Modeling COVID-19 Vaccine Rollout in Lebanon for Better Impact

Full Version
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Citation

Selection Process
A search of the literature was undertaken to identify articles -systematic reviews and single studies- addressing COVID-19 rollout. The combination of the following words ("Rollout" OR "Inoculation" OR "campaign" OR "immunization" OR "Strategy" OR "Deployment") AND ("COVID-19 Vaccine" OR "Pfizer vaccine" OR "Pfizer BioNTech" OR "Sinopharm" OR "Sputnik V" OR "Moderna" OR "Oxford-AstraZeneca" OR "Johnson and Johnson") were used to search the following databases: Medline/Pubmed and Health Systems Evidence. Google Scholar and grey literature were also reviewed. Last search was done on the May 1st, 2021.
Lebanese Context

Closure and Re-opening Episodes in Lebanon

On February 21st, 2020 Lebanon recorded its first COVID-19 case. Three weeks later the government declared full mobilization and the country entered complete lockdown [1]. Starting May 2020, the government started easing restrictions and fully reopened its airport on July 1st [2]. The number of cases gradually increased leading to a surge in July and a subsequent lockdown in August [3]. Amidst this lockdown, a massive blast rocked the capital, Beirut, exacerbating the situation as casualties flooded hospitals and people rushed to help the injured, overlooking social distancing measures amidst a very difficult humanitarian situation. The surge in the number of cases following the blast led the country into a third, two-weeks lockdown on the 21st of August [4]. Meanwhile, the number of daily cases continued to grow in the fall leading to another closure in November 2020 [5].

Near the end-of-year holidays, the government completely reopened the country hoping that the economy would catch its breath after an unprecedented economic collapse and currency devaluation. During this time the number of cases grew exponentially reaching a record high of 6,000+ daily cases by mid-January (Figure 1) [6]. As expected, three weeks later, the country documented close to 100 daily deaths, the highest since the beginning of the epidemic. With acute and intensive care hospital beds reaching their full capacity, the country entered its fifth lockdown in less than one year (Figure 2) [7].

The repeated closure and reopening episodes further worsened the economic situation in the country, decreased the public’s trust in the national public health response to the epidemic, and were not successful in sustainably suppressing infection spread. As we exit our fifth lockdown, and as our community is slowly getting inoculated, it is imperative that a data-driven strategy is developed and implemented that would spare both, the economy and the health care system further loss.

Figure 1: COVID-19 situation in Lebanon: daily confirmed cases and deaths [6]
Figure 2. Timeline of the lockdowns imposed in Lebanon in response to the COVID-19 pandemic [1, 3-9]
Why didn’t the multiple lockdowns prevent epidemic surges, and what should be done to prevent new epidemic surges?

To prevent epidemic expansion and a surge in cases, a key indicator, Rt, needs to be closely monitored to inform imposing and easing of restriction. The effective reproductive number, Rt, is the average number of secondary cases produced by one infected individual at any point in time throughout the epidemic. As long as Rt is smaller than 1, the epidemic will be declining. If Rt is greater than the threshold of 1, restrictions should be imposed; otherwise there will be resurgence. Restrictions should only be gradually lifted when Rt is less than 0.7 with continuous monitoring to ensure it remains below 1. (Further details on Rt and its use in guiding policy are found in the box below and Annex 1).

We plotted the trend in Rt in Lebanon over time since the end of June 2020 where SARS-CoV-2 epidemic expansion became noticeable to explore why the imposed lockdowns were not successful in sustainably suppressing the epidemic (Figure 3). We further delineate the next steps decision-makers should take to control epidemic spread and prevent resurgence.

Figure 3. Trend in Rt in Lebanon, 20 June 2020-5 May 2021, and correlation with major events and response landmarks. Rt is estimated using the Robert Koch Institute method using case series data [10]. The graph highlights the two important thresholds: Rt of 0.7 which is the recommended threshold for when to start gradual easing restrictions (green line) and Rt of 1 which if crossed with easing too many restrictions will result in resurgence (red line).
Rt has exceeded 1 since June 2020 which explains ongoing transmission in the community.

A consistent observation is that all lockdowns were lifted prematurely when Rt was >0.7, therefore not low enough, which explains the quick surges that were subsequently observed. Lockdowns 2, 3, and 4 were lifted when Rt was above 1 or just below 1, which did not allow any buffer for the increase in spread following easing of restrictions. The most recent and strictest lockdown to date (lockdown 5) was more successful in reducing Rt than previous lockdowns. However, it was not sufficiently sustained given the dire economic situation; and the gradual easing of restrictions began when Rt was still above 0.7. The introduction of the more transmissible UK variant, as well as the very slow vaccination rollout, did not help as restrictions were being eased, which led to an increase in cases.

