethics so much, that unethical apps face low adoption, and are thus unsuccessful? The QCA method used in this thesis allows us to answer this.

The literature indicated that there are several principles and requirements for contact-tracing apps that reduce the amount of privacy they infringe on and increase confidentiality and transparency. These principles and requirements are summarized in table 2. This table will be used later to assess if an app is implemented ethically.

Determinants for an ethical implementation of contact-tracing apps
1. Is the app voluntary?
2. Is data handled safely? (encryption, no external uses for the data)
3. Does the app clearly state how user's data will be collected, used, and stored?
4. Do users need to give consent for the collection and storage of their data?
5. Can users delete their data at any time?
6. Is a decommissioning process in place? Is the data deleted after the pandemic? Is there a certain threshold in place for the deletion of the data?

Table 2: Determinants for an ethical implementation of contact-tracing apps

2.2.2 Condition 2: Effective underlying technology

The second hypothesized condition to assess the success of contact-tracing apps is the use of an effective underlying technology. Governments can opt to use several technologies while designing contact-tracing apps. What are the requirements for an effective underlying technology?

According to Kleinman & Merkel (2020), there can be several pitfalls in the use of technology. For example, measurement errors in the underlying technologies can result in missing exposures or false exposures. They write that *“missing exposures or falsely identifying exposures both have ramifications, including unnecessary exposure of others or unnecessary quarantine, with its resultant psychological, financial and social toll”* (Kleinman & Merkel 2020: p. 654). According to Trivedi & Vasisht (2020), false exposures will increase the strain on test locations, reduce trust in contact-tracing apps and overwhelm the healthcare resources. False negatives yield negative effects as well, since large clusters of infected individuals will be missed by the application. The researchers found that 85% of the population is willing to install contact-tracing apps when they are completely accurate in predicting transmissions (Trivedi & Vasisht 2020). Braithwaite et al. (2020) stress the point that the effectiveness of the underlying technology of contact-tracing apps depends on the system factors such as the timeliness and accuracy of the case and contact identification. According to Rowe (2020), the underlying technology should provide correct information qualifying individuals as infected and contagious. However, Rowe (2020) stresses the importance of access to testing in addition to these requirements.

The underlying technology is successful when it is epidemiologically sound, it has been assessed by simulations and it can be improved and optimized after the initial deployment of the app (Hinch et al. 2020). Also, the contact-tracing app needs to record proximity events with such precision that the described missing exposures or false identifications of exposures can be prevented. The measure of success here is the capability of the app to accurately measure exposures. The app thereby prevents that people unnecessarily go into quarantine while they are not exposed or sick (Hinch et al. 2020).

Two types of underlying technologies that could be used for contact-tracing apps are described by Kleinman & Merkel (2020). The first type of contact-tracing uses Bluetooth to infer the distance from infected individuals and the duration of proximity (Kleinman & Merkel 2020). Google and Apple provided a framework that will help countries to develop contact-tracing apps based on Bluetooth (Kleinman & Merkel 2020).

An alternative approach to contact-tracing is GPS-based. This way, the proximity and length of proximity to infected individuals are determined. However, the use of GPS has several disadvantages compared to the use of Bluetooth (Bay et al. 2020). First of all, GPS-tracing is less accurate in detecting the distance from other individuals. GPS-tracing has an accuracy of about 10 meters (Bay et al. 2020). Moreover, vertical accuracy is limited, meaning that it will barely detect people being on different floors in large buildings. Also, GPS-tracing increases battery drain. Finally, accuracy is poor in public transport due to low signal in tunnels and low accuracy in moving vehicles (Bay et al. 2020).

In summary, effective underlying technologies should be Bluetooth-based, since this provides the most accurate results. Effective contact-tracing should prevent false and missing exposures. Moreover, extensive testing is needed to ascertain the effectiveness of the underlying technology. Finally, effective contact-tracing should identify exposures accurately. The higher the ability of the underlying technology to accurately identify exposures, the higher its effectiveness. As an added benefit, an accurate technology could increase the trust citizens have in contact-tracing apps, thereby increasing adoption rates. These findings are summarized in table 3.

Determinants for an effective underlying technology of contact-tracing apps
1. Is the underlying technology Bluetooth-based?
2. Are false exposures and missing exposures prevented minimized through the underlying technology? Does it accurately predict exposure?
3. Has the app been extensively tested?

Table 3: Determinants for an effective underlying technology of contact-tracing apps

2.2.3 Condition 3: Effective follow-up after initial detection of exposure

What happens after the app detects the possibility of a COVID-19 transmission? Do all persons that got close to the infected person get a notification? Can these people get tested immediately? These are questions related to the *follow-up* of the initial detection.

An effective follow-up has two requirements. The first requirement is that all people that get into contact with an infected person get a notification (Braithwaite et al. 2020). When people know that they have a high chance of having contracted COVID-19, they can act on this by testing themselves and/or going into quarantine.

This leads to the second requirement of an effective follow-up: there should be access to diagnostic testing for everyone that got a notification (Kleinman & Merkel 2020). When this requirement is not put in place, this can lead to people getting in quarantine for longer periods of time while they are not contagious. Hinch et al. (2020) underline this point: rapid testing of citizens that were exposed to COVID-19 will improve the effectiveness of contact-tracing apps, while also resulting in fewer quarantined people. A study by Kretzschmar et al. (2020) found that access to testing increases the effectiveness of contact-tracing apps. Moreover, testing all people that are exposed to COVID-19 could detect asymptomatic persons (Kleinman & Merkel 2020). Hinch et al. (2020: p. 20) write that *"Conventional contact tracing may be used to validate the approach, and to enhance it"*. Rowe (2020) writes that access to tests is a requirement for the success of contact-tracing apps. However, Rowe (2020) argues that many asymptomatic citizens fail to get a test, even when they get an exposure notification. Access to tests is not enough, the population should get tested as well. This point suggests that mandatory tests could increase the effectiveness of the follow-up, however, this raises some ethical questions: mandatory tests would clash with the ethical principle of 'voluntary' use of contact-tracing apps.

The final requirement for the follow-up is that infected persons get into quarantine. When people fail to do this, this renders contact-tracing apps useless. This implies that mandatory quarantine would be the most effective, however, just like mandatory testing this would raise some ethical questions. Most existing contact-tracing apps recommend citizens who came into contact with COVID-19 to self-quarantine until they are tested negative (Menges et al. 2021). Another option would be that quarantine is mandatory until a citizen has been tested negative. Successful contact-tracing apps should reduce the number of people that go into quarantine: *"A measure of success for digital contact tracing is the extent to which it reduces onwards transmission of the virus whilst simultaneously minimizing the number of people in quarantine"* (Hinch et al. 2020: p. 2).

In summary, an effective follow-up depends on direct notifications to potentially infected persons, access to diagnostic testing, and people getting into quarantine. These findings can be summarized by the following citation: *"The effectiveness of the policy in controlling the epidemic is dependent on people's response to the messages; the app alone should not be seen as an intervention independent of widespread public health activities focused on appropriate use and response, and will require trust in the system"* (Hinch et al. 2020: p. 20). These findings are summarized in table 4.

Determinants for an effective follow-up of contact-tracing apps
1. Does the person that is exposed get a notification?
2. Is there direct and fast access to diagnostic testing?
3. Are individuals flagged as 'exposed' encouraged to go into quarantine by the app until they are tested negative?

Table 4: Determinants for an effective follow-up after initial detection of exposure

2.2.4 Condition 4: Promotion from the government

Literature on the effect of governmental promotion on the success of contact-tracing apps is limited. Governments have often used classical means of promotion for contact-tracing apps, such as billboards, newspaper advertisements, television commercials, and digital advertisements. Kleinman & Merkel (2020) find that promotion is key for the widespread adoption of contact-tracing apps. Promoting contact-tracing apps should especially be done in highly populated urban areas where traditional methods of contact-tracing are inadequate. Traditional contact-tracing in supermarkets, businesses, social gatherings, and public transport would be tedious (Kleinman & Merkel 2020). In these circumstances, digital-contact tracing could help to identify COVID-19 transmissions. Moreover, adoption should be promoted to people working in health care, since those people have a high chance of contracting COVID-19. In contrast, Munzert et al. (2021) find that informative and motivational videos created by the government have a very limited effect on the adoption rate. They find that only small monetary incentives increase the adoption of contact-tracing apps. Toussaert (2021) confirms the findings that promotion does affect the adoption of contact-tracing apps, although this effect is limited.

However, while the literature suggests that the effect on adoption rates is small, the effect is still there. No clear consensus is apparent, however, the fact that there is evidence that it could be relevant is sufficient enough to include it in the analysis. In this thesis, it will be assessed if promotion is a necessary or sufficient condition for a successful contact-tracing app. Promotion could take the form of informative and motivational videos, through classical means and social media, and finally through other incentives, such as monetary ones.

Determinant for effective promotion of contact-tracing apps
Does the government use extensive promotional campaigns and inform the public extensively and accurately about the contact-tracing app?

Table 5: Determinant for an effective promotion strategy from the government

2.2.5 Condition 5: Trust in the government

The existing literature describes a relationship between the trust citizens have in their national government and the intention to download and use a contact-tracing app (Altmann et al. 2020). A study has shown that citizens who completely trust their government are 25% more likely to download a contract-tracing app (Altmann et al. 2020). This is supported by another study, which states *“(...) the less a society trusts their government the less successful will government-*

led approaches to proximity tracing expected to be" (Riemer et al. 2020: p. 739). Horvath, Banducci & James (2020) write that high trust in the government leads to higher acceptance in sacrificing privacy for contact-tracing apps. Munzert et al. (2021) write that high trust in the national government leads to a higher acceptance level of contact-tracing apps. Finally, Parker et al. (2020) find that *"the successful and appropriate use of mobile phone apps to facilitate instantaneous contact tracing in the context of COVID-19 in democratic countries depends on the establishment of sustained and well-founded public trust and confidence"* (Parker et al. 2020: p. 430).

It can be concluded that all literature and studies point in the same direction: trust in the government can be a sufficient or necessary condition for the success of contact-tracing apps.

Determinant for trust in the government
What is the percentage of people that trust their national government?

Table 6: Determinant for trust in the government

2.2.6 Condition 6: Willingness of citizens to adopt new technologies

The sixth, - and final condition is the willingness of citizens in a country to adopt new technologies. According to Jahanmir & Cavadas (2018), attitudes towards technologies and consumer innovativeness can influence the adoption of new digital technologies. According to Zaunbrecher, Kowalewski & Ziefle (2014), acceptance of new technologies is for a large part based on where someone lives. It can be assumed that a higher willingness to adopt new technologies would lead to more citizens having smartphones and more people downloading contact-tracing apps. Moreover, it can be expected that people that are willing to adopt new technologies are also more open to the idea of traditional contact-tracing being transitioned to digital solutions. Therefore, it is hypothesized that this is an important condition for the success of contact-tracing apps.

Determinant for the willingness of citizens to adopt new technologies
Are the citizens of the country willing to adopt new technologies?

Table 7: Determinant for the willingness of citizens to adopt new technologies

2.3 Final theoretical framework

In this part of the chapter, several conditions for the success of contact-tracing apps have been hypothesized. These conditions are expected to influence the success of contact-tracing apps by influencing one or more of the determinants of success either directly or indirectly. Success is determined by the adoption rate, the successful identification of COVID-19 exposures, and the continuation, cancellation, or suspension of contact-tracing apps. These findings are summarized in table 8. For a QCA approach, it is not necessary to dig into the interactions between the conditions and the outcome at this time, these will be revealed by the analysis.

Literature has shown that all conditions could affect the determinants of success of digital contact-tracing. For example, an effective underlying technology is hypothesized to influence the adoption rate through an increase in trust. Moreover, promotion by the government could increase the adoption rate, thereby increasing the number of COVID-19 exposures tested, identified, or quarantined.

In the next chapter, the method for analyzing which conditions are sufficient or necessary for a contact-tracing app to be successful will be discussed. The literature from the theoretical framework will be used for the operationalization of the conditions.

Condition	**Outcome**
1. Ethical implementation	**Overall success of the contact-tracing app** **Determinants of success:** - Adoption rate - General effectiveness in identifying / quarantining / testing cases - The contact-tracing app has been canceled, suspended, or continued
2. Effective underlying technology	
3. Effective follow-up	
4. Promotion from the government	
5. Trust in the government	
6. Willingness of citizens to adopt new technologies	

Table 8: Conditions for success and determinants of success

3. Methods

In the previous chapter, existing literature on (digital) contact-tracing and ethics has been used to hypothesize six necessary or sufficient conditions for the successful implementation of contact-tracing apps in the wake of the COVID-19 pandemic. In this chapter, it will be explained how this thesis will assess these conditions. For this purpose, *crisp-set Qualitative Comparative Analysis (csQCA)* will be used. Insight from the book *'Configurational Comparative Methods'* by Rihoux & Ragin (2009) will be used to design a sound model for analysis. This chapter is structured as follows: first, the rationale behind the chosen method will be explained. Afterward, the hypothesized conditions will be operationalized and be given 'thresholds'. Finally, case selection will be discussed.

3.1 Why QCA?

QCA methods are used for small-N to intermediate-N research situations. The quality of QCA lies in its fundamental combination of both qualitative and quantitative techniques. Cases are mostly qualitatively assessed, and then coded and analyzed in a quantitative set-theoretic way. *"(...) QCA techniques strive to meet advantages of both the 'qualitative' (case-oriented) and 'quantitative' (variable-oriented) techniques"* (Rihoux & Ragin 2009: p. 6). For this thesis, crisp-set QCA will be used (csQCA). Complex cases can be assessed in a configurational manner, meaning that each case will be assessed on various conditions. A *configuration* is a combination of conditions that are either present or absent in a case. The goal of QCA is to assess which conditions are necessary or sufficient to lead to the outcome of interest, or in this case 'success of contact-tracing apps'.

The cases in this thesis can be very complex, which makes QCA methods more applicable than standard regression analysis. For example, an ethical implementation of contact-tracing apps can mean very different things across countries, making a direct comparison using classical statistical methods difficult. It is not a 'one-sided' concept that can directly be measured quantitatively. The same goes for conditions like an effective underlying technology, the types of promotion the contact-tracing app receives, and an effective follow-up. Case studies could pose as a logical solution; however, this would be infeasible for comparative research across 16 cases. This is why the QCA method is fitting: it allows for qualitative measurement of the conditions of more cases (you could even argue these are small case studies), while still drawing on the benefits of some quantitative techniques for comparison. This greatly enhances the external validity of the research, since single case studies could hardly be seen as generalizable to the entire population of contact-tracing apps.

The choice for QCA also lies in the way it deals with causality. In contrast to more common statistical methods, QCA can handle '*multiple conjunctural causations'*, which simply means that multiple paths can lead to the same outcome. The concept of 'additivity' is abandoned, meaning that it is no longer assumed that every variable has an independent effect on the outcome variable. This phenomenon can also be described by the concept of '*equifinality*'. According to Rihoux & Ragin (2009: p. 9) equifinality means that *"the idea that each single cause has its own separate, independent impact on the outcome is abandoned and replaced by the assumption that 'conjunctural causation' is at work, meaning that several causes can be simultaneously present".* In other words, there can be multiple *causal combinations* of factors that lead to a certain outcome. For example, in the context of contact-tracing apps, that could mean that two combinations of conditions (e.g. promotion & trust in the government, and promotion & effective underlying technology) can both individually lead to success. QCA allows the researcher to look at how the combination of conditions is important for an outcome, not only the individual conditions themselves. Trust in the government and promotion by the government could intuitively interact with each other, and with the outcome. In contrast to statistical research, QCA allows us to handle this equifinality. The method can look at the combination of variables, or in this case conditions, that will lead to the outcome 'success' being present or absent (Rihoux & Ragin 2009).

Moreover, QCA can detect the *necessary* and *sufficient* conditions. A necessary condition simply means that the absence of that condition will result in an unsuccessful contact-tracing app. However, the presence of the condition does not directly mean that the outcome will occur. Those types of conditions are called sufficient conditions: the presence of a sufficient condition leads to a successful contact-tracing app. Note that a combination of multiple conditions could also be necessary or sufficient.

QCA has the advantage of having multiple uses. Five types of uses of QCA techniques are described by Rihoux & Ragin (2009). In this thesis, QCA will be used to summarize the data, check the coherence of the data, check the conditions following from the theoretical framework, test possible conjunctures (multiple paths leading to the same outcomes), and finally possibly developing new theoretical arguments.

The final consideration for the use of the QCA technique is for its transparent and replicable characteristics. This thesis will strive to clearly describe the conditions, thresholds, outcomes, and resulting data points. Due to this high transparency, the results can be easily replicated (Rihoux & Ragin 2009). This increases the reliability of the research.

3.2 Crisp-set QCA and truth table

Crisp-set QCA (csQCA) will be used. csQCA is the most common form of QCA, due to its high applicability and the way it can visualize data in a way that makes the underlying logic easy to understand (Rihoux & Ragin 2009). csQCA uses dichotomized data, simply meaning that all conditions and the outcomes are coded either a [0] for 'condition or outcome absent' or a [1] for 'condition or outcome present'.

An alternative to csQCA is multi-value QCA (mvQCA), which has the added advantage of replacing the dichotomized data for the conditions (not the outcome) for multi-value variables, which as a result has a lower 'loss of information' (Rihoux & Ragin 2009). However, multi-value QCA (mvQCA) greatly enhances the number of cases that are needed. This leads to the problem of *limited diversity: "only a tiny subset of all logically possible configurations are found in the empirical cases, and given the higher complexity of the data sets with multi-valued conditions, this problem is much more acute than in strictly Boolean csQCA"* (Rihoux & Ragin 2009: p. 75). An increase in the number of cases decreases the ability to explain individual cases: only a small description could be achieved instead of a full explanation. Fuzzy-set QCA (fsQCA) is the final alternative. fsQCA makes it possible to lose the dichotomization of the outcome variable and can even use 'continuous' sets. However, fsQCA loses the advantage of the ease of interpretation and visualization that csQCA has. Moreover, since the outcome variable 'success' is not purely defined as a quantitative measure, and a very clear threshold for 'adoption rate' can be put in place, the information loss by choosing csQCA for the outcome variable is not too high. Two conditions could benefit from mvQCA or fsQCA, which are 'trust in the government' and 'willingness of citizens to adopt new technologies', since these are quantitative not dichotomous in nature. However, since the other conditions and the outcome variable are more naturally dichotomous, it was opted to go for csQCA. This means that it is important to create clear and transparent thresholds for these non-dichotomous conditions.

In this thesis, the cases will be individually assessed on the hypothesized conditions and outcomes. Afterward, all the conditions and outcomes will be coded with either a [0] or [1]. The resulting data from all the cases can then be summarized in a 'truth table', showing all the

[0]'s and [1]'s for all conditions and outcomes for all the cases. This table simply clusters the cases with the same results on the conditions together. These clusters of cases are the 'configurations' of the data. However, it could be possible that contradictory outcomes occur. This happens when one configuration of cases leads to both successful and unsuccessful contact-tracing apps.

Boolean minimization is used to minimize the 'paths' or configurations that lead to either the outcome [0] or [1]. This is done using the TOSMANA software. The use of Boolean minimization algorithms will result in a *minimal formula* for outcome [0] or [1]. Afterward, the resulting minimal formula shows the necessary or sufficient conditions for the success of the contact-tracing apps.

It is possible that some configurations are not represented by a case. These non-observed configurations are the *logical remainders* (Rihoux & Ragin 2009). The logical remainders are used to further minimize the minimal formula. Simplifying assumptions can be made on the logical remainders when the software suspect it can be expressed as part of another configuration: the software *"selects some logical remainders (only those that are useful to obtain a shorter minimal formula), adds them to the set of observed cases, and makes 'simplifying assumptions' regarding these logical remainders"* (Rihoux & Ragin 2009 p. 60). It is of importance to create minimal formulas for outcome [0] and [1], both with and without the inclusion of logical remainders. These formulas must then be interpreted.

The truth table and minimal formulas will be visualized in a Venn-diagram. The Venn-diagram graphically shows the configurations and logical remainders that either leads to outcome [0] or [1]. The diagram clearly shows how these logical remainders are assumed to be part of a bigger group of configurations that will lead to either outcome [0] or [1]. Moreover, the minimal formulas can be seen in the Venn-diagram.

3.3 Success, conditions, and thresholds

In the theoretical framework, six conditions were hypothesized to be relevant for successful contact-tracing apps. This part of the chapter will operationalize when a condition is absent [0] or present [1]. Moreover, it will be determined when a contact-tracing app is successful [1] or unsuccessful [0]. The main data sources are the information within the downloaded contact-tracing apps themselves, official government releases, online newspaper articles, data sets, and the official website of the contact-tracing app. The articles were mainly used to look for factual information. Subjective commentary on success or the absence of presence of conditions has been kept to a minimum, thereby preventing making the analysis too normative in nature.

By defining clear thresholds for the success of contact-tracing apps and the individual conditions, the reliability of the research design is increased. Future researchers could use the same thresholds and assess the cases in the same manner, which would lead to the same results.

The validity of the research design is established in three ways. First of all, the operationalization of the conditions and success matches the descriptions of the theoretical framework very well. Therefore, it can be assumed that the hypothesized conditions are measured by how they are operationalized. Moreover, the focus of analysis lies on factual information from the sources, and not on normative statements. Finally, since the theoretical framework showed how the conditions are related to the success of contact-tracing apps, it can be assumed that they are connected to the outcome. Therefore, the model correctly measures these relations.

3.3.1 Thresholds for the success of the contact-tracing app

As seen in table 1 of the theoretical chapter, success is dependent on three things: adoption rate, the general effectiveness of the app in detecting and quarantining COVID-19 cases, and if a contact-tracing app was suspended, canceled, or continued. These three determinants are combined, and show whether the app is unsuccessful [0] or successful [1]. The outcome [1] is present when the app is successful as a whole.

The adoption rate is the only quantitative measure for success. Data on adoption rates can be found in various sources, such as newspaper articles from the respective country or in the downloaded app itself. Moreover, governments often publish data on adoption rates. The theoretical chapter has shown that the higher the adoption rate is, the better. However, contact-tracing apps are most effective when the adoption rate is higher than 55% (Hinch et al. 2020). This would be a poor threshold since almost no apps reach this adoption rate. Therefore, it would be better to construct a more mechanical cut-off point. The threshold for adoption rate is set at 20% since this splits the cases into two almost equally large groups. Moreover, existing literature suggested that contact-tracing apps start to be successful at much lower levels than 55% (Hinch et al. 2020). Of course, this threshold could be seen as arbitrary. Therefore, a more qualitative measure is added to determine the success of contact-tracing app: general effectiveness in identifying COVID-19 cases.

The general effectiveness of the app will be determined with a more case-by-case qualitative measure since comparable quantitative data is severely lacking. The primary sources of this measurement will be government reports and media articles on the success of contact-tracing apps in identifying COVID-19 measures. The accessible data can vastly differ between cases, so the comparability of this measure is lower than for the adoption rate. For many countries, Google Translate will be used to translate the local sources to English. When the majority of the assessed articles for a case detect high effectiveness in predicting exposures, this determinant of the condition is present.

When both the adoption rate and the general effectiveness are high, the contact-tracing app is successful [1]. When both are absent, the contact-tracing app is a failure [0]. When only one of these determinants is present, the app is a failure [0]. In the theoretical chapter, it was concluded that a canceled app is an 'instant failure' of such apps, therefore this will directly lead to a [0] on the outcome variable, despite the other determinants being present.

3.3.2 Thresholds for conditions

In the theoretical chapter, six conditions were hypothesized to be necessary or sufficient for the success of contact-tracing apps. This part of the chapter will go into how the conditions will be measured or assessed. Some conditions are more quantitative in nature, while others are more qualitative. The qualitative measures will be individually assessed by using relevant newspaper articles and government publications from the respective countries. The quantitative measures will be taken from existing data sets. Table 9 (after section 3.5) shows all the conditions and determinants that will be used in the analysis. Condition 3, 'effective follow-up' is absent in the table, for reasons that will be discussed below.

3.3.2.1 Condition 1: An ethical implementation

The theoretical chapter showed six determinants that indicate an ethical implementation of contact-tracing apps. These determinants will be individually assessed for all cases in a qualitative way. The main source of information will be the privacy statements that most applications present after downloading the respective contact-tracing apps. When this is not available, data from official websites and government releases will be used. Finally, newspaper articles that discuss the ethical implementations of the respective contact-tracing apps will be used. All conditions had to be in place for the condition to be present [1]. However, after assessing the cases it appeared that the determinant 'decommission process is in place' was often not present. Therefore, it was decided that this determinant can be missing, since it would otherwise lead to many of the cases not having this condition present.

3.3.2.2 Condition 2: Effective underlying technology

The theoretical chapter showed three determinants for an effective underlying technology: the use of Bluetooth, the accuracy of the predictions of exposed individuals, and the extent to which the app has been extensively tested. These determinants will be assessed using qualitative data from the respective countries. This qualitative data will mainly be newspaper articles, official websites from the respective contact-tracing apps, and official government releases. All three determinants need to be in place for the condition to be present.

3.3.2.3 Condition 3: Effective follow-up

The theoretical chapter showed that three determinants need to be in place for an effective follow-up: the notification of the exposed individual, access to diagnostic testing, and the extent to which the app encourages exposed individuals to go into quarantine. All three determinants need to be in place for the condition to be present.

However, after assessing the cases it appeared that all countries had free and open access to diagnostic testing. Moreover, the notification of the individuals was always very clear. All notifications tell people to stay at home and to get tested when symptoms are developed. Therefore, variation between cases was very low. According to Rihoux & Ragin (2009: p. 28) "*a variable must vary".* For QCA, conditions that do not vary across the cases must not be included in the analysis (Rihoux & Ragin 2009). When variables do not vary, no useful conclusions can be made on the presence or absence of the condition concerning the outcome. Therefore, it was decided to remove this condition from the analysis. This does not mean an effective follow-up is not necessary for the success of contact-tracing apps, however, within the selected cases this condition cannot be effectively assessed to be necessary or sufficient. For this purpose, more cases would need to be present where this condition would be absent.

3.3.2.4 Condition 4: Promotion by the government

It will be individually assessed if the respective country promoted contact-tracing apps extensively. Only when the amount of promotion has been extensive, will the condition be seen as present [1]. This assessment will be done qualitatively. When it appears that promotional campaigns or information from the government was lacking, the condition will not be present.

This could occur when the government failed to launch large campaigns, or when the information the government spread was unclear. When it appears that many citizens do not know the existence of the app, or simply do not fully know how the app works, it is seen as a result of an absence of promotion and clear information. Newspaper articles, government releases, and articles from marketing bureaus will be used to assess this condition.

3.3.2.5 Condition 5: Trust in government

OECD data from 2020 will be used to assess the general trust in government from each analyzed country (OECD 2020). This is a percentage of citizens that have trust in their respective government. The threshold is set at 50% since this clearly splits the distribution in two. The median of trust is 42.9%, however, one case is directly on this level. Therefore, the threshold is set at a much clearer 50%. This can be seen from figure 1, where the red line shows the median and the green line shows the set threshold. The cases are represented by the orange dots. Moreover, a number higher than 50% indicates that the majority of the citizens trust their government, while a number lower than 50% indicated that a minority trusts the governments.

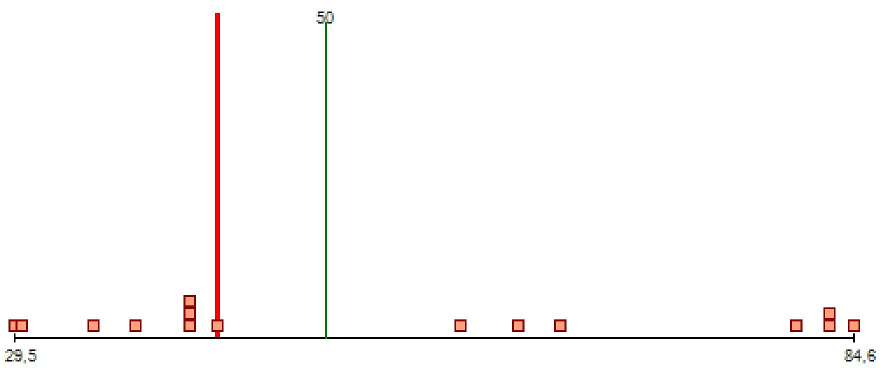

Figure 1: minimum, maximum, median, and threshold for trust in government

3.3.2.6 Condition 6: Willingness of citizens to adopt new technology

To assess the willingness of citizens to adopt new technologies, the Digital Adoption Index (DAI) will be used from the World Bank dataset from 2016. The website states that *"The DAI is a worldwide index that measures countries' digital adoption across three dimensions of the economy: people, government, and business"* (The World Bank 2016). For the purpose of this thesis, only the DAI for 'people' will be used. The DAI is a number from 0 to 100, which shows the willingness of people (by country) to adopt new digital technologies. This measure lines up with the concept discussed in the literature section. The threshold for the DAI is set at 70. This is lower than the median of the cases, however, many of the cases are spread around the median of 73. Therefore, information loss will be greater when the threshold is set at this point. Figure 2 shows the median with the red line (with the cases clustered around it) and the threshold with the green line. The threshold could also have been set slightly above the median, however, this resulted in contradictory cases.

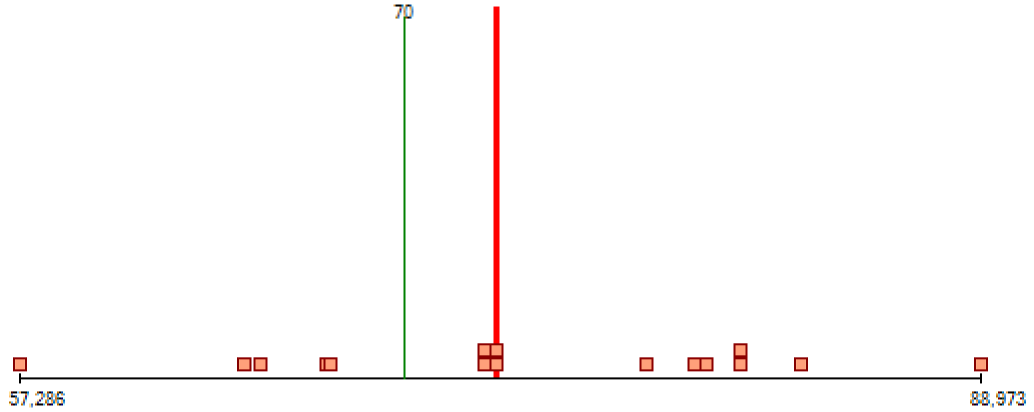

Figure 2: minimum, maximum, median, and threshold for Digital Adoption Index

Outcome		**Determinants**	**Method**	**Threshold**	**Outcome = [1] when**
Success	SUCCESS	1. Adoption rate	Quantitative	20%	- Combination of 1 + 2 + 3 - Combination of 1 + 3 or 2 + 3 only sufficient when this is determined by a qualitative case-by-case analysis
		2. General effectiveness in identifying / quarantining / testing cases	Qualitative	Qualitative case-by-case analysis indicates effectiveness	
		3. The app has been canceled / suspended / continued	Qualitative	The app has been continued	
Condition		**Determinants**	**Method**	**Threshold**	**Condition = [1] when**
1. Ethical implementation	ETHIC	1. App voluntary / mandatory	Qualitative	The app is voluntary	- 6 out of 6 (6/6) determinants need to be in place - The only exception is determinant 6, which can be missing
		2. Handling of data	Qualitative	Data is handled safely (encryption, no external uses)	
		3. Clear / unclear statement of data collection, usage, and storage	Qualitative	App clearly states how data is collected, used, and stored	
		4. User consent	Qualitative	Users give consent for data collection, usage, and storage	
		5. Ability to delete data at any time	Qualitative	Users can delete their data at any time	
		6. Decommissioning process	Qualitative	There is a decommissioning process in place	
2. Effective underlying technology	EFFTECH	1. Technology used	Qualitative	The app is Bluetooth-based	3 out of 3 (3/3) determinants need to be in place
		2. Accuracy of predictions	Qualitative	The app is accurate	
		3. Testing of the app	Qualitative	The app has been tested extensively	
3. Promotion by the government	PROMO	1. Promotion by the government	Qualitative	The government has promotional campaigns and informs the public about the contact-tracing app	Determinant is in place
4. Trust in the government	GOVTRUST	1. % of citizens that trust the government (OECD 2020 data)	Quantitative	50%	Determinant is in place
5. Willingness of citizens to adopt new technologies	DAI	1. Digital Adoption Index (The World Bank 2016)	Quantitative	70%	Determinant is in place

Table 9: Outcome and hypothesized conditions with thresholds

3.4 Case selection

Cases will be chosen based on the availability of the data. In general, the entire population of western European countries with contact-tracing apps needs to be considered. Only European countries are chosen to limit the scope of the research. Moreover, language barriers would make including more countries from other continents harder. Within Europe, translator programs (Google Translate) were already needed to assess some cases. A larger language barrier could pose a problem. Moreover, in general, quantitative data on adoption rates must be present in the chosen cases. Finally, for some countries, multiple versions of the app have been released. In that case, both versions are included as separate cases.

These restrictions on case selection led to the following countries being included in the analysis: Austria, Belgium, Bulgaria, Denmark, Czech Republic, France, Finland, Germany, Greece, Hungary, Ireland, Italy, the Netherlands, Norway, Poland, Portugal, Spain, Switzerland, and England. In the data collection process, it appeared that data was lacking for Austria, Czech Republic, Denmark, Poland, and Greece. Therefore, they were excluded from the analysis. France and Norway released two different versions of the app, which will be analyzed separately. This means that 16 cases will be included in the QCA.

Since only European countries are included, the external validity of the research decreases. While the results could be generalized to apps within Europe, they can hardly be generalized to countries outside of Europe. Moreover, the included apps are all voluntary in nature. The results of the analysis can therefore not be generalized to other countries where the apps are mandatory in nature. However, the results could still give significant insight into what determines success, and the findings could still be meaningful for countries outside Europe.

The 16 cases will be included in appendices A-P. Each case will be assessed on five conditions using the sources that were discussed above. These appendices can essentially be seen as individual case studies. According to Rihoux & Ragin (2009), it needs to be prevented that only a small description of each case is obtained. It is of importance that each case is extensively assessed and fully understood by the researcher: *"There must be sufficient 'case-based knowledge' before engaging in the further technical operations of QCA"* (Rihoux & Ragin 2009: p. 24). This will result in a *"certain degree of intimacy with each one of the cases under consideration"* (Rihoux & Ragin 2009: p. 24). Therefore, it was opted to assess each condition quite extensively, resulting in multiple pages of information and data per case.

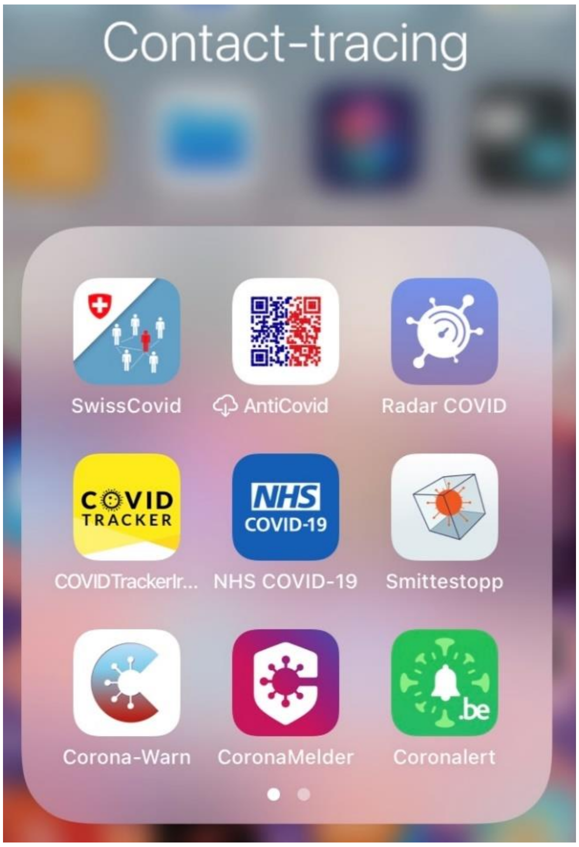

Figure 3: A selection of the apps downloaded on iOS for the research purposes

3.5 Iterative process

Earlier in this chapter, the concept of *'contradictory configurations'* has been described. This means that multiple outcomes occur in one configuration. Contradictory configurations are the main pitfall of csQCA, and it requires the researcher to commence in an iterative process with the research.