Since March 8th 2021, Rt has been hovering at around 1 with a marked decrease in the last two weeks and an Rt=0.7 on May 5. It is worth noting that even though the epidemic had been rather stable during this time, incidence was relatively high with an average of 2000 diagnosed cases per day. This overall stability of the epidemic suggests a certain balance between, on one hand, transmission due to social contacts and, on the other, abidance by certain levels of social distancing restrictions and other preventive measures as well as immunity built up in the community (mostly due to ongoing infections given the slow vaccine rollout).

While immunity build up in the community is helping curb infection spread and may explain the decrease in Rt most recently observed, caution should be taken because we are still far from population immunity levels that would prevent resurgence with full return to normalcy (estimated to be at least 80% for the new SARS-CoV-2 variants of concern) (see below for mathematical modeling simulations of this scenario).

At the current stage, and given the economic collapse and difficulty to sustain closures for long periods of time, scaling up vaccination and speeding up their rollout will increase the level of immunity in the community hence alleviating the need for additional, stricter, and lengthier social distancing restrictions.

During the process, weekly monitoring of Rt is recommended to guide policy and inform decisions to lift or impose restrictions. With rapid scale-up of vaccination coverage, more restrictions could be lifted without increasing Rt closer to or above 1.

What is Rt?

- **Rt** measures the average number of secondary cases produced by one infected individual at any point in time throughout the epidemic in a partially immune population (due to natural infection and/or vaccination) and where control measures could be in place.

Why is quantifying Rt important?

- Quantifying Rt in different settings at regular and frequent times is needed to evaluate the effectiveness of interventions, to monitor epidemic trends, and to guide decision making for imposing or easing social distancing restrictions.

How can we use Rt to monitor spread and control the epidemic?

- Two important thresholds:
  - Rt = 0.7, the value at which easing of restrictions could start
  - Rt = 1, the value which if crossed will lead to resurgence

- Easing of restrictions should be very gradual, starting at an Rt <0.7 and with continuous monitoring to ensure it is always below 1.

- Restrictions should be imposed when Rt crosses 1.

- Lockdowns are not always necessary. The level of restrictions imposed will depend on the value of Rt and on overall epidemic situation.

(See Annex 1. for further details)
If vaccination levels in the total population remain lower than that required to reach herd immunity, Lebanon would be trapped in the ongoing cycle of alternating periods of imposing (as cases rise and hospitals fill up) and easing of restrictions. Since emerging data suggest that the new variants are more transmissible and/or more severe [11-13], lockdowns and/or strict restrictions will be needed to prevent or alleviate overburdening of the health care sector and, hence, immunity built up due to natural infection may not be fast enough to stop the epidemic. The increased transmissibility of the new variants also means that a higher herd immunity level is needed (at least 80% of the population need to be immune), which reiterates the crucial role of vaccination and the urgency to scale up its roll out to reach herd immunity with the least burden of hospitalizations and deaths possible (see below for mathematical modeling simulations of the impact of vaccination).
Why didn’t the multiple lockdowns prevent epidemic surges?
All lockdowns were prematurely lifted when Rt was above the recommended threshold of 0.7, which did not allow any buffer for the increase in spread following the easing of restrictions and explains the quick surges that were subsequently observed.

What should we do to prevent new epidemic surges?

→ Continuously, frequently, and closely monitor Rt (weekly estimations recommended).

→ Only start lifting restrictions when Rt is less than 0.7.

→ Stop lifting further restrictions if Rt approaches the threshold of 1.

→ Impose restrictions as soon as Rt crosses 1. (Lockdowns are not always necessary - The level of restrictions imposed will depend on the value of Rt and on the overall epidemic situation)

→ Scale-up vaccination and speed up their rollout to increase the level of immunity in the community, which will alleviate the need for additional, stricter, and lengthier social distancing restrictions.

→ If Rt remains consistently below 0.7 for at least one week, gradual easing of restrictions could be started

→ During the process, monitor closely Rt to guide policy and inform decisions to lift or impose restrictions.
COVID-19 Vaccine in Lebanon

Vaccination Strategy in Lebanon

On February 14, 2021, the Ministry of Public Health launched its vaccination campaign and inoculated its first resident marking a new phase of the pandemic in Lebanon and, hopefully, the beginning of its end. At that time, supported by international organizations, the ministry had reserved enough doses to immunize 35% of its 6.8 million inhabitants by the end of 2021 through COVAX and a direct contract with Pfizer [14]. The government was later able to sign a separate agreement with Oxford-AstraZeneca for another 1.5 million doses [15].