Contradictory configurations need to be resolved or, should at least strived to be reduced to a minimum (Rihoux & Ragin 2009). There are several strategies for this. First of all, more conditions could be added to the model. The more conditions the model has, the less likely that contradictions will occur. However, the addition of more conditions would make the analysis more complex. It would be a possibility to replace a condition with another one (Rihoux & Ragin 2009). Moreover, the thresholds on the conditions could be the reason why the contradictory configurations occur. Therefore it can be necessary to alter the thresholds during the research process. Another possibility is to add or remove cases, especially when some included cases appear to be extreme 'outliers'.

In this thesis, the iterative process mainly occurred as follows: Initially, only five conditions were hypothesized to influence the success of contact-tracing apps. In the analysis in this thesis, it appeared that the condition ‘effective follow-up’ had too little variation to say anything meaningful about the outcome variable. Therefore, the condition was removed. However, the removal of this condition led to a contradictory configuration. This was solved by adding the ‘Digital Adoption Index’ as a condition. This condition was then added to the literature and methods chapters. Moreover, it appeared that the determinant ‘decommissioning process in place’ of the ‘ethical implementation’ condition was absent in too many cases, therefore it was decided that this determinant can be missing while still resulting in the presence of the condition.

4. Analysis

In this chapter, the cases will be analyzed in a narrative and technical way using csQCA. After commencing in the csQCA, minimal formulas will be derived that will show which conditions are sufficient or necessary for successful digital contact-tracing. These minimal formulas will be used for theory building. The chapter will end with a discussion of some limitations of the research design.

4.1 Introduction

In this part of the thesis, some cases will be analyzed in a narrative manner, before resorting to csQCA to assess the more complex cases. For an extensive look at the individual cases, please refer to appendices A-P. There, each case is outlined and coded. It is not necessary to read all the cases before proceeding with reading this thesis, however, assessing how the cases have been coded will help in understanding the findings.

After having analyzed the cases, it appeared that many countries use a decentralized framework designed by Google & Apple. This framework uses low-energy Bluetooth signals to detect potential COVID-19 exposures. For apps using this framework, all data is anonymized and cannot be traced back to individuals. Moreover, users have the option to pause the app and delete their data at any time. Finally, these apps usually contained very extensive privacy statements. All collected data is stored in a decentralized matter, which means that data is stored on the phone itself, not on a central server. All data is deleted automatically after 2 to 3 weeks. These factors directly point to an ethical implementation. Therefore, countries that used the Google-Apple framework could be seen as 'ethical'. Moreover, since the apps using this framework rely on Bluetooth, they can be seen as an effective underlying technology, provided that they have been extensively tested. Some countries opted to use GPS data or were very limited in their privacy statements. These apps were seen as unethical.

First of all, let us have a look at two cases where all conditions were present: the Netherlands and Switzerland. According to our model, this would be a 'good' implementation of contact-tracing apps. In the Netherlands and Switzerland, the Google-Apple framework was used, and the apps were extensively tested with field tests, which indicate an ethical implementation and an effective underlying technology. Moreover, trust in the government and the willingness of citizens to adopt new technologies is high. Finally, the governments of these countries made extensive efforts to promote the contact-tracing app. Given the theoretical framework, it comes as no surprise that these apps were successful. There is also the stark opposite. In Bulgaria, none of the conditions are present. The resulting outcome is an unsuccessful app. This fits with the hypothesized conditions.

This is where it becomes interesting though. The Netherlands and Switzerland are our 'all conditions present' cases. What happens when one condition is absent? In Ireland, citizens are not very willing to adopt new technologies, with a DAI lower than the threshold. It would be expected that this would greatly hinder adoption, however, that is not what happened. Ireland's app had the highest adoption rate of all the cases that were analyzed, with 51% (Covid Tracker Ireland 2021). The Irish app is often used as an example for other countries of 'successful' contact tracing (Warwick 2020; Newcomb 2020). This shows, that when all conditions are present except for a high willingness to adopt new technologies, a contact-tracing app could still be successful.

The same can be said for the cases of Belgium and England: they have all conditions present, except for 'trust in the government'. Both countries face low levels of government trust. This did not seem to hinder the success of their respective contact-tracing apps, since adoption was still relatively high, and the apps were effective in identifying COVID-19 transmissions. Finally, for Germany, Finland, and the second version of the app in Norway, all conditions were present except for 'effective underlying technology'. While these countries used the effective Google-Apple Bluetooth framework, they failed to extensively test their contact-tracing apps. However, these apps were still successful, with high effectiveness in identifying COVID-19 cases and relatively high adoption.

However, some cases can be more complex. For example, the first version of the app in France, 'StopCovid', did not use the Google-Apple framework, had a very unclear privacy statement, and was not extensively tested. Moreover, information about the app from the government was lacking. No large marketing campaigns were launched, and the app faced many criticisms. Public opinion on the app was poor. Trust in the government was lacking. With all these conditions absent, the app was prone to failure. The only present condition is a DAI above the threshold. A few months later, a second version of the app was released, 'TousAntiCovid'. This app improved on many ethical issues, making a much more extensive privacy statement, giving the users the option to pause the app or delete the collected data. Moreover, the privacy statement showed that all data is anonymized and could not be traced back to individuals. The new app launched with an extensive marketing campaign, which improved adoption rates drastically from 3.6% to 22.7%. Two conditions were still absent: trust in the government (since this is more static) and effective underlying technology. However, the new version of the app was much more successful.

These complex cases show why the csQCA can increase our understanding of the relation between the conditions and the outcomes. Also, there are instances of cases where even more conditions were missing. Detecting the necessary or sufficient conditions becomes more difficult. Therefore, the thesis now resorts to the csQCA approach, which can deal with a greater number of different types of configurations.

4.2 Truth table, configurations, and minimal formula's

4.2.1 Truth table and configurations

The TOSMANA software is used to generate a truth table. The truth table can be seen below in table 10. The truth table contains all configurations (combinations of conditions and outcomes) that relate to the cases. For example, we can see that for the Netherlands (NLD) and Switzerland (CHE) all conditions were present, which leads to outcome [1].

Conditions					Outcome	n	Cases
ETHIC	EFFTECH	PROMO	TRUST	DAI	SUCCESS		
0	0	0	0	0	0	1	BGR
0	0	0	0	1	0	1	FRA[v1]
0	0	1	1	1	0	1	NOR[v1]
0	1	0	0	0	0	1	HUN
1	0	1	0	1	1	1	FRA[v2]
1	0	1	1	1	1	3	NOR[v2], DEU, FIN
1	1	0	0	0	0	2	ITA, ESP
1	1	0	1	1	0	1	PRT
1	1	1	0	1	1	2	BEL, ENG
1	1	1	1	0	1	1	IRL
1	1	1	1	1	1	2	NLD, CHE

Table 10: Truth table showing the configurations

This truth table can be seen graphically in a Venn-diagram in figure 4. As can be seen in both the truth table and the Venn-diagram, successful apps had the combination of an ethical implementation and promotion from the government. Most successful apps had high DAI's and high trust in the government, but these conditions were not necessary for success. Finally, an effective underlying technology was not always present for successful contact-tracing apps.

The TOSMANA software is used to generate a minimal formula for both outcomes [0] and [1].

4.2.2 Minimization of the [1] Outcome

First of all, a minimal formula is created for successful contact-tracing apps [1]. Without computing logical remainders, the minimal formula looks like this:

$$\underset{\substack{(NLD+CHE,\ BEL+ENG,\\ NOR[v2]+DEU+FIN,\\ FRA[v2])}}{\boldsymbol{ETHIC * PROMO * DAI}} \; + \; \underset{(NLD\,+\,CHE,\ IRL)}{\boldsymbol{ETHIC * EFFTECH * PROMO * TRUST}} \; \rightarrow \; \boldsymbol{SUCCESS}$$

In this formula, the [*] means ‘AND’, while the [+] means ‘OR’. The uppercase letters show that the condition or outcome is present. The formula shows that in the analyzed cases, either the combination of an ethical implementation, promotion of the app, and a high level of the digital readiness of a country, or a combination of an ethical implementation, an effective underlying technology, promotion, and trust in the government lead to a successful contact-tracing app.

The minimal formula can be rewritten as follows:

$$\boldsymbol{ETHIC * PROMO *} \begin{cases} \boldsymbol{DAI} \\ \boldsymbol{EFFTECH * TRUST} \end{cases} \rightarrow \boldsymbol{SUCCESS}$$

In figure 4, you can see the configurations that are shown by the formula. These are all the configurations with the horizontal stripes that are represented by one or multiple cases (configurations 10111, 10101, 11110, 11111, 11101).

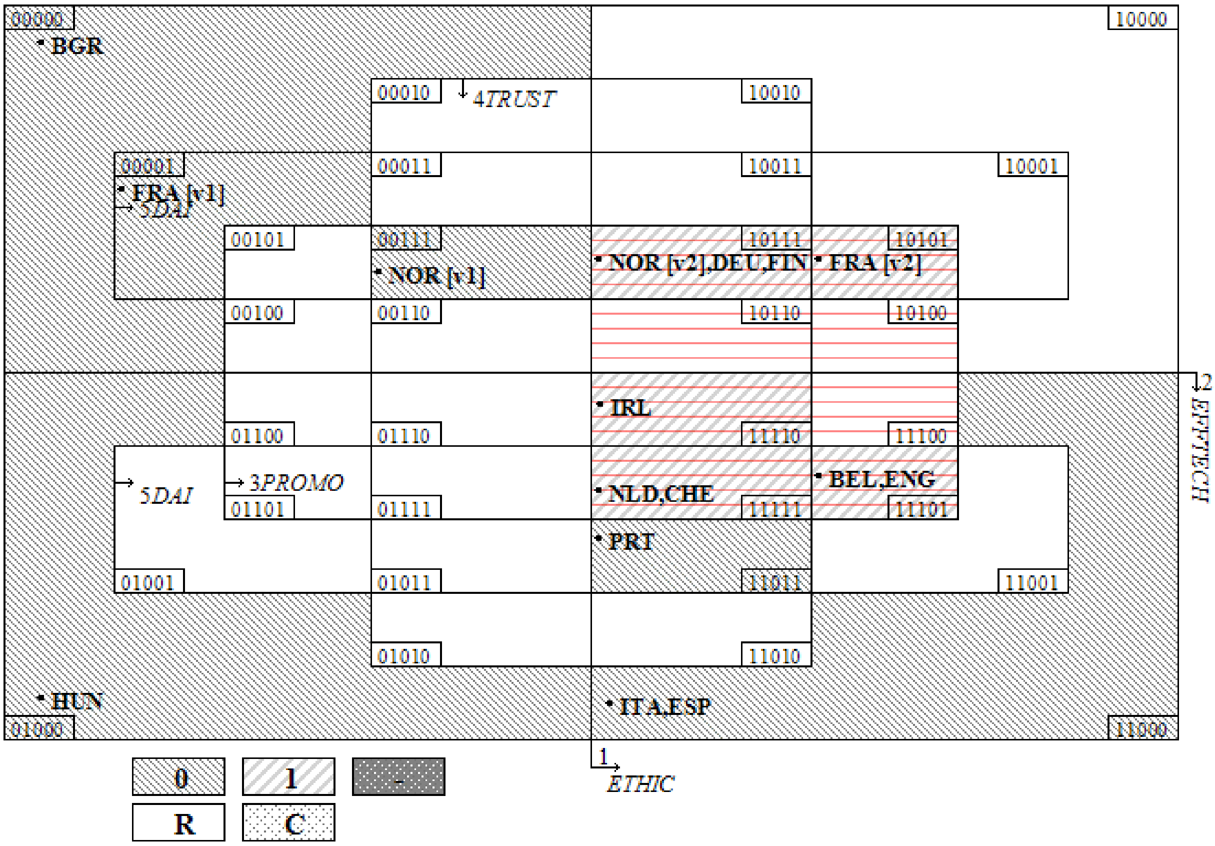

Figure 4: Venn-diagram for outcome [1]

What happens when logical remainders are included? After running the software with the inclusion of logical remainders, the following minimal formula is derived:

$$\boldsymbol{ETHIC * PROMO \rightarrow \ \ SUCCESS}$$

The evidence for this formula can be seen in figure 4. The area marked by the horizontal stripes shows the combination of an ethical implementation and promotion by the government. All countries with successful contact-tracing apps are included within this area. Three configurations contain no cases: configurations 10110, 10100, and 11100. These configurations are the logical remainders within this area. To achieve more parsimony, it is assumed by the software that these configurations would lead to outcome [1] (SUCCESS) as well. Those configurations are taken as *simplifying assumptions*. The simplifying assumptions can be seen in table 11.

#	ETHIC	EFFTECH	PROMO	TRUST	DAI
1	1	0	1	0	0
2	1	0	1	1	0
3	1	1	1	0	0

Table 11: Simplifying assumptions for outcome [1]

According to this formula, the combination of an ethical implementation and promotion by the government always leads to successful contact-tracing apps. This would mean that the absence of one of the two conditions would result in the app being unsuccessful. This implication can be seen in the second minimal formula as well, which will be discussed below.

When one of these conditions is absent, the outcome will be [0]. Therefore, both conditions are *necessary conditions for outcome [1]*. However, the conditions on their own are not sufficient for a successful outcome. Only the combination of the two conditions is necessary and sufficient for outcome [1].

When it is assumed that these simplifying assumptions would result in outcome [1], the conditions EFFTECH (effective underlying technology), TRUST (trust in the government), and DAI (digital adoption index) would not be relevant for the outcome. All cases with outcome [1] fall in the zone where both an ethical implementation and promotion are present. More conditions are not needed for configurations within this area to be successful. When we look at the paths to success without the inclusion of logical remainders, the importance of trust, DAI and effective underlying technology is more apparent. The fact that they are not included in the final minimal formula does not mean they are not causally related. Without the inclusion of remainders, for all cases with outcome [1], either a DAI above the threshold or the combination of effective underlying technology and trust in the government above the threshold was necessary in addition to ETHIC and PROMO. It was only when the logical remainders were included in the analysis that these were conditions left out of the equation. By using the logical remainders, a more parsimonious formula was realized. However, we must not forget that these are not the only conditions that have an effect: the analysis only suggests that the combination of an ethical implementation and promotion can cover a wider range of configurations. This range of configurations is *expected* to result in a successful contact-tracing app.

Trust is not included in the minimal formula because the apps in France (version 2), Belgium, and England were successful, even though the trust in the government is relatively low in these countries. In Norway, trust in the government is very high at 83%. However, it appeared that the unethical nature of the first app hindered high adoption. In Portugal, trust in the government is above the threshold with about 61.5%. However, promotion efforts were low. Since promotion is a necessary condition, the app was a failure. 6 out of the 9 cases with outcome [1] involved high government trust, indicating a consistency of around 66,7%. The consistency shows how necessary a condition is for an outcome. While trust in the government has not been important in combination with other conditions, trust was still present in 66,7% of the successful cases.

The Digital Adoption Index was expected to be an important condition for a successful contact-tracing app since it was hypothesized that it is important that citizens are open to new technologies. However, in Ireland, the DAI is relatively low and below the threshold. However, this app was seen to be one of the most successful ones. Other countries even took the Irish app as an example of how digital contact tracing must proceed. 8 out of 9 cases with outcome [1] had high DAI's, indicating a consistency of around 89%. That means that the statement that 'a DAI above the threshold' is necessary for outcome [1] is true for 89% of the cases, which is quite high. While the DAI is not included in the minimal formula, a high DAI is still present in most successful cases.

Finally, we look at the condition 'effective underlying technology'. This condition has not been very relevant to determine the success of contact-tracing apps. An effective underlying technology would only lead to a successful contact-tracing app in combination with an ethical implementation, promotion, and trust in the government. Moreover, the condition appeared in the formula without logical remainders for outcome [0], revealing that the presence of this condition does not point to one direction of the success of contact-tracing apps. As can be read from figure 4, many cases with outcome [1] appear both above and under the horizontal 'EFFTECH' line. Norway (version 2), Germany, and Finland all had ineffective underlying technologies due to a lack of testing of the app prior to release. However, these apps were still successful. Only 5 out of 9 cases with outcome [1] had an effective underlying technology, indicating a coverage of 56%. Therefore, it can be concluded that the underlying technology is the least relevant in determining the success of contact-tracing apps.

4.2.3 Minimization of the [0] Outcome

The process is repeated for outcomes where the contact-tracing apps would not be successful. Without computing logical remainders, the minimal formula looks like this:

$$\boldsymbol{ethic * efftech * promo * trust +} \qquad (FRA[v1] + BGR)$$

$$\boldsymbol{EFFTECH * promo * trust * dai +} \qquad (ITA, ESP + HUN)$$

$$\boldsymbol{ethic * efftech * PROMO * TRUST * DAI +} \qquad (NOR[v1])$$

$$\boldsymbol{ETHIC * EFFTECH * promo * TRUST * DAI} \qquad (PRT)$$

$$\boldsymbol{\rightarrow success}$$

In this formula, lower case letters show an *absence* of a condition or outcome. Upper case letters show that the condition is present. As can be seen in the formula, in the cases there were four combinations of conditions that would lead to outcome [0]. When we look at figure 5, we can see these four combinations represented by the cases. The first part of the formula is represented by configurations 00000 and 00001. The second part of the formula is represented by 11000 and 01000. The third part of the formula by 00111 and the final part by 11011.

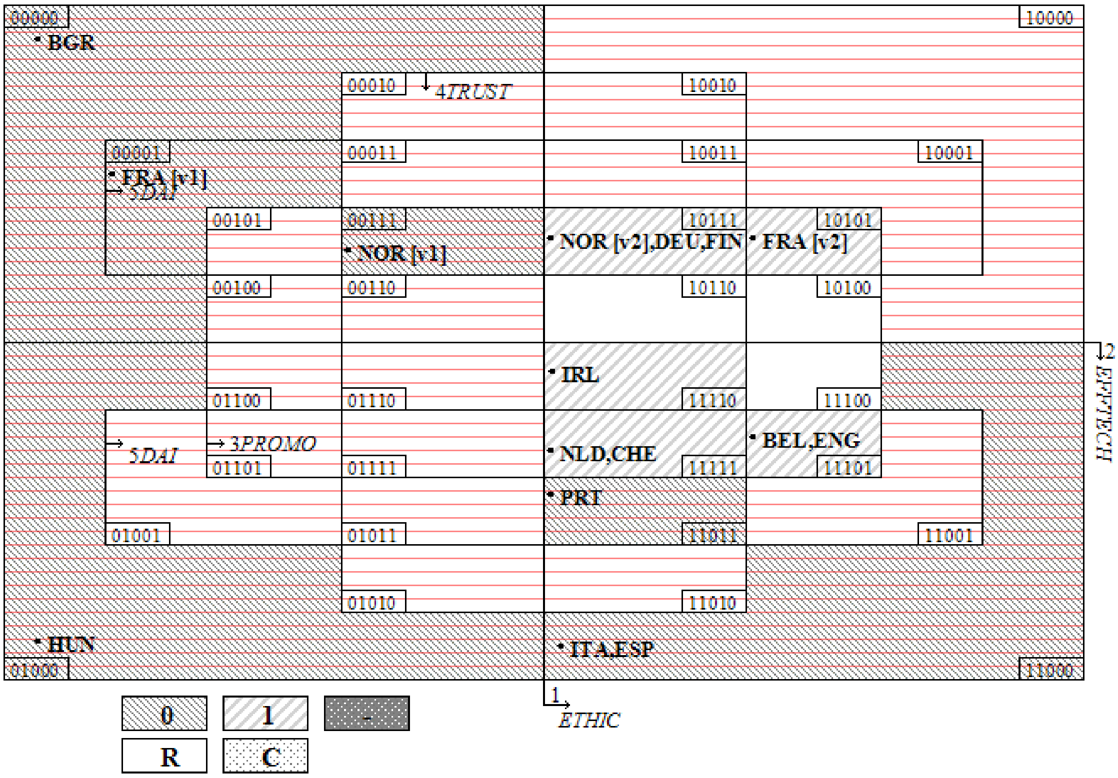

Figure 5: Venn-diagram for outcome [0]

The minimal formula can be rewritten as follows:

$$\begin{aligned} &\boldsymbol{ethic} * \boldsymbol{efftech} * \begin{cases} \boldsymbol{promo} * \boldsymbol{trust} \\ \boldsymbol{PROMO} * \boldsymbol{TRUST} * \boldsymbol{DAI} \end{cases} \\ &\quad + \boldsymbol{EFFTECH} * \boldsymbol{promo} * \begin{cases} \boldsymbol{trust} * \boldsymbol{dai} \\ \boldsymbol{TRUST} * \boldsymbol{DAI} * \boldsymbol{ETHIC} \end{cases} \\ &\quad \rightarrow \boldsymbol{success} \end{aligned}$$

However, just like the minimization of the [1] outcomes, we can include the logical remainders. This would result in the following minimal formula:

$$\boldsymbol{ethic} + \boldsymbol{promo} \rightarrow \boldsymbol{success}$$

This formula is highlighted by the horizontal stripes. As can be seen, this minimization requires the inclusion of many more simplifying assumptions. All configurations within this area that are not represented by a case need to be included. The software assumes that these configurations would result in outcome [0] as well. The simplifying assumptions can be seen in table 12.

This minimal formula directly complements the minimal formula of outcome [1], since the absence of either an ethical implementation or promotion by the government would be sufficient for an unsuccessful contact-tracing app. The first minimal formula states that the presence of either an ethical implementation or promotion by the government is necessary for a successful contact-tracing app. This directly implies that the absence of one of these conditions is *sufficient* for unsuccessful contact-tracing apps. This can be seen in the minimal formula for outcome [0], which states that the absence of an ethical implementation OR promotion by the government would lead to unsuccessful contact-tracing apps.

#	ETHIC	EFFTECH	PROMO	TRUST	DAI
1	0	0	0	1	0
2	0	0	0	1	1
0	0	0	1	0	0
4	0	0	1	0	1
5	0	0	1	1	0
6	0	1	0	0	1
7	0	1	0	1	0
8	0	1	0	1	1
9	0	1	1	0	0
10	0	1	1	0	1
11	0	1	1	1	0
12	0	1	1	1	1
13	1	0	0	0	0
14	1	0	0	0	1
15	1	0	0	1	0
16	1	0	0	1	1
17	1	1	0	0	1
18	1	1	0	1	0

Table 12: Simplifying assumptions for outcome [0]

These results can be traced back to the cases. The first versions of the app in France and Norway and the apps in Hungary and Bulgaria were unethical, and were thus unsuccessful. For Hungary and Bulgaria, almost all conditions were absent, including promotion by the government and an ethical implementation. These apps did not use the Google-Apple framework. Moreover, the apps used either location data instead of Bluetooth, or saved data on a centralized server. Therefore, these apps failed to successfully implement contact-tracing apps.

The combination of an unethical implementation and a successful app did not appear anywhere in the cases. Therefore, the absence of an ethical implementation is a sufficient condition for failure. However, the absence of the condition is not necessary for failure. Italy, Spain, and Portugal implemented contact-tracing apps in an ethical way but still failed to be successful.

The same can be said for promotion. The absence of promotion is a sufficient condition for the failure of contact-tracing apps. The first version of the app in France and the apps in Italy, Spain, Hungary, Portugal, and Bulgaria all failed due to the lack of promotional campaigns or the lack of information from the government. The Portugal case shows what happened when the condition 'promotion by the government' is absent, while all other conditions are present. Portugal failed to extensively promote the app. The app initially faced high levels of adoption, however, the app failed due to the number of users dropping rapidly (Parreira 2021). Moreover, newspaper articles suggested that the app failed to effectively combat the COVID-19 pandemic (Pequenino 2021; Alonso 2021). However, the same can be said here: the absence of promotion is not a necessary condition for failure. The first version of the app in Norway was unsuccessful, while the government promoted the app extensively

4.2.4 In summary

When the results (horizontal lines) of two Venn diagrams are compared, it can be noted that they fully complement each other, meaning that all Boolean property space has been used. This also means that there are no contradictory simplifying assumptions that need to be solved. Moreover, after commencing with csQCA with the described cases and conditions, no contradictory configurations were found.

In summary, it can be said that an ethical implementation and promotion are both necessary conditions in the cases. Without these conditions present, the contact-tracings apps were a failure. Moreover, the combination of these two conditions was sufficient for successful contact-tracing apps. The Digital Adoption Index, trust in the government, and effective underlying technology were not included in the minimal formula. The conditions Digital Adoption Rate and trust in the government were often present in cases with outcome [1]. However, the condition effective underlying technology seemed less important for the outcomes.

4.3 Limitations

While these results are promising, some limitations of the research design must be addressed. Pure crisp-set QCA has the downside of severe information loss due to the dichotomization of data. Moreover, the setting of thresholds can be arbitrary, and using different thresholds could yield different results.

The internal validity of the research is determined by how the data is measured, and if the measurements reflect what *needs* to be measured. According to Rutten (2020), the internal validity of csQCA is determined by assessing if the included conditions are causally related to the outcome variable. Since most of the conditions have been hypothesized using existing literature and research, it can be argued that internal validity is in place. However, the internal validity might also be hindered by the problem of limited diversity (Rutten 2020). In this thesis, only 11 of the 24 configurations are represented by one or multiple cases. Therefore, the software needs to use more simplifying assumptions, which could be a problem for internal validity. Also, some configurations are only represented by one case. The internal validity would increase when one configuration yields multiple cases with the same outcome.

Moreover, the decision on how to dichotomize the data could have an effect on the final results. A threshold must be set for conditions or outcomes to be present or absent. For example, the threshold for the Digital Adoption Index was set at 70. Portugal is slightly above this threshold, Italy slightly below. Are they really that different? The same can be said for adoption rates. The decision of where to put the threshold determines the outcome. Threshold setting can seem arbitrary or manipulable (Rihoux & Ragin 2009). Moreover, the coding of the different conditions and outcomes can sometimes be quite subjective. For different cases, different types of data sources are available. For some cases, extensive information on the conditions was available, while for many other cases, information was lacking. This thesis tried to be as transparent as possible about the coding and threshold setting of the conditions and outcomes, however, the problems cannot be written off completely.

Also, the results of the research are fully dependent on the annotation of the conditions and outcomes. For the condition ‘promotion’ information was often lacking. Therefore, the question if a case had enough promotion was often only based on the question *if* the government promoted their apps, and through which means. The quality and extensiveness of the promotion were often difficult to assess. It would have been ideal if data on the budgets for marketing campaigns for contact-tracing apps were known, however, this data is not freely available. This is an important limitation of the research.

Finally, the condition ‘effective underlying technology’ appeared to be very similar in many cases. The condition was present when the underlying technology used was Bluetooth and the app has been tested extensively. However, ethical implementations of the apps in the cases coincided with the use of Bluetooth. This can be seen in the truth table, where almost all cases with an ethical implementation also have an effective underlying technology. The only difference then has to do with whether or not the app has been extensively tested. For example, in Germany, the app has not extensively been tested before release, therefore the condition was absent. However, since almost all apps use the Google-Apple framework, you could argue that tests would not be very necessary anymore for successful contact-tracing. Therefore, it could be argued that the inclusion of this condition appeared to be not very relevant after assessing the cases. This is confirmed by the findings: an effective underlying technology was not a sufficient or necessary condition and was only present in 5 out of the 9 cases with successful contact-tracing apps. However, the inclusion of the condition did not alter the final results. When the condition is left out of the software, the same minimal formula is achieved.

The face validity of the research appears to be in order, since the research design clearly is very suitable for the research question. The complex nature of success and the equifinality of the conditions makes the QCA approach applicable.

The external validity of the research is compromised by the case selection. Only cases within Europe were selected. However, many more cases across the world exist. Some continents have mandatory COVID-19 apps. In the analysis, it was found that unethical contact-tracing apps yielded lower adoption. Mandatory apps pose a stark opposite to that. The mandatory aspect makes the app both unethical, but, - according to how success is defined in this thesis, also very successful. Including these cases would make the analysis more difficult, although very interesting. The external validity of the research could be increased by including more cases, since the results could then be generalizable to other countries. Since a QCA approach is not a large-N research by design, external validity can generally be seen as lacking.

Since this thesis used clearly defined conditions and thresholds, the reliability of the research is quite high. Coding the cases again, using the same thresholds, would probably lead to the same results. For some more qualitative measures, some subjectivity can be hard to avoid. Other researchers might conclude that a case was successful, while another researcher might not. In this thesis, the way the cases were coded and assessed was done in a very transparent way. Therefore, other researchers can follow the same steps and obtain the same results.

5. Conclusion & Discussion

Contact-tracing apps are a large part of many countries' policies to combat the COVID-19 pandemic. However, existing literature has not focused on the factors that determine the success of these apps. Therefore, this thesis started with the research question 'What conditions are sufficient or necessary for contact-tracing apps to be successful?'. The question was answered by assessing sixteen different cases of contact-tracing apps.

In the literature section, six conditions were hypothesized to be relevant for successful contact-tracing apps. Five of these conditions were used in the analysis. By using crisp-set QCA, it was assessed which of these conditions were sufficient or necessary for a successful app. Two minimal formulas were computed.

In light of the discussed limitations, a new theory for the success of contact-tracing apps is articulated. This causal theory states that the presence of ethical implementations and promotion by the government is both necessary and sufficient for successful contact-tracing apps. This theory needs to be tested further, which will be discussed in this part of the thesis.

The theory is based on the two final minimal formulas that were found in the analysis chapter. The first formula showed that the combination of an ethical implementation and promotion by the government is sufficient and necessary for a successful contact-tracing app. Although an ethical implementation and promotion by the government are not sufficient on their own, they are both necessary conditions: when either the ethical implementation or promotion is absent, the contact-tracing apps proved to be unsuccessful. This is underlined by the second formula, which states that the absence of an ethical implementation or the absence of promotion by the government would lead to an unsuccessful app. The conditions 'trust in the government' and 'high willingness to adopt new technologies' proved not to be sufficient or necessary conditions, however, they were still present for many of the successful cases. Therefore, their importance cannot be understated. The condition 'effective underlying technology' was not necessary or sufficient for the outcomes either. Moreover, this condition was often not present in successful contact-tracing apps.

The results of the analysis are quite interesting. First of all, it shows that many of the hypothesized conditions are not necessary or sufficient for the outcome. The final minimal formulas that were derived were very simple in nature, with only two conditions.

Second, the results show that it can be very beneficial for countries to spend their resources on promotional campaigns. The countries that did were much more successful in creating successful contact-tracing apps than countries that did not. Following the analysis, promotion proved to be *necessary* for any form of success with contact-tracing apps. All countries that failed to adequately promote their contact-tracing app, failed. Even Portugal, where all other conditions were present except for promotion, failed.

Third, much focus has been put on the effectiveness – ethics debate. As seen in the theoretical chapter, more privacy is thought to lead to a less effective app. This would mean that for contact-tracing apps to be a success, they should not be implemented ethically. However, with these findings, we found that an ethical implementation of contact-tracing apps was a *necessary* condition for successful contact-tracing apps. This sheds new light on the effectiveness – ethics debate for contact-tracing apps. These findings contrast some existing literature. Apparently, citizens value the ethics of contact-tracing apps highly. High levels of privacy, confidentiality, and transparency would appear to result in high adoption rates, and thus successful contact-tracing apps. Instead of ethics and effectiveness being stark opposites, it could be argued that - in the case of contact-tracing apps, they could just as well complement each other. This way of thinking can be extended when the analysis showed that an effective underlying technology is not an important condition for the success of contact-tracing apps. An ethical implementation proved to be much more beneficial to the success of contact-tracing apps. It must be stressed that this finding is of course dependent on how 'success' is coded. In this case, it means that our findings show that ethical implementations are very important for both adoption rate and how newspaper and online articles assess the effectiveness of contact-tracing apps. If success would be measured by more quantitative data (when this data is available), the results could be very different. However, it remains an interesting way to look at the debate.

This is interesting for the proportionality principle for contact-tracing apps as well: any infringements on privacy, confidentiality, or transparency should be proportionate to the increase in effectiveness. These findings could imply the opposite: based on how the success of contact-tracing apps and the conditions are assessed in this thesis, ethical implementations would increase adoption rates and effectiveness. Of course, these findings only account for European apps that were included in the analysis. There are apps in other parts of the world which are mandatory. These apps are highly unethical, but due to these apps having very high adoption rates, they can technically be seen as successful. Including these cases in the analysis would yield very different results.

Fourth, in contrast to the expectations, trust in the government and a high Digital Adoption Index (DAI) were not necessary or sufficient conditions for successful contact-tracing apps. However, it can be argued that the presence of these conditions increases the chance of success drastically. The exclusion of these conditions was part of simplifying assumptions, however, they could still be very important for successful digital contact-tracing: we simply do not know if the picture is as simple as the minimal formulas. Countries with high trust in the government and high willingness to adopt new technologies proved to have a much larger proportion of successful contact-tracing apps. However, the fact that these conditions are not necessary for successful contact-tracing apps, is beneficial for many countries with low trust and low willingness to adopt new technologies. While ethical implementations and promotions are conditions that can be influenced by governments, government trust and DAI are much more static.

These findings are both societally and academically relevant. The findings are relevant for society since, - as is discussed above, they can help governments shape their contact-tracing apps. Since ethical implementations and promotion from the government are directly influenceable by governments, these findings could help governments increase the success of current and future digital contact-tracing apps. Moreover, this thesis adds a comparative look at the current contact-tracing apps. Governments can use this information and look at other countries as examples of successful and unsuccessful contact-tracing. Finally, the thesis is academically relevant since no large configurational research on contact-tracing app could be found in the published literature. Most existing literature is based on individual case studies of contact-tracing apps. By extending the research to multiple cases, we learned what factors could be decisive in determining the success of contact-tracing apps. This made the findings much more generalizable, increasing the external validity.

The results are not conclusive though. The theory that the success of contact-tracing apps is mainly dependent on ethical implementations and promotion needs to be tested further. Future research should include much more cases, not only from Europe. The differences in success between mandatory and voluntary contact-tracing apps should be considered, just as the ethical implications. Moreover, this thesis suggested an interesting look at the proportionality principle for contact-tracing apps. Research on this should be extended, since these findings were only based on European apps and based on one specific view of ‘success’. Mandatory apps (which are unethical according to the standards in this thesis) can turn these findings for the proportionality principle on its head. A research gap still exists here: existing literature has not focused on the effects of mandatory versus. voluntary apps. Including more cases to assess the ethical implications of mandatory versus voluntary applications would be interesting for further research, however, it would likely necessitate different operationalization and research design. Moreover, it would be important to determine the success of contact-tracing apps in various other ways than adoption rates and qualitative assessments of published articles. This thesis found that an ethical implementation of contact-tracing apps yields successful contact-tracing apps. Very unethical implementations could yield successful contact-tracing apps as well, since mandatory apps will lead to high adoption. What is the equilibrium?

Also, research opportunities could be extended once more data is released in the future. Comparable data between countries was often lacking. Especially data on government expenditures on promotion could be beneficial for future research. Future research could take a more quantitative approach, thereby removing some information loss and bias resulting from a QCA approach. Finally, future case studies could look into some extreme cases, such as Bulgaria, to more extensively assess why such cases failed.