Considering its limited ability to purchase the vaccine for all the population, the government decided to mobilize the private sector in the procurement of the vaccine. As such, 18 companies were authorized to negotiate for the Sinopharm, Sputnik V, and the Oxford-AstraZeneca vaccines [16], hoping that this will speed up vaccine rollout.

Until the date of this report, a total of 9.94 M doses have been reserved (MOPH 6.19 M, COVAX 2.73 M, private sector 1.0 M, and 15,000 from the Indian government), which would ensure 73% coverage of the total population. Out of those, only 592,770 (6%) doses have been received so far (Table 1). As a result of the slow vaccine supply, the National COVID-19 Vaccination Committee has recently decided to delay the administration of the second Pfizer dose from the standard 3 week period to six weeks [17].
### Table 1. Vaccines efficacy, doses booked, and doses received

<table>
<thead>
<tr>
<th>Vaccine</th>
<th>Efficacy*</th>
<th>Doses Reserved</th>
<th>Doses received</th>
</tr>
</thead>
</table>
| Pfizer-BioNTech    | 95% [18]    | • 3.6 M doses through a direct agreement with the company (750,000 of which are reserved for eight universities) [14, 19-21]  
                      |             | • Up to 2.73 M doses supplied through COVAX** [14]                              | • ~ 28,500 (13/2/2021) [22]        |
|                    |             |                                                                                  | • ~ 31,500 (20/2/2021) [15]        |
|                    |             |                                                                                  | • 42,120 (27/2/2021) [23]          |
|                    |             |                                                                                  | • 32,760 (6/3/2021) [24]           |
|                    |             |                                                                                  | • 36,270 (13/3/2021) [25]          |
|                    |             |                                                                                  | • 53,820 (20/03/2021) [26]         |
|                    |             |                                                                                  | • 25,740 (28/03/2021) [27]         |
|                    |             |                                                                                  | • 46,800 (03/04/2021) [28]         |
| Oxford-AstraZeneca | 70-4% [33]  | • 1.5 M doses through a direct agreement with the company [15]                  | 33,600 (25/3/2021)-through COVAX   |
|                    |             | • Up to 2.73 M doses supplied through COVAX** [14]                              | [34]                               |
|                    |             | • 15,000 doses donated by the Indian government for UN employees in Lebanon [17] |                                    |
|                    |             | • Private sector (2 companies authorized) [16]                                   |                                    |
|                    |             |                                                                                  | 50,000 (25/3/2021) [37]            |
| Sputnik V          | 91-6% [35]  | • 1 M doses reserved through the private sector [36] (11 companies authorized) [16] |                                    |
|                    |             | • 1M doses reserved through MOPH [36]                                           |                                    |
| Sinopharm          | 79-86% [38] | • Private sector (7 companies authorized) [16]                                   | 40,000 doses (06/04/2021) [39]     |
|                    |             | • 90,000 donated by the Chinese Government [39]                                  |                                    |
| Moderna            | 94.1% [40]  | • No negotiations pre-2022 [17]                                                 | None to date                       |
| Johnson & Johnson  | 66% [41]    | • 600,000 doses (early negotiations and dependent on study results) [17]        | None to date                       |
|                    |             | • Up to 2.73 M doses supplied through COVAX** [14]                              |                                    |

* Efficacy against the wild type virus as per published clinical trials (except for Sinopharm, no peer-reviewed efficacy data)

* The MOPH reserved a combined total of 2.73 M doses of Oxford-AstraZeneca, Pfizer-BioNTech, and potentially Johnson & Johnson vaccines combined. The exact number of doses to be received from each vaccine is not clear yet and will depend on the availability of vaccines at the time of distribution.

M: million
As of May 5, 2021, 493,290 people were vaccinated of which 182,307 (37%) received their 2nd dose [42]. The government had planned a clear prioritization process based on risk of exposure to the infection and risk of developing severe disease (Figure 4) [14]. Residents of all eligible ages were requested to register on an online platform through a dedicated media campaign that targeted vaccine hesitancy. By May 5, 2021, 1,279,280 residents (19% of the total population) had registered to receive the vaccine on MoPH’s official vaccine platform [42]. An additional 15% of the population are estimated to be registered on employer-based platforms such as army individuals, security forces, and members of the syndicate of lawyers in Lebanon [17].

**Figure 4. Phases of Vaccination [14, 43]**
What is the predicted impact of vaccination on COVID-19 epidemic course in Lebanon?

With the expected relaxation of social distancing restrictions in the upcoming summer months and with the threat of the potential introduction of more transmissible and likely more severe SARS-CoV-2 variants, we conducted mathematical modeling analyses to forecast the short term (by end of year) impact of COVID-19 vaccination in Lebanon.