While the results might not be conclusive, it is highly notable that in this thesis, the combination of an ethical implementation and promotion by the government appeared to be both necessary and sufficient for successful contact-tracing apps. The importance of these conditions should at least be noted by governments and academics, since the future will most likely bring much more 'digital' solutions to international problems with health and safety. Simply put, lessons from the past must be taken into account.

6. Literature

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Appendix A. Case The Netherlands: 'CoronaMelder"

Success

The adoption rate of the Dutch CoronaMelder app is 27,4% as of the 25th of April 2021 (Rijksoverheid 2021a, translated).

According to the 'Factsheet CoronaMelder', which is published by the Rijksoverheid (2021a, translated), there have been 167,724 people tested as an effect of the CoronaMelder app since the introduction of the app in October. Around 8.2% of these tests were positive. Of all people who tested positive, about 10% was as a result of a notification of the application (Frijters 2021). While that is not very high, the app still was able to detect COVID-19 transmissions that would not have been indicated without the contact-tracing app (Frijters 2021). What helps is that since December 2020 citizens can test themselves when they do not have any symptoms.

According to the Dutch government, the app can be seen as a success (Rijksoverheid 2021b, translated). This is since 90% of the people that got a notification got tested and stayed at home. Moreover, the installation of the app seemed to have no adverse effects on the behavior of citizens: citizens do not appear to act less carefully when they have the app installed (van der Laan, van der Waal & de Wit 2020).

A report by prof. Dr. Wolfgang Ebbers finds that 58% of the citizens that got a transmission notification from the CoronaMelder app were never notified by the classical means of contact-tracing, indicating effective digital contact-tracing. Without the app, these citizens would have never been identified for a potential transmission (Ebbers 2021, translated).

The CoronaMelder app has never been suspended or canceled, and is still in full operation.

Condition 1: Ethical implementation

The CoronaMelder app is accessible from the app store and is voluntary in use. According to the privacy statement in the app, the app does not collect any location data, only Bluetooth is used to indicate a citizen's direct contacts. The app can be paused at any time. Data is not uploaded on a central server but is decentralized on the user's smartphone.

When downloading the app, the respective app stores clearly state that no one will know who you are and where you are. The app contains a very clear statement of privacy, indicating how the app collects, stores, and uses Bluetooth data. The data that is collected does not include personal data, such as names and location. The data that is collected is technical (and not directly traceable to individuals), such as the IP address, signal strength, length of the contact, diagnosis keys, first sick day, and validation codes. The data is only stored for 14 days, after that, the data is permanently deleted. This indicated that the data is handled safely. The data is handled by the Ministry of Health, Welfare and Sport. Moreover, it is possible to delete the data that is collected by yourself at any time.

When installing the app for the first time, the app asks you to read the privacy statement and give consent.

Finally, the official documents and privacy statement do not reveal a decommissioning process for when the app will be shut down.

Condition 2: Effective underlying technology

The app uses Bluetooth low energy signals, a technique designed by Google and Apple (Leswing 2020). The literature section has shown that Bluetooth is very effective in indicating transmissions.

The Google / Apple framework has been extensively tested (Leswing 2020). Moreover, the Dutch CoronaMelder app has been extensively tested as well (Rijksoverheid 2021b, translated). At first, small technical tests were conducted. Afterward, the app was extensively tested on a University. Finally, a big field test was done with 1500 people. In August, the app was released in five regions for a large final test. The app was released in October (Rijksoverheid 2021b, translated).

Condition 3: Promotion by the government

The Dutch government extensively promotes the CoronaMelder app. According to the official website, TV commercials, radio commercials, billboard advertisements, and social media is used to promote the contact-tracing app (CoronaMelder 2021, translated). The government asked 116 companies to promote the app (Parlementaire Monitor 2020, translated). A campaign was launched which shows the motivations of citizens to download the app, as can be seen in figure 6.

Figure 6: "I download the app to protect my grandfather" (translated).

Condition 4: Trust in the government

OECD survey data from 2020 determines that 78.1% of Dutch citizens trust the government (OECD 2020). This is higher than the threshold of 50%.

Condition 5: Digital Adoption Index

The DAI of the Netherlands is 79.6, which is above the threshold of 70 (The World Bank 2016).

The Netherlands → 'CoronaMelder'			
Outcome	**Determinants**	**Outcome determinants**	**Unsuccessful [0] / Success [1]**
SUCCESS	1. Adoption rate	27.4% [1]	Success [1]
	2. General effectiveness in identifying cases	High → [1]	
	3. The app has been cancelled / suspended / continued	Continued → [1]	
Condition	**Determinants**	**Outcome determinants**	**Condition absent [0] / present [1]**
1. ETHIC	1. App voluntary / mandatory	Voluntary → [1]	Present [1]
	2. Handling of data	Safe → [1]	
	3. Clear / unclear statement of data collection, usage and storage	Clear → [1]	
	4. User consent	Yes → [1]	
	5. Ability to delete data at any time	Yes → [1]	
	6. Decommissioning process	No → [0]	
2.EFFTECH	1. Technology used	Google-Apple Decentralized Bluetooth→ [1]	Present [1]
	2. Accuracy of predictions	Accurate → [1]	
	3. Testing of the app	Extensive → [1]	
3. PROMO	1. Promotion by the government	Yes → [1]	Present [1]
4. GOVTRUST	1. % of citizens that trust the government	78.1% → [1]	Present [1]
5. DAI	1. The DAI for the country	79.6 → [1]	Present [1]

Appendix B. Case Belgium: 'Coronalert'

Success

As of the 3rd of May, the adoption rate of the Belgium Coronalert app is 30% (Interfederal Committee Testing & Tracing 2021, translated). Around 733,000 people were tested as a result of the app. Around 9.6% of these people were tested positive (Interfederal Committee Testing & Tracing 2021, translated). In general, the app has been received positively. The app appears to be effective in identifying COVID-19 cases. According to Walrave, Baert & Ponnet (2020) the app is still important in the battle against COVID-19. Moreover, the app has been praised due to its high standards of privacy and user-friendliness (Test Aankoop 2020, translated). There are some problems with the app not reaching older people, however, it can be assumed that these problems occur in many countries due to the lower penetration of smartphones in that age group (Visterin 2020, translated). According to an article by HLN, it is difficult to assess the effectiveness of the app (HLN 2021, translated). Epidemiologist Wouter Arrazola de Oñata suggested that the apps would be effective, however, it is impossible to fully say how effective it is due to lacking data (HLN 2021, translated).

After initial detection, citizens get a notification. This notification contains advice to get tested and distance themselves from others. Moreover, there is access to diagnostic testing for everyone who has symptoms or got a notification from the Coronalert app.

The app has been continued.

Condition 1: Ethical implementation

The Coronalert app is very comparable to the Dutch CoronaMelder app. First of all, it is accessible from the app store and is voluntary in use. Since both apps use the Google-Apple framework, the same type of data is collected. Moreover, the data is also deleted automatically after 14 days.

The app contains a very detailed privacy statement, and users need to give consent for the collection of the data. Moreover, the app can be paused at any time. The Belgian federal governmental agency 'Sciensano' is responsible for the app and management of the data. The privacy statement clearly states how the data is handled. It is possible to delete all the data that the app collected at any time.

In contrast to the Dutch 'CoronaMelder' app, there is a decommissioning process in place. The process states that when the Belgian government declares that the pandemic is over, the app will be deactivated and removed from all app stores. All users will receive a notification requesting to delete the app. After 14 days, all data will be automatically deleted.

Condition 2: Effective underlying technology

The app uses the same framework as the Dutch app, and thus uses low-energy Bluetooth transmissions. This has been proven to be an effective technology to identify COVID-19 exposures.

Just like the Dutch CoronaMelder app, the app has been extensively tested. A beta version of the app has been released to a group of 10,000 citizens. Moreover, the app has been tested internally (Belghmidi & Maesseneer 2020, translated).

Condition 3: Promotion by the government

The Belgian government hired several firms for the promotion of the Coronalert app. The promotion consisted of television and radio commercials, billboards, and social media advertisements (Mediamarketing 2020, translated). The Belgian government provides campaign materials for the Coronalert app online, which companies can use to help with the promotion (Agency for Care and Health 2021, translated).

Figure 7: "My I-want-to-stop-corona app is on" (translated).

Condition 4: Trust in the government

According to OECD survey data from 2020, the trust in the government that citizens have is 29,5% (OECD 2020). This is below the threshold of 50%.

Condition 5: Digital Adoption Index

The DAI of Belgium is 72.7, which is above the threshold of 70 (The World Bank 2016).

Belgium → 'Coronalert'			
Outcome	**Determinants**	**Outcome determinants**	**Unsuccessful [0] / Success [1]**
SUCCESS	1. Adoption rate	30% → [1]	Success [1]
	2. General effectiveness in identifying cases	Effective → [1]	
	4. The app has been cancelled / suspended / continued	Continued → [1]	
Condition	**Determinants**	**Outcome determinants**	**Condition absent [0] / present [1]**
1. ETHIC	1. App voluntary / mandatory	Voluntary → [1]	Present [1]
	2. Handling of data	Safe → [1]	
	3. Clear / unclear statement of data collection, usage and storage	Clear → [1]	
	4. User consent	Yes → [1]	
	5. Ability to delete data at any time	Yes → [1]	
	6. Decommissioning process	Yes → [1]	
2.EFFTECH	1. Technology used	Google-Apple Decentralized Bluetooth → [1]	Present [1]
	2. Accuracy of predictions	Accurate → [1]	
	3. Testing of the app	Extensive → [1]	
3. PROMO	1. Promotion by the government	Yes → [1]	Present [1]
4. GOVTRUST	1. % of citizens that trust the government	29.5% → [0]	Absent [0]
5. DAI	1. Digital Adoption Index	72.7 → [1]	Present [1]

Appendix C. Case England: 'NHS COVID-19 app'
Success

In England, as of the 3rd of May 2021, the app has been downloaded 23,010,648 times (National Health Service 2021). This indicated an adoption rate of around 35% of the population of England. This is a high adoption rate when compared to other European countries.

The app resulted in 4,139,406 tests being conducted. Of these tests, around 22% were positive (National Health Service 2021). According to researchers, the app has been very successful in identifying COVID-19 cases (Wymant et al. 2021). The researchers found that the app works, and it helped to suppress the pandemic. Briers, Holmes & Fraser (2021) confirm these findings, suggesting that the NHS COVID-19 app successfully identified many COVID-19 cases. They state the following: *"We estimated that for every 1% increase in app users, the number of infections can be reduced by 0.8% (from modeling) or 2.3% (from statistical analysis)*". (Briers, Holmes & Framers 2021).

The app sends notifications to users when they have been exposed, either due to Bluetooth proximity or through a venue where the citizens scanned the QR-code. Moreover, the app notifies users when they should stay at home or when they are 'released' from quarantine. The app gives the users guidance on what they should do when they have been identified as exposed or tested positive. The app encourages citizens to go into quarantine when they are exposed or tested positive. Moreover, citizens are encouraged to register their positive tests in the app to notify their contacts.

The NHS Covid-19 app has been continued and has never been canceled or suspended.

Condition 1: Ethical implementation

The NHS COVID-19 app is fully voluntary in use. The NHS COVID-19 app uses the Google-Apple framework. It collects the same types of data as described in the previous cases that use this framework. The data can in no way be linked back to individual persons, and no location based on GPS is used. However, the NHS COVID-19 app does allow citizens to scan venue QR-codes. In this way, location data is saved. However, the app states that *"If you choose to use the venue check in function, your phone will hold protected data about which venues you checked into, and at what time. The NHS and the government will not have access to any of this data. They cannot use the app to track your location, for law enforcement or to monitor self-isolation and social distancing"* (NHS COVID-19 app 2021).

The National Health Service (NHS) is responsible for the app and the data collection. After 14 days, all data (including location data based on QR codes) is deleted. The app contains an extensive privacy statement and asks users for consent. However, no decommissioning process was found in the governmental releases or inside the app.

Condition 2: Effective underlying technology

The app is based on the Google-Apple framework and uses low-energy Bluetooth transmissions. This technology is proven to be effective in identifying COVID-19 transmissions. In addition to this, the app can scan QR-codes of venues. When a citizen tested positive and shared their key, everyone that has been at that venue will receive a notification. This makes the app even more effective.

The app has been tested extensively in the Isle of Wight in June of 2020. It was a large-scale test of the NHS COVID-19 app. Afterward, in August and September, the app was tested again by invited users (NHS 2021b). According to the NHS, *"The trial showed us that the app is accurate, responsive and has received positive feedback from users"*.

Condition 3: Promotion by the government

The app has extensively been promoted by several marketing campaigns. The marketing bureau 'MullenLowe Group' was hired by the government to run a large campaign on TV, radio, print, and social media (MullenLowe Group 2020). The government is very open about how the app works. The government publicly provides campaign materials, which companies can use to promote the app themselves (Public Health England). One of the included posters can be seen in figure 8. The poster clearly states that the app will protect the privacy of the users.

Figure 8: Publicly provided campaign materials for the NHS COVID-19 app

Condition 4: Trust in the government

Trust in the government lies at 34,7%, which is lower than the threshold of 50% (OECD 2020).

Condition 5: Digital Adoption Index

The DAI of England is 79.9, which is higher than the threshold of 70% (The World Bank 2016).

England → 'NHS COVID-19 app'			
Outcome	**Determinants**	**Outcome determinants**	**Unsuccessful [0] / Success [1]**
SUCCESS	1. Adoption rate	35%	Success [1]
	2. General effectiveness in identifying cases	High → [1]	
	4. The app has been cancelled / suspended / continued	Continued → [1]	
Condition	**Determinants**	**Outcome determinants**	**Condition absent [0] / present [1]**
1. ETHIC	1. App voluntary / mandatory	Voluntary → [1]	Present [1]
	2. Handling of data	Safe → [1]	
	3. Clear / unclear statement of data collection, usage and storage	Clear → [1]	
	4. User consent	Yes → [1]	
	5. Ability to delete data at any time	Yes → [1]	
	6. Decommissioning process	No → [0]	
2. EFFTECH	1. Technology used	Google-Apple Decentralized Bluetooth + QR → [1]	Present [1]
	2. Accuracy of predictions	Accurate → [1]	
	3. Testing of the app	Extensive → [1]	
3. PROMO	1. Promotion by the government	Yes → [1]	Present [1]
4. GOVTRUST	1. % of citizens that trust the government	34.7% → [0]	Absent [0]
5. DAI	1. Digital Adoption Index	79.9 → [1]	Present [1]

Appendix D. Case Germany: ‘Corona-Warn-App’

Success

As of the 28th of April 2021, around 27.4 million people have downloaded the Corona-Warn-App (Robert Koch Institut 2021, translated). Based on the population of Germany, this results in an adoption rate of around 33%. That is above the threshold of 20%, therefore this determinant is present.

There is no data available on the number of people that have tested on COVID-19 as a result of the contact tracing app. Around 10-15 percent of all people that get a positive test result decide to share the key with the app. According to Scherschel (2021, translated), the app is successful in identifying COVID-19 cases. According to Friemel & Bellmer (2020, translated), the app is generally effective, however, the human factor can be a problem. To be more effective, more people should share their positive test keys. The problem is not the technology: that can be very effective to identify exposures. According to Germany’s Health Ministry *“The coronavirus app is effective, it is in high demand, and it functions well, helping prevent further infections”* (Scholz 2020, translated). However, the same article suggests that the adoption rate is too low for the app to be effective at all (Scholz 2020, translated). According to the Hertie School (2021), low adoption can indeed be a problem for the app’s effectiveness. However, since the app has a higher adoption rate than many other European countries, it can still be assumed that this app is a success *relative* to other contact-tracing apps.

The app is continued.

Condition 1 – Ethical implementation

The app is based on the Google-Apple Bluetooth framework. When the app is opened, it is shown what data is collected. No personal data is collected. The app shows a privacy statement, which states how and what data is processed. The app is published by the Robert Koch Institute. Data is automatically deleted after 14 days. Users have to ability to pause the app and delete their data at any time.

Moreover, just like the app from the United Kingdom, people can scan QR-codes to register their locations. However, this is entirely voluntary, and users have to separately give consent for this feature. Data from this feature will be deleted automatically after 16 days.

No decommissioning process is in place.

Condition 2 – Effective underlying technology

The app is based on the Google-Apple framework and uses low-energy Bluetooth transmissions. Moreover, the app can scan QR codes to register your presence at a location. This increases the effectiveness even more. This combination is very comparable to the underlying technology of the United Kingdom. Therefore, the underlying technology can be seen as successful.

However, the Corona-Warn-App has only been internally tested. It seems that no field tests or Beta tests have taken place.

Condition 3 – Promotion by the government

The German app has been extensively promoted by governmental campaigns. The focus was especially shifted towards social media marketing. The campaign clearly states how the app works, and how the app handles collected data in a safe way (Theobald 2020, translated). Moreover, *"In order for the campaign to reach as many citizens as possible in Germany, the agency and the federal government have also developed a kit that influencers and other multipliers - be it politicians, business and media, companies or institutions - use and thus become an active part of the Campaign"* (Theobald 2020, translated). For this purpose, the government provides campaign material online which everyone can use (Bundesregierung 2021, translated).

As can be seen in figure 9, the campaign focused on increasing the feeling of responsibility within citizens.

Figure 9: "Doesn't know them. Helps them anyway" (translated).

Condition 4 – Trust in the government

Trust in the government is at 65.4%, which is higher than the threshold (OECD 2020).

Condition 5 – Digital Adoption Index

The DAI of Germany is high at 77.9% (The World Bank 2016). This is higher than the threshold of 70%.

Germany → 'Corona-Warn-App'			
Outcome	**Determinants**	**Outcome determinants**	**Unsuccessful [0] / Success [1]**
SUCCESS	1. Adoption rate	33% → [1]	Success [1]
	2. General effectiveness in identifying cases	Effective → [1]	
	4. The app has been cancelled / suspended / continued	Continued → [1]	
Condition	**Determinants**	**Outcome determinants**	**Condition absent [0] / present [1]**
1. ETHIC	1. App voluntary / mandatory	Voluntary → [1]	Present [1]
	2. Handling of data	Safe → [1]	
	3. Clear / unclear statement of data collection, usage and storage	Clear → [1]	
	4. User consent	Yes → [1]	
	5. Ability to delete data at any time	Yes → [1]	
	6. Decommissioning process	No → [0]	
2. EFFTECH	1. Technology used	Google-Apple Decentralized Bluetooth + QR → [1]	Absent [0]
	2. Accuracy of predictions	Accurate → [1]	
	3. Testing of the app	Not extensive → [0]	
3. PROMO	1. Promotion by the government	Extensive → [1]	Present [1]
4. GOVTRUST	1. % of citizens that trust the government	65.4% → [1]	Present [1]
5. DAI	1. Digital Adoption Index	77.9 → [1]	Present [1]

Appendix E. Case Norway version 1: ‘Smittestopp’

Success

The app Smittestopp was released in April 2020. In June 2020, the adoption rate was quite low at around 10% of the population of Norway (Ikeda 2020). In June 2020, all data collection by Smittestopp was cancelled, after several, after several privacy issues were brought to light by the Norwegian Data Protection Authority (Norwegian Institute of Public Health, 2020). Finally, in September 2020, the app was discontinued. A new version of the app was released in December 2020, which was based on the Google-Apple Bluetooth framework.

According to a paper by Sandvik (2020) the original app was plagued with problems of inefficiency and the creation of many false positives. Moreover, user-friendliness, functionality, downloading failures, and high battery use posed as problems for the app (Sandvik 2020). In combination with the low adoption rate, the general effectiveness in identifying cases was therefore low. Since the app was canceled, this version of the app can be seen as unsuccessful.

Condition 1: Ethical implementation

The Smittestopp app was canceled mainly due to concerns the citizens had with privacy (Sandvik 2020). The app was released very quickly after the start of the pandemic. The app used a combination of Bluetooth and GPS. Moreover, SMS was used to notify users of potential exposure, This was a very controversial choice since SMS can easily be traced back to individual users. Moreover, SMS was susceptible to fraud, since sender addresses and the content of text messages can be altered, therefore *“tricking recipients into giving out sensitive personal data, including financial data—or harassment”* (Sandvik 2020: p. 4).

The Norwegian Defence Research Establishment even advised to not release the app at all. However, these warnings were ignored (Rise & Venæs 2020, translated). Moreover, since location data (GPS) was used in combination with Bluetooth, individual locations could technically be traced back to citizens. Therefore, the data was handled poorly. The Norwegian Institute of Public Health was responsible for the app, and even they wrote that *“we cannot rule out the possibility that the recipients of SMS notifications will know the identity of the infected individual”* (Sandvik 2020: p. 4). Amnesty International released a list of the most privacy-invasive contact tracing apps. The Smittestopp app landed near the top (Ikeda 2020, translated).

In contrast with these issues, the app clearly stated how data will be collected and asks citizens for consent. According to Sandvik (2020, translated), the low adoption rate was a result of people not wanting to consent due to the ethical issues. The app does not state any decommissioning process. Finally, the app gives users the option to delete the location data at any time (Nikel 2020, translated).

The app does state that data can be used for other purposes, such as research purposes. The app gives users no option to opt out for this.

Condition 2: effective underlying technology

The app used a combination of Bluetooth and GPS. Bluetooth has been proved to be an efficient technology to assess exposures. While the literature showed that GPS tracking might work worse than Bluetooth tracking, the combination of the two technologies could complement each other (Grantz et al. 2020). According to Sandvik (2020, translated) the app has been released without any large tests. The testing phase of the app started only after the app was released.

Condition 3: Promotion by the government

The government focused extensively on social media promotion, mainly through Facebook and Google. Moreover, the app has been advertised in newspapers, on billboards, and on television (Hauger 2020, translated). A marketing bureau was hired to be in charge of the promotion. They did extensive research on how to reach hard-to-reach target groups, such as older people. The campaign tried to be transparent about the app so that citizens will know how the app works (Hauger 2020, translated). The campaign focused on people missing the 'old life' before COVID-19, and how the app could help in returning to that.

Figure 10: "I miss being able to visit my old mother" and "I miss that my patient can be visited more often" (translated).

Condition 4: Trust in the government

Trust in the government is high, at around 83% (OECD 2020). This is above the threshold of 50%.

Condition 5: Digital Adoption Index

The Digital Adoption Index of Norway is high, at 81.1% (The World Bank 2016).

Norway → 'Smittestopp' [VERSION 1]			
Outcome	**Determinants**	**Outcome determinants**	**Unsuccessful [0] / Success [1]**
SUCCESS	1. Adoption rate	10% → [0]	Unsuccessful [0]
	2. General effectiveness in identifying cases	Low → [0]	
	3. The app has been cancelled / suspended / continued	Cancelled → [0]	
Condition	**Determinants**	**Outcome determinants**	**Condition absent [0] / present [1]**
1. ETHIC	1. App voluntary / mandatory	Voluntary	Absent [0]
	2. Handling of data	Unsafe → [0]	
	3. Clear / unclear statement of data collection, usage and storage	Clear → [1]	
	4. User consent	Yes → [1]	
	5. Ability to delete data at any time	Yes → [1]	
	6. Decommissioning process	No → [0]	
2.EFFTECH	1. Technology used	GPS / Bluetooth	Absent [0]
	2. Accuracy of predictions	Accurate	
	3. Testing of the app	Not extensive	
3. PROMO	1. Promotion by the government	Yes → [1]	Present [1]
4. GOVTRUST	1. % of citizens that trust the government	83% → [1]	Present [1]
5. DAI	1. Digital Adoption Index	81.1% →[1]	Present [1]

Appendix F. Case Norway version 2: 'Smittestopp'
Success

In December 2020, the Smittestopp app was released after the initial failures in June and September. The app was now based on the Bluetooth framework provided by Google and Apple. GPS data was no longer used.

According to data from the Norwegian Institute of Public Health and the application, the adoption on May 17th, 2021 was around 20% of the total population of Norway, an increase of about 10% compared with the first version of the app. Considering that the new app attracted more users, it is interesting to see what the differences in the conditions for this app are. The new app may not reach high levels of adoption, however, treating the app as a 'success' is beneficial for our analysis.

According to Egge & Borstad (2021, translated) data is lacking to assess the effectiveness of the app. However, the Norwegian Institute of Public Health is confident that the app is working properly (Egge & Borstad 2021, translated). However, the article suggests that more downloads are needed to make the app function more effectively.

Condition 1: Ethical implementation

The app is based on the Google-Apple framework and uses low-energy Bluetooth transmissions. After downloading the app, we notice that the app features an extensive privacy statement. It describes what data the app will collect. Moreover, the app deletes all data after fourteen days. The user can delete their data at any time. Data can in no way be traced back to an individual user, not even for the Norwegian Institute of Public Health. Notification via SMS is abandoned, this only goes through the app itself. The app no longer collects GPS/location data. The app is entirely voluntary in use.

The app asks users for consent for the use of the app and the use of Bluetooth. The app can be paused at any time. However, no decommissioning process is in place.

Condition 2: Effective underlying technology

Since the app used low-energy Bluetooth transmission based on the Google-Apple framework, the app has an effective underlying technology. The accuracy of the predictions with this technology can be seen as accurate. However, the Norwegian Institute of Public Health does not provide any information on if and how they tested the new app. Any justifications of the quality of the app are only based on results from other countries that use the Google/Apple framework. Therefore, this condition can be seen as absent.

Condition 3: Promotion by the government

With the new apps came a new promotion campaign. This new campaign focuses on how the app changed. The campaign hopes to increase the trust in the app, thereby increasing the adoption rate (Njie 2020, translated). *"(...) privacy, anonymity and functionality are an important part of the campaign, and that solutions have been developed that explain this in 43 different languages"* (Njie 2020, translated). The campaign is still based mainly on social media, however, advertisements for televisions, newspapers, and billboards are still present.

Condition 4: Trust in the government

Trust in the government lies around 83%, which is above the threshold (OECD 2020).

Condition 5: Digital Adoption Index

The Digital Adoption Index of Norway is high, at 81.1% (The World Bank 2016).

Norway → 'Smittestop' [VERSION 2]			
Outcome	**Determinants**	**Outcome determinants**	**Unsuccessful [0] / Success [1]**
SUCCESS	1. Adoption rate	20% → [1]	Success [1]
	2. General effectiveness in identifying cases	Effective → [1]	
	3. The app has been cancelled / suspended / continued	Continued → [1]	
Condition	**Determinants**	**Outcome determinants**	**Condition absent [0] / present [1]**
1. ETHIC	1. App voluntary / mandatory	Voluntary	Present [1]
	2. Handling of data	Safe → [1]	
	3. Clear / unclear statement of data collection, usage and storage	Clear → [1]	
	4. User consent	Yes → [1]	
	5. Ability to delete data at any time	Yes → [1]	
	6. Decommissioning process	No → [0]	
2.EFFTECH	1. Technology used	Google-Apple Decentralized Bluetooth + QR → [1]	Absent [0]
	2. Accuracy of predictions	Accurate → [1]	
	3. Testing of the app	Absent → [0]	
3. PROMO	1. Promotion by the government	Yes → [1]	Present [1]
4. GOVTRUST	1. % of citizens that trust the government	83% → [1]	Present [1]
5. DAI	1. Digital Adoption Index	81.1% → [1]	Present [1]

Appendix G. Case France version 1: ‘StopCovid’

Success

The French app ‘StopCovid’ was deployed in June 2020. In the first three weeks of deployment, only 14 exposure notifications had been sent (Braun 2020, translated). In August 2020, the number of exposure notifications was still only 72 (O’Brien 2020). This indicates that the app was very unsuccessful in tracing COVID-19 exposures. While the app uses Bluetooth low-energy signals, it does not use the Google-Apple framework. The app was plagued with issues, like battery drain and a low amount of users reporting their positive tests (Garousi, Cutting & Felderer 2020, translated; O’Brien 2020). Moreover, the app cannot transfer data with other apps in the European Union, since France opted to use a centralized system of data collection, in contrast to almost all other European nations (Connexxion France 2020).

In September 2020, the adoption rate of the app was only 3,6% of the entire population of French. In October 2020, the French ‘StopCovid’ app was canceled and replaced by the ‘TousAntiCovid’ (Together Against Covid) app, which will be assessed as a separate case. Therefore, the StopCovid app can be seen as a failure.

Condition 1: Ethical implementation

In contrast to many other European countries, France opted to not use the Google-Apple decentralized Bluetooth structure. Instead, they use a centralized approach, where all Bluetooth data is uploaded to a government server. Of course, this raised many questions related to government surveillance and trust (France24 2020, translated). The app had an unclear privacy statement; therefore citizens could not fully know how their data will be used by the government (McKenzie 2020). Moreover, since all data is centrally uploaded, the data is prone to be hacked (Schönborn 2020, translated).

According to the French Data Protection Authority, there are several issues with the StopCovid app. First of all, the app does not provide enough information in the privacy statement, especially regarding the use of the application and how and when personal data will be deleted. Moreover, no specific information about minors and parents is included (McKenzie 2020, translated). Data is pseudonymized, and is therefore hard to trace back to individuals (Dillet 2020, translated). However, the data is still not fully anonymous.

Users have to give consent for the collection of the data. People cannot delete their data at any time. Users cannot pause the app (Travieso 2020, translated). No decommissioning process is in place (Government 2020).

Condition 2: Effective underlying technology

The StopCovid app does not use low-energy Bluetooth transmissions from the Google-Apple framework. Instead, the app uses regular Bluetooth, therefore increasing the battery drain from the app. In the literature section, it was assumed that a decentralized low-energy Bluetooth approach would be the most effective underlying technology. In practice, it has been shown that the technology has not been very effective, with low numbers of exposures identified (O'Brien 2020). After 3 weeks and 2 million downloads of the app, only 14 notifications were sent out. Government officials even argued that they were halted by Apple not wanting to help them make the app more effective for iOS devices, which would make their app more effective (Kar-Gupta & Rose 2020, translated). The French minister for digital technology even argued that *"Apple could have helped us make the application work even better on the iPhone. They have not wished to do so"* (Parkinson 2020). What is interesting as well, is that that government releases do not mention extensive testing of the underlying technology.

Condition 3: Promotion by the government

The prime minister of France concluded that the low adoption rate for the StopCovid app was a result of lacking communication. The app was not promoted enough by the government, especially when compared to other European countries (Vitard 2020, translated). While a promotion campaign was in place (on social media, billboards, radio, and television), this was small in comparison to other countries (Vitard 2020, translated). Moreover, these campaigns were overshadowed by negative messages on the StopCovid app in the media. The campaigns only started at the beginning of June, but at that time, public opinion was already shaped by negative messages in the media (Turcan 2020, translated). According to the Directorate General of Health, a new promotional campaign was needed. This only happened when the 'TousAntiCovid' app replaces the 'StopCovid' app. Finally, the existing advertisements failed to advertise how the app could be effective in attacking the pandemic (Cuny-le Callet 2020, translated).

Condition 4: Trust in the government

Trust in the government is, according to OECD 2020 survey data, quite low at 41% (OECD 2020).

Condition 5: Digital Adoption Index

The Digital Adoption Index of France is above the threshold, at 73%.

France → 'StopCovid' [VERSION 1]			
Outcome	**Determinants**	**Outcome determinants**	**Unsuccessful [0] / Success [1]**
SUCCESS	1. Adoption rate	3,6% → [0]	Unsuccesful [0]
	2. General effectiveness in identifying cases	Low → [0]	
	4. The app has been cancelled / suspended / continued	Cancelled → [0]	
Condition	**Determinants**	**Outcome determinants**	**Condition absent [0] / present [1]**
1. ETHIC	1. App voluntary / mandatory	Voluntary → [0]	Absent [0]
	2. Handling of data	Unsafe → [0]	
	3. Clear / unclear statement of data collection, usage and storage	Unclear → [0[	
	4. User consent	Yes → [1]	
	5. Ability to delete data at any time	Yes → [1]	
	6. Decommissioning process	No → [0]	
2.EFFTECH	1. Technology used	Centralized Bluetooth → [0]	Absent [0]
	2. Accuracy of predictions	Low → [0]	
	3. Testing of the app	Not extensive → [0]	
3. PROMO	1. Promotion by the government	Low → [0]	Absent [0]
4. GOVTRUST	1. % of citizens that trust the government	41% → [0]	Absent [0]
5. DAI	1. Digital Adoption Index	73% → [1]	Present [1]

Appendix H. Case France version 2: ‘TousAntiCovid’

Success

After the introduction of the new app, the adoption rate increased to around 22.7% of the entire population, indicating a much more successful app. Moreover, the app has been effective in indicating exposures. In August 2020, only 72 exposure notifications had been sent out (Open Data du Gouvernement 2021, translated) After the introduction of the new app in October 2020, these numbers started to increase drastically, with around (cumulative) 3700 notifications on the 1st of November and around 15,125 notifications on the 1st of December. Today, around 189,000 notifications of exposures have been send (Open Data du Gouvernement 2021, translated). According to new articles, the new app ‘takes its revenge’ after the ‘usefulness’ of the first app (Lesaffre 2020, translated; Hue 2020, translated). The increasing numbers of exposure notifications seem to imply higher effectiveness of the app (Hue 2020, translated).

The current app is continued.

Condition 1: Ethical implementation

The app uses the same centralized Bluetooth technology as the original ‘StopCovid’ app. The only difference related to privacy is that citizens are now able to pause the app at any time (Travieso 2020, translated). Moreover, the app contains a much clearer privacy statement (Travieso 2020, translated). In the new version of the app, data can in no way be traced back to individuals. All data is encrypted and anonymized. The privacy statement contains a clear decommissioning process. Users are able to delete their data at any time.

Condition 2: Effective underlying technology

The app uses the same technology as the original ‘StopCovid’ app. The only differences are ease-of-use additions, such as the introduction of new languages, a new layout, data on the coronavirus in your region, and the ability to download curfew exemption forms (Reynoud 2020, translated).

Condition 3: Promotion by the government

The rebranding of the app could be seen as a large promotional campaign as well since this is what is hypothesized to be the reason the adoption rate so significantly. The rebranding of the app came with a new and extensive marketing campaign, which were more comparable to campaigns of other European countries (Lesaffre 2020, translated). Moreover, the new marketing campaign focused on how the app can be effective to combat COVID-19 (Cuny-le Callet 2020, translated).

Figure 11: "Help us fight against the epidemy. Here I activate my application TousAntiCovid" (translated).

Condition 4: Trust in the government

Trust in the government is, according to OECD 2020 survey data, quite low at 41% (OECD 2020).

Condition 5: Digital Adoption Index

The Digital Adoption Index of France is above the threshold, at 73% (The World Bank 2016).

France → 'TousAntiCovid' [VERSION 2]			
Outcome	**Determinants**	**Outcome determinants**	**Unsuccessful [0] / Success [1]**
SUCCESS	1. Adoption rate	22,7% → [1]	Success [1]
	2. General effectiveness in identifying cases	High → [1]	
	4. The app has been cancelled / suspended / continued	Continued → [1]	
Condition	**Determinants**	**Outcome determinants**	**Condition absent [0] / present [1]**
1. ETHIC	1. App voluntary / mandatory	Voluntary → [1]	Present [1]
	2. Handling of data	Safe → [1]	
	3. Clear / unclear statement of data collection, usage and storage	Clear → [1]	
	4. User consent	Yes → [1]	
	5. Ability to delete data at any time	Yes → [1]	
	6. Decommissioning process	No → [0]	
2. EFFTECH	1. Technology used	Centralized Bluetooth → [0]	Absent [0]
	2. Accuracy of predictions	Low → [0]	
	3. Testing of the app	Not extensive → [0]	
3. PROMO	1. Promotion by the government	High → [1]	Present [1]
4. GOVTRUST	1. % of citizens that trust the government	41% → [0]	Absent [0]
5. DAI	1. Digital Adoption Index	73% → [1]	Present [1]

Appendix I. Case Italy: 'Immuni'

Success

In Italy, 10,443,641 people have downloaded the 'Immuni' app, resulting in an adoption rate of about 17.3 percent (Immuni 2021). This is lower than the threshold, identifying an unsuccessful contact-tracing app.

97,550 citizens got a notification that they may have contracted COVID-19. Of these citizens, 18,56% were tested positive. According to Follis (2020), the app has been ineffective in predicting COVID-19 exposures, due to the low adoption rate. The article suggests that the app could be effective at higher levels of uptake. According to the Minister of innovation, "Immuni is part of a broader strategy. It obviously will be more effective if it is used by a larger part of the population" (Follis 2020).

According to Cau (2020, translated): "*Immuni, the contact tracing application created by the government, has so far contributed little to attempts to contain the second wave of the coronavirus that has affected Italy*".

In general, we can assume the app to be a failure. The app is continued.

Condition 1: Ethical implementation

The Italian 'Immuni'-app used the Google-Apple framework, such as many European countries. The app is voluntary in use. When the app is opened, we are met with a very clear English privacy statement, which states what types of data are collected. The data is collected in a decentralized manner and used low-energy Bluetooth. No personal data or location data is collected, and the collected data can in no way be traced back to individual users. The app clearly asks for consent. All collected data is deleted automatically after 14 days. Moreover, the app can be paused at any time, and just like the other apps with the Google-Apple framework, all the collected data can be deleted at any time. A decommissioning process is in place, since the app states that all data will be deleted no later than December 31st, 2021.

Condition 2: Effective underlying technology

Since the app uses the decentralized Google-Apple framework with low energy Bluetooth signals, we can assume the app uses an effective underlying technology, just like in previous cases. The Immuni app faced extensive testing in four different regions before the official launch of the app (Zampano 2020, translated). These tests yielded positive results.

Condition 3: Promotion by the government

According to Italian minister Pisano, there has been *"a great deal of misinformation about the app"* (Follis 2020, translated). Moreover, the app has been met with controversy due to sexist images in the app. Finally, many of the informational television spots have only been released in October, 4 months after the initial release of the app (Governo Italiano 2020, translated). Only in November did the Minister of Health increase the promotion efforts even more, after realizing the positive effect promotion and public awareness could have (Ministero Della Salute 2020, translated). Some articles even suggest rebranding the app, just like the French 'StopCovid' app. The Immuni app is not in the minds of citizens enough, and only a rebranding might ignite a new rise in adoption: *"The risk is that given the low adoption and above all the low effectiveness, the fate of the app is unfortunately marked and that the name 'Immuni' no longer arouses interest and trust in public opinion"* (Nepori 2021, translated).

Condition 4: Trust in the government

Trust in the government is quite low, at 37.5% (OECD 2020).

Condition 5: Digital Adoption Index

The DAI of Italy is below the threshold, at 67.5% (The World Bank 2016).

Italy → 'Immuni'			
Outcome	**Determinants**	**Outcome determinants**	**Unsuccessful [0] / Success [1]**
SUCCESS	1. Adoption rate	17,3% → [0]	Unsuccessful → [0]
	2. General effectiveness in identifying cases	Low → [0]	
	4. The app has been cancelled / suspended / continued	Continued → [1]	
Condition	**Determinants**	**Outcome determinants**	**Condition absent [0] / present [1]**
1. ETHIC	1. App voluntary / mandatory	Voluntary → [1]	Present [1]
	2. Handling of data	Safe → [1]	
	3. Clear / unclear statement of data collection, usage and storage	Clear → [1]	
	4. User consent	Yes → [1]	
	5. Ability to delete data at any time	Yes → [1]	
	6. Decommissioning process	Yes → [1]	
2. EFFTECH	1. Technology used	Google-Apple Decentralized Bluetooth → [1]	Present [1]
	2. Accuracy of predictions	Accurate → [1]	
	3. Testing of the app	Extensive → [1]	
3. PROMO	1. Promotion by the government	Not extensive → [0]	Absent [0]
4. GOVTRUST	1. % of citizens that trust the government	37.5% → [0]	Absent [0]
5. DAI	1. Digital Adoption Index	67.5% → [0]	Absent [0]

Appendix J. Case Spain: 'Radar COVID'

On May 11th, 2021 the Spanish 'Radar COVID' app had 7.3 million cumulative downloads. Based on the population of Spain, that indicates an adoption rate of about 15.5%. This is below the set threshold; therefore, the app is not successful. Moreover, according to the Spanish government, the app will be effective at uptake of 20%, which the app has not reached (Govan 2020, translated).

A paper by Rodríguez et al. (2021) assessed the Spanish contact-tracing app to determine the usefulness of contact-tracing apps. This assessment was based on the first field tests that were done for the app. They predicted that the app would face an uptake of about 33 percent. Based on that percentage, they found that the Radar COVID could be an effective tool to combat COVID-19 in Spain. However, the actual adoption rate proved to be much lower, at 15.5%. The authors write: *"Overall results of the controlled experiment study are positive and we can conclude that, a priori, this technology works and after appropriate communication campaigns it might have the sufficient level of penetration and compliance to help and serve as a useful complement to manual contact tracing and other non-pharmaceutical interventions in the containment of epidemic outbreaks, thus justifying its nationwide deployment"* (Rodríguez et al. 2021: p. 5). According to the authors, promotion by the government should have increased the adoption rate. Moreover, the authors argued that the app would face problems with a low percentage of positively tested citizens sharing their test results with the app (Rodríguez et al. 2021). *"While adoption and detection are high, the low percentage of those close-contacts that follow-up (10%) is concerning, and this is probably an important point to consider in any communication campaign devoted to raise awareness on the DCT app"* (Rodríguez et al. 2021: p. 5).

According to multiple news outlets, the Radar COVID is not effective and faces too low adoption rates. Moreover, the outlets argue that the low effectiveness of the app does not stand in relation with the high monetary expenditures on the app (Sierra 2021, translated; García 2020, translated). Moreover, only about 2 percent of positively tested citizens shared their test results with the app (García 2020, translated; ABC Español 2020, translated) confirming the predictions from the paper by Rodríguez et al. (2021).

The app has been continued.

Condition 1: Ethical implementation

The Spanish 'Radar COVID' app is based on the Google-Apple framework. Therefore, it does not collect any location data, and the data the app collects can in no way be traced back to individuals. After downloading the app, we are met with an extensive privacy statement. Users need to give consent to the collection of the encrypted data before they can continue. The app explicitly states that the app can be disabled or deleted at any time. According to the app *"your name, email, geolocation and phonenumber are NOT collected".*

The app is under the control of the Secretariat of State for Digitalisation and Artificial Intelligence. The Secretariat vows to protect the data as safely as possible. All collected data is deleted automatically after fourteen days. A user can delete their data at any time as well.

No clear decommissioning process can be found in government releases or the app.

Condition 2: Effective underlying technology

The app uses the decentralized Google-Apple low-energy Bluetooth framework. Therefore, it can be assumed that the underlying technology is effective in detecting COVID-19 cases.

The Spanish app has been tested extensively. Moreover, as discussed above, the effectiveness of the app has been researched based on these tests (Rodríguez et al. 2021). The field experiment took place in La Gamora on the Canary Islands in June and July of 2020 (Vega 2020, translated). The experiment was split up into three phases: the launch phase (based on communication, promotion, and downloads), the monitoring phase (where an outbreak of COVID-19 was simulated), and a post-pilot phase (how many people keep the app on their phone or submit positive tests). The results of these tests were positive (De La Gomera 2020, translated).

Condition 3: Promotion by the government

The app has not been promoted very extensively by the government. The government published some promotional material online, however, the quantity is very low at only one poster and one informational video. Moreover, very little information on promotional campaigns can be found. It appears that all autonomous communities in Spain were responsible for their promotion (Castilla-La Mancha).

The only nationwide campaign was one involving pharmacies, which collaborated in promoting the Radar Covid application (PMFarma 2020, translated).

As suggested above, the existing promotion for the app failed to effectively increase uptake.

Condition 4: Trust in the government

The trust in the Spanish government is below the threshold, at 41% (OECD 2020).

Condition 5: Digital Adoption Index

The DAI of Spain is below the threshold, at 67.4% (The World Bank 2016).

Spain → 'Radar COVID'			
Outcome	Determinants	Outcome determinants	Unsuccessful [0] / Success [1]
SUCCESS	1. Adoption rate	15.5% → [0]	Unsuccessful [0]
	2. General effectiveness in identifying cases	Low → [0]	
	4. The app has been cancelled / suspended / continued	Continued → [1]	
Condition	Determinants	Outcome determinants	Condition absent [0] / present [1]
1. ETHIC	1. App voluntary / mandatory	Voluntary → [0]	Present [1]
	2. Handling of data	Unsafe → [0]	
	3. Clear / unclear statement of data collection, usage and storage	Unclear → [0]	
	4. User consent	Yes → [1]	
	5. Ability to delete data at any time	Yes → [1]	
	6. Decommissioning process	No → [0]	
2. EFFTECH	1. Technology used	Google-Apple Decentralized Bluetooth → [1]	Present [1]
	2. Accuracy of predictions	High → [1]	
	3. Testing of the app	Extensive → [0]	
3. PROMO	1. Promotion by the government	Low → [1]	Absent [0]
4. GOVTRUST	1. % of citizens that trust the government	41% → [0]	Absent [0]
5. DAI	1. Digital Adoption Index	67.4% → [0]	Absent [0]

Appendix K. Case Ireland: ‘Covid Tracker Ireland’

Success

The contact-tracing app ‘Covid Tracker Ireland’ uses the Google-Apple framework. According to the statistics in the app, the app has around 2.52 million downloads, indicating an adoption rate of 51%. This is the highest adoption rate for apps that are not mandatory. About 25,000 citizens got a notification on their phones that they might have been exposed, indicating that many people share their positive test keys. According to the chief from the Health Service Executive Ireland (HSE), the app had the *“most successful launch of this app anywhere in the world”* (McGrath 2020). For many countries, the Covid Tracker Ireland is used as an example of how contact-tracing apps should be implemented (Warwick 2020; Newcomb 2020). Ireland was one of the first countries in the world to link their contact-tracing apps with apps from other states from the European Union (Department of Health 2020). According to Minister for Health*: "Ireland has consistently been a leader in the development of contact tracing apps and had one of the world’s most successful contact tracing app launches, with a huge uptake in the first 24 hours. Currently the app has more than 1.3 million active users. The Irish app already works on an all-island basis and today’s launch of the European Federated Gateway Service will facilitate apps working on a pan-European basis"* (Department of Health 2020).

The app gives users the option to share a phone number in the app. This way, exposed individuals get additional advice to quarantine themselves and get themselves tested. When someone is tested positive, they get a phone call as well. The positively tested citizens are encouraged to share their positive tests in the app.

The app is continued.

Condition 1: Ethical implementation

The app is based on the Google-Apple framework with low-energy Bluetooth signals. The data is saved in a decentralized matter. When the app is opened, the user is met with an extensive Data Protection Information Notice (DPIN). The user must agree with both the Data Protection Information Notice and the Terms & Conditions. The DPIN contains all information about what and how data is collected. The data cannot be traced back to individuals and is anonymous. Therefore, the data is handled safely. Users can decide to share a phone number in the app. When a user does this, the user will not only get a notification after an exposure alert but will also receive a phone call. However, sharing a phone number is not mandatory.

The responsibility for the app lies with the Health Service Executive Ireland. The app can be paused at any time. Moreover, all collected data will be deleted after fourteen days and can be deleted by the user at any time. No decommissioning process could be found within the DPIN and Terms & Conditions.

Condition 2: Effective underlying technology

The app is based on the Google-Apple low energy Bluetooth framework, therefore we can assume that is a proven underlying technology for an accurate prediction of COVID-19 transmissions.

The app underwent almost 5000 hours of testing (Gorey 2020). 3,400 individual software tests were done before the initial launch of the application. *"Tests included ensuring that the app could handle large volumes of people downloading it and using it at the same time without crashing; analyzing Bluetooth strength between devices; seeing whether it was user friendly; and making sure information was populated in the database without interfering with the anonymized data of other users. This was done in a number of simulated environments and later on different forms of public transport to ensure only the right users were getting notifications"* (Gorey 2020). A paper was written on how users would respond to different versions of the app. Therefore, multiple versions of the apps were tested. These tests led to the final version of the app (Julienne et al. 2020).

It can be concluded that the app uses an effective underlying technology that has been tested extensively.

Condition 3: Promotion by the government

The Health Service Executive Ireland organized an extensive promotional campaign with the release of the app. The campaign emphasized the need for the app: "*The more we can get consistent messaging out there about how this can affect change and save lives and start moving the country or the state back to some level of normality and take away the confusion, we can get people to more actively engage"* (Newcomb 2020). Moreover, the campaign needs to make clear how and what data is collected, to gain trust from citizens: *"These apps have to be very clear, not just about privacy and data, but by also sharing quality information about why the app is important and how contact tracing can help break the chains of transmission"* (Newcomb 2020).

A marketing bureau was hired for the campaign. Emphasis was placed on social media marketing (Dept Agency 2020). According to the marketing bureau: *"The aim of the social campaign was to raise awareness while also encouraging users to download the app via a strong call to action"* (Dept Agency 2020). Moreover, more classical means of advertising have been used for the campaign, such as newspaper advertisements, billboards, and TV/radio commercials.

Condition 4: Trust in the government

According to OECD survey data from 2020, trust in the government in Ireland is 58,8% (OECD 2020). That is above the threshold.

Condition 5: Digital Adoption Index

Ireland has a DAI below the threshold, at 64.7% (The World Bank 2016).

Ireland→ 'COVID Tracker Ireland'			
Outcome	**Determinants**	**Outcome determinants**	**Unsuccessful [0] / Success [1]**
SUCCESS	1. Adoption rate	51% → [1]	Success → [1]
	2. General effectiveness in identifying cases	Effective → [1]	
	4. The app has been cancelled / suspended / continued	Continued	
Condition	**Determinants**	**Outcome determinants**	**Condition absent [0] / present [1]**
1. ETHIC	1. App voluntary / mandatory	Voluntary → [1]	Present [1]
	2. Handling of data	Safe → [1]	
	3. Clear / unclear statement of data collection, usage and storage	Clear → [1]	
	4. User consent	Yes → [1]	
	5. Ability to delete data at any time	Yes → [1]	
	6. Decommissioning process	No → [0]	
2.EFFTECH	1. Technology used	Google-Apple Decentralized Bluetooth → [1]	Present [1]
	2. Accuracy of predictions	Accurate → [1]	
	3. Testing of the app	Extensive → [1]	
3. PROMO	1. Promotion by the government	Yes→ [1]	Present [1]
4. GOVTRUST	1. % of citizens that trust the government	58,8% → [1]	Present [1]
5. DAI	1. Digital Adoption Rate	64.7% → [0]	Absent [0]

Appendix L. Case Switzerland: 'SwissCovid'

Success

No official download rates of the SwissCovid app have been released. However, the app states that it is active on 1.76 million phones as of May 14th, 2020. Based on the current population of Switzerland, that indicates an active user rate of around 21%. Since many people have likely stopped using the app, initial adoption (downloads) must be higher than that. Therefore, the app has certainly met the threshold requirements.

According to the Federal Office of Public Health, the SwissCovid app is not effective after a certain threshold, however, is effective at any amount of uptake (Federal Office of Public Health 2021a, translated).

According to a paper by Ballouz et al. (2020) that researched digital contact-tracing in Switzerland, the SwissCovid app helped to identify COVID-19 exposures earlier than traditional means of contact-tracing. They conclude that *"non-household contacts notified by the app started quarantine one day earlier than those not notified by the app. These findings constitute the first evidence that DPT (Digital proximity tracing) may reach exposed contacts faster than MCT (Manual contact-tracing), leading to earlier quarantine and potential interruption of SARS-CoV-2 transmission chains"* (Ballouz et al. 2020: p. 2). Therefore, it can be concluded that the app has been a success.

The app is continued.

Condition 1: Ethical implementation

The SwissCovid app is based on the decentralized Google-Apple framework. The app is voluntary in use. After downloading the app, the user is met with an extensive privacy statement. The user needs to give consent.

No personal data is collected. The app uses Bluetooth, not location data. The data is handled safely by the Federal Office of Public Health (FOPH). All data will be deleted automatically after fourteen days. The app can be paused at any time. Moreover, citizens can delete their data at any time.

Sang-il Kim, head of digital transformations at FOPH stated that *"we want to reassure citizens that this app ensures maximum protection of data and privacy, thanks to the decentralization of the information and the Bluetooth technology, which blocks geolocation"* (Ibrahim 2020).

No decommissioning process is in place.

Condition 2: Effective underlying technology

The Switzerland app is based on the Google Apple low-energy Bluetooth transmissions framework. Just like other countries in Europe, the framework has been proven to be effective for identifying COVID-19 exposures.

Multiple tests have been performed with the app before the initial release in June. Pilot tests of the app started in May 2020 (Barraud 2020; Ibrahim 2020). More than 15,000 citizens participated in the Beta tests. Moreover, the application had accidentally been uploaded to Google's Play Store and Apple's App Store while the app was still in the testing phase. However, this appeared to have helped the testing phase of the app (SWI 2020, translated). Therefore, the app has been extensively tested before release.

These recommendations combined, and the fact that citizens have access to testing, leads to the app having an effective follow-up.

Condition 3: Promotion by the government

With the release of the SwissCovid app came an extensive marketing campaign called 'Protect yourself and others' (Federal Office of Public Health 2020a, translated). The marketing campaigns were focused on social media and classical means of promotion, such as newspapers, television, radio, and billboards. Moreover, the campaign focused on hiring influencers to promote the app (Hollenstein 2020, translated).

In October, additional effort was done to promote the SwissCovid app (Federal Office of Public Health 2020b, translated). These efforts were not aimed at social media or classical media: *"The campaign aims to make the app known among the population at large, clarifying open questions and offering to assist people with its installation"* (Federal Office of Public Health 2020b, translated). This campaign focused on face-to-face informational sessions at companies.

Figure 12: "SwissCovid stops chains of infection" (translated).

Condition 4: Trust in the government

According to OECD survey data from 2020, trust in the government is high, at 84.6%.

Condition 5: Digital Adoption Index

Switzerland's DAI is above the threshold, at 90%.

Switzerland → 'SwissCovid'			
Outcome	**Determinants**	**Outcome determinants**	**Unsuccessful [0] / Success [1]**
SUCCESS	1. Adoption rate	> 21% → [1]	Success → [1]
	2. General effectiveness in identifying cases	Effective → [1]	
	4. The app has been cancelled / suspended / continued	Continued	
Condition	**Determinants**	**Outcome determinants**	**Condition absent [0] / present [1]**
1. ETHIC	1. App voluntary / mandatory	Voluntary → [1]	Present [1]
	2. Handling of data	Safe → [1]	
	3. Clear / unclear statement of data collection, usage and storage	Clear → [1]	
	4. User consent	Yes → [1]	
	5. Ability to delete data at any time	Yes → [1]	
	6. Decommissioning process	No → [0]	
2.EFFTECH	1. Technology used	Google-Apple Decentralized Bluetooth → [1]	Present [1]
	2. Accuracy of predictions	Accurate → [1]	
	3. Testing of the app	Extensive → [1]	
3. PROMO	1. Promotion by the government	Yes→ [1]	Present [1]
4. GOVTRUST	1. % of citizens that trust the government	84.6% → [1]	Present [1]
5. DAI	1. Digital Adoption Rate	90% → [0]	Present [1]

Appendix M. Case Portugal: ‘STAYAWAY COVID’

Success

The Portuguese ‘STAYAWAY COVID’ app has been downloaded almost 3.2 million times as of April 21st, 2021 (Parreira 2021, translated). This indicates an adoption of about 31%.

This would indicate a very successful adoption. However, there are some problems with the app being effective in detecting COVID-19 exposures. While the app has been downloaded almost 3.2 million times, only around 1 million users still have the app on their phones (Parreira 2021, translated). Moreover, only a very small amount of the positive test keys that are given out are registered in the STAYAWAY COVID app (Pequenino 2021, translated). People simply refuse or forget to fill in their keys, or do not understand how the system works. Individuals that are tested positive have to request a positive key themselves via a phone call, and do not get a key automatically. This seems to hinder the effectiveness of the app (Pequenino 2021, translated).

While the app is continued and the initial adoption was high, the number of users declined rapidly and the app is not effective in detecting COVID-19 transmissions. Therefore, the app can be seen as a failure.

Condition 1: Ethical implementation

The app is based on the Google-Apple decentralized framework. After downloading the app (which is fully translated to English) we are met with the privacy statement. Users need to give consent for the collection of the anonymized data. All data is stored on the phones of the users and is not uploaded to a centralized server. Therefore, we can assume the data is handled safely. The app states that all data is deleted automatically after fourteen days. Users can delete their data at any time, and the data can in no way be traced back to individual users.

No decommissioning process is in place. However, since all other determinants are in place, the app is implemented ethically.

Condition 2: Effective underlying technology

Since the app is based on the Google-Apple framework, we can again assume that the underlying technology is effective. Moreover, the app has been tested extensively by INESC TEC, one of the institutions behind the development of the app. A pilot test that took 10 days was performed to assess the usability of the app. Around 9000 participants were invited to the test (INESC TEC 2020, translated). Multiple test versions of the app have been released.

Condition 3: Promotion from the government

Little information about promotional campaigns can be found in government and media releases. Some informational videos were released in September 2020. Moreover, the government promoted the app through social media.

However, the promotion from the Portuguese government failed to correctly inform the public. Citizens complained that they did not even know how they could receive and register a positive test key in the app. According to epidemiologist Henrique Barros, the app's underlying technology was effective. However, the information the government provided was scarce and lacking (Nunes 2021, translated).

Non-governmental development organization 'APDSI' advised the government to create a more effective communication campaign, focusing on how the app works. They argued that the Portuguese distrusted COVID apps and new technologies (APDSI 2020, translated).

Condition 4: Trust in the government

Trust in the government lies at 61.5% according to OECD survey data from 2020 (OECD 2020). Therefore, this condition is present.

Condition 5: Digital Adoption Index

The DAI of Portugal is 72.6, therefore this condition is present.

Portugal → 'STAYAWAY COVID'			
Outcome	Determinants	Outcome determinants	Unsuccessful [0] / Success [1]
SUCCESS	1. Adoption rate	31% → [1]	Unsuccessful [0]
	2. General effectiveness in identifying cases	Low → [0]	
	4. The app has been cancelled / suspended / continued	Continued → [1]	
Condition	Determinants	Outcome determinants	Condition absent [0] / present [1]
1. ETHIC	1. App voluntary / mandatory	Voluntary → [0]	Present [1]
	2. Handling of data	Safe → [1]	
	3. Clear / unclear statement of data collection, usage and storage	Clear → [1]	
	4. User consent	Yes → [1]	
	5. Ability to delete data at any time	Yes → [1]	
	6. Decommissioning process	No → [0]	
2. EFFTECH	1. Technology used	Google-Apple Decentralized Bluetooth → [1]	Present [1]
	2. Accuracy of predictions	High → [1]	
	3. Testing of the app	Extensive → [1]	
3. PROMO	1. Promotion by the government	Low → [0]	Absent [0]
4. GOVTRUST	1. % of citizens that trust the government	61.5% → [1]	Present [1]
5. DAI	1. Digital Adoption Index	76.2% → [1]	Present [1]

Appendix N. Case Bulgaria: 'ViruSafe'

Success

No numbers on adoption rates or downloads are published by the Bulgarian government. However, the Google Play Store indicates that the number of downloads lies between 50,000 – 100,000. Apple does not publish any statistics about how many times an app has been downloaded. However, the market share of Google (Android) vs. Apple (iOS) phones in Bulgaria can give us a proxy of the number of downloads of the app. The market share of Android phones in Bulgaria is around 85%, compared to 15% for iOS phones. Therefore, it is estimated that the number of downloads for both Google and Apple phones lies somewhere between 59,000 and 118,000. Based on the population of Bulgaria, that indicates an adoption rate of 0,84 – 1,7%.

Little is known about the effectiveness of the app. Multiple articles suggest that the app has been highly ineffective in detecting COVID-19 cases, due to the low number of citizens that downloaded the app (Nikolov 2020, translated)

Condition 1: Ethical implementation

The app can be seen as highly unethical due to multiple factors. First of all, all data is saved on a central government server (Parkinson 2020, translated). Therefore, data is not handled safely. Moreover, the app used location data instead of Bluetooth data, which is much more privacy-invasive (Parkinson 2020). Finally, personal data may be sent to third parties (Krastev 2020, translated). The app sends information to doctors, hospitals, and the government (OffNews 2020).

According to the website of ViruSafe (2021): *"In order to enable the full range of features of the application, users need to enter personal data, such as personal ID, age, any chronical diseases they may have and allow the app to use their location. This in turn will give the Ministry of Health and local authorities all necessary information, in case further actions are needed. Important: All personal data is accessible only by Ministry of Health and authorized governmental institutions".*

The app cannot be accessed or downloaded from the Netherlands. Moreover, the official website of ViruSafe contains very little information. No privacy statement or FAQ could be found. Therefore, there is little information on decommissioning processes, deletion of data, privacy statement, and consent. Since the app is centralized, uses location data, and shares this data with multiple institutions, the app can be seen as unethical.

Condition 2: Effective underlying technology

The app does not use Bluetooth data. In the theory section, we assumed that location data is less effective in identifying COVID-19 exposures. Moreover, no information about the app being extensively tested could be found. Therefore, we assume that an effective underlying technology is absent

Condition 3: Promotion by the government

No promotional campaigns on the app could be found.

Condition 4: Trust in the government

No OECD data is known for trust in the government for Bulgaria. However, Eurofound (2018) assessed the levels of trust in national governments. According to them, trust in the national government lies around 30% in 2017. According to the Bertelsmann Transformation Index (2020) trust in the Bulgarian government has always been low, and was around 22% in 2020.

Condition 5: Digital Adoption Index

The digital adoption index of Bulgaria is 57.3%, which is below the threshold of 70% (The World Bank 2016).

Bulgaria → 'ViruSafe'			
Outcome	Determinants	Outcome determinants	Unsuccessful [0] / Success [1]
SUCCESS	1. Adoption rate	0,84 – 1,7% → [0]	Unsuccessful [0]
	2. General effectiveness in identifying cases	Low → [0]	
	4. The app has been cancelled / suspended / continued	Continued → [1]	
Condition	Determinants	Outcome determinants	Condition absent [0] / present [1]
1. ETHIC	1. App voluntary / mandatory	Voluntary → [1]	Absent [0]
	2. Handling of data	Unsafe → [0]	
	3. Clear / unclear statement of data collection, usage and storage	Unclear → [0]	
	4. User consent	Yes → [1]	
	5. Ability to delete data at any time	No → [0]	
	6. Decommissioning process	No → [0]	
2.EFFTECH	1. Technology used	Centralized GPS → [0]	Absent [0]
	2. Accuracy of predictions	Low → [0]	
	3. Testing of the app	Not extensive → [0]	
3. PROMO	1. Promotion by the government	High → [1]	Absent [0]
4. GOVTRUST	1. % of citizens that trust the government	22 – 30% → [0]	Absent [0]
5. DAI	1. Digital Adoption Index	57.3% → [0]	Absent [0]

Appendix O. Case Hungary: 'VirusRadar'

Success

Information from the government on the Hungarian 'VirusRadar' is extremely limited. The app has only been released on Android devices. This is because the app does not use the Google-Apple framework. This means that for Apple devices, the app could only work when the app is running in the foreground. Apple does not allow third-party apps to use Bluetooth in the background when these apps do not use the Google-Apple framework. Therefore, the app developers decided to not release the app on Apple devices (Keller-Alánt 2020, translated).

The government does not publicly provide numbers on the amount of downloads or adoption rates. Luckily, since the app is only accessible from the Google Play store, we can consult the download numbers from there as a proxy for the adoption rate. The Google Play Store states there have been 100,000+ downloads of the app. The next threshold for downloads is 500,000+, meaning that the actual number of downloads lies between 100,000 and 500,000. A broad range, however, even with 500,000 downloads the actual adoption rate would only be around 5.1%. With these low numbers, the app cannot be very effective in identifying COVID cases. Therefore, we can conclude that the app has not been successful.

The app has been continued.

Condition 1: Ethical implementation

The VirusRadar app opted to not use the Google-Apple framework. While most data is collected decentralized, phone numbers are stored on a centralized server. The data is stored on servers from the Governmental Agency for IT Development (Kaszás 2020, translated). The phone numbers can be used by authorities to contact potentially exposed individuals. According to the official website of Virusradar, *"authorities will receive a telephone number of potentially infected people from a central, secure server that will allow them to help in accordance with the protocol and will be able to notify potential infected people"* (VirusRadar 2021, translated). While the government writes that the data is secure, phone numbers could still hypothetically be traced back to individuals (Kaszás 2020, translated). Centrally stored data are more prone to hacking. Moreover, Hungary is one of the only countries in Europe that decided to not share the source code of the app, making it unclear how the app collects and uses the data (Moreno 2020, translated).

Other than the centralized approach to storing phone numbers and user IDs, most other data is stored on phones themselves. This approach is comparable to other European countries, where users can stop the data collection at any time. Moreover, all locally stored data is deleted automatically after fourteen days. Users can delete the data from their phone at any time, however, data from the central servers cannot be deleted at any time (VirusRadar 2021, translated).

Users need to give consent before being able to use the app.

The app is voluntary in use. No decommissioning process is in place.

Condition 2: Effective underlying technology

While the app is not based on the Google-Apple framework, essentially the technology works the same. The app uses low-energy Bluetooth transmissions to detect COVID-19 exposures. This technology can be very accurate in predicting exposures.

Condition 3: Promotion by the government

The Hungarian app has not had any promotional campaigns*: "Government communication is brought together by the Prime Minister's Office under Antal Rogán. Until the Cabinet Office nods to a campaign - and provides resources for it - a ministry can't start a series of ads"* (Keller-Alánt 2020, translated). It can be assumed that this is one of the reasons why the apps failed to gain traction.

Condition 4: Trust in the government

Trust in the government is 42.9% according to OECD survey data, which is lower than the threshold (OECD 2020).

Condition 5: Digital Adoption Index

The DAI of Hungary is 65,3%, which is below the threshold (The World Bank 2016).

Hungary → 'VirusRadar'			
Outcome	**Determinants**	**Outcome determinants**	**Unsuccessful [0] / Success [1]**
SUCCESS	1. Adoption rate	1 % - 5,1% → [0]	Unsuccesful [0]
	2. General effectiveness in identifying cases	Low → [0]	
	3. The app has been cancelled / suspended / continued	Continued → [1]	
Condition	**Determinants**	**Outcome determinants**	**Condition absent [0] / present [1]**
1. ETHIC	1. App voluntary / mandatory	Voluntary → [1]	Absent [0]
	2. Handling of data	Unsafe → [0]	
	3. Clear / unclear statement of data collection, usage and storage	Unclear → [0]	
	4. User consent	Yes → [1]	
	5. Ability to delete data at any time	No → [0]	
	6. Decommissioning process	No → [0]	
2. EFFTECH	1. Technology used	Decent. + Cent. Bluetooth → [0]	Present [1]
	2. Accuracy of predictions	Accurate → [1]	
	3. Testing of the app	Not extensive → [0]	
3. PROMO	1. Promotion by the government	No → [0]	Absent [0]
4. GOVTRUST	1. % of citizens that trust the government	42.9% → [0]	Absent [0]
5. DAI	1. Digital Adoption Index	65.3% → [0]	Absent [0]

Appendix P. Case Finland: 'Koronavilkku'

Success

The last data that is available about the number of downloads stems from November 2020. However, at that time, the app had already been download around 2.5 million times. This indicated adoption of 45% of the population (Finnish Institute for Health and Welfare 2020, translated). Four days after the initial release of the application, one in four Finnish citizens had already downloaded the application (Reuters 2020, translated). Moreover, around 35% of all citizens that are tested positive share their positive test key, which is a high number compared to other European countries (Finnish Institute for Health and Welfare 2020). Users who get a positive exposure warning can immediately get tested, with or without symptoms (Koronavilkku 2021, translated).

Other countries are looking at the success story of Finnland's contact-tracing app (McDonnell 2020, translated). According to the Finnish Institute for Health and Welfare, *"Koronavilkku has received attention outside Finland as well. The high download rate of the app has been featured in publications such Le Monde in France and The New York Times in the US"* (Finnish Institute for Health and Welfare 2020, translated). Developer Solita received several awards for their marketing campaign that resulted in one of Europe's most downloaded contact-tracing apps (Solita 2021, translated). They received an award for best user experience and an honorable mention for the best mobile service.

The app is currently continued.

Condition 1: Ethical implementation

The app is based on the Google-Apple framework. After installing the app, we are met with the privacy statement, which very clearly states how and what data will be collected. Users need to give consent to the collection of the data. Just like the other apps using the framework, all data is anonymized and cannot be traced back to individuals. In contrast to other apps within this framework, data is deleted automatically after 21 days, not after 14 days (Solita 2020, translated). Users can pause the app or delete their collected data at any time. Moreover, the app is voluntary in use and a decommissioning process is in place (Koronavilkku 2021, translated).

Condition 2: Effective underlying technology

Since the app uses the Google-Apple framework, the app can be effective in accurately predicting COVID-19 exposures.

However, the government or developers have not held any field tests or beta tests (Koronavilkku 2021, translated; Solita 2021, translated). No information can be found on any internal testing as well. Therefore, we can assume no extensive testing has taken place.

Condition 3: Promotion by the government

The Finnish government has organized multiple campaigns for the promotion of the Koronavilkku app. The government focused its resources on social media and influencer advertising, in addition to classical means of promotion through television, radio, newspapers, and billboards (Lehtonen 2021, translated; Government Communications Department 2021, translated). The app has been integrated into informational campaigns to combat COVID-19, as can be seen in the picture below. According to a survey, 9 out of 10 Finnish citizens have heard of the app (Finnish Institute for Health and Welfare 2020, translated). Therefore, we can see the promotional campaign as a success.

Figure 13: "Complete control of Corona" (translated.)

Condition 4: Trust in the government

At 80.9%, trust in the government is high (OECD 2020).

Condition 5: Digital Adoption Index

The DAI in Finnland is high, at 83.1% (The World Bank 2016).

Finnland → 'Koronavilkku'			
Outcome	**Determinants**	**Outcome determinants**	**Unsuccessful [0] / Success [1]**
SUCCESS	1. Adoption rate	45% → [1]	Success [1]
	2. General effectiveness in identifying cases	High → [1]	
	3. The app has been cancelled / suspended / continued	Continued → [1]	
Condition	**Determinants**	**Outcome determinants**	**Condition absent [0] / present [1]**
1. ETHIC	1. App voluntary / mandatory	Voluntary → [1]	Present [1]
	2. Handling of data	Safe → [1]	
	3. Clear / unclear statement of data collection, usage and storage	Clear → [1]	
	4. User consent	Yes → [1]	
	5. Ability to delete data at any time	Yes → [1]	
	6. Decommissioning process	Yes → [0]	
2.EFFTECH	1. Technology used	Google-Apple Decentralized Bluetooth → [1]	Absent [0]
	2. Accuracy of predictions	Accurate → [1]	
	3. Testing of the app	Not extensive → [0]	
3. PROMO	1. Promotion by the government	Yes → [1]	Present [1]
4. GOVTRUST	1. % of citizens that trust the government	80.9% → [1]	Present [1]
5. DAI	1. Digital Adoption Index	83.1% → [1]	Present [1]