We simulated what would be the epidemic course if all restrictions are gradually eased over four months starting April 15, 2021, and if variants of concern are introduced, for the following three scenarios (Figure 5):

→ **Scenario 1:** No vaccination

→ **Scenario 2:** vaccination started on February 14, 2021, and will gradually reach 80% coverage by the end of 2021 (Target coverage)

→ **Scenario 3:** vaccination started on February 14, 2021, and will gradually reach 40% coverage by the end of 2021 (A more realistic scenario given the current vaccination rollout)

We assumed that 20% of the Lebanese population had already been infected on January 1, 2021.

**Vaccine Coverage** is defined as the proportion of the population that had received the vaccine at a given point in time, regardless of their immunity status (they could already have natural immunity or they could be vaccinated but not immune because the vaccine is not 100% effective). Vaccine coverage is therefore a programmatic definition and, while they strongly overlap, is different than population immunity.

*Figure 5.* Impact of SARS-CoV-2 vaccination on the daily number of new infections* assuming gradual easing of all restrictions starting April 15, 2021.

* Of note that these are the estimated “true” infections, which include not only diagnosed/confirmed cases but also undocumented cases (asymptomatic/mild infections and any infections that did not present for testing).
Modelling study methods brief

We implemented an age-structured SEIR mathematical model of SARS-CoV-2 transmission. The model stratifies the population into cohorts based on vaccination status, age group, infection status, infection stage, and disease stage. The model was fitted to SARS-CoV-2 case series of infections and deaths in Lebanon [44]. It was parametrized using state-of-the-art empirical evidence for the infection’s natural history and epidemiology. Details of the model structure and parameter values can be found in previous publications [45, 46]. The following assumptions were made:

- 20% of the population in Lebanon (includes all residents) has already been infected by January 1, 2021.
- The basic reproduction number of the SARS-CoV-2 variants of concern introduced starting April 15, 2021 is R0=6 (based on evidence of increased transmissibility of these variants [11, 13]).
- Vaccine is introduced on February 14, 2021 and scaled-up at a linear rate to reach the desired coverage rate by December 31, 2021.
- The vaccine has a ‘real-world’ effectiveness of 80% against infection [47-50].
- Both natural-immunity and vaccine-induced immunity last for one year.

Limitations

- Model estimations are contingent on the validity of the input data. While most up-to-date evidence was used to justify model assumptions and parameter values, our understanding of the epidemiology of the infection is still evolving.
- The durations of natural and vaccine-induced immunity remain unknown. If they prove to be less than the assumed one year, the impact of the vaccine will be reduced.
- The level of prior exposure to the infection in Lebanon is unknown. It was assumed to be 20%, a sensible estimate based on a triangulation of available local national data.
- Analyses were conducted at a national level, whereas the vaccine impact will likely differ between geographic locations with different epidemic transmission dynamics, different levels of compliance to preventive measures, and different vaccine uptake levels.
The model estimated that on April 15, 2021, around 40% of the population in Lebanon have natural immunity against SARS-CoV-2 (due to prior infection).

With this estimated population-level immunity and with the vaccination campaign being still in early phases, gradual easing of all restrictions starting mid-April and introduction of new variants of concern is predicted to result in a new epidemic wave, of larger scale than the one experienced in December 2020.

Yet, reaching 80% vaccination coverage by the end of 2021 will noticeably flatten the epidemic curve (yellow curve), resulting in a smaller epidemic (37% decrease in peak daily number of infections compared with the no vaccination scenario). Vaccination did not fully prevent a new epidemic surge because the current contact rate in the community is not sufficiently low and the herd immunity level not sufficiently high, and because of the higher transmissibility of the new variants.

Most importantly, the 80% vaccination coverage would result in a 37% decrease in the peak daily number of severe and critical cases (needing hospitalization on that day) and a 34% decrease in the peak daily number of deaths compared with the no vaccination scenario (Table 2).

On the other hand, the 40% vaccination coverage was not able to noticeably flatten the curve (orange curve) and hence had a much smaller impact on epidemic course compared with the target 80% coverage rate. Achieving 40% coverage over a whole year implies a rollout that is too slow to have a big impact against fast-moving incidence (10-11% decrease in peak daily number of infections, severe/critical cases, and deaths compared with the no vaccination scenario).

Hence, there is an urgent need to scale up vaccination coverage to reach the desired 80% vaccine coverage rate.

### Table 2. Impact of SARS-CoV-2 vaccination on the peak daily numbers of new infections, severe/disease cases, and deaths based on different vaccine coverage scenarios

<table>
<thead>
<tr>
<th>Percent decrease in peak daily number of:</th>
<th>40% vaccine coverage scenario compared with no vaccination</th>
<th>80% vaccine coverage scenario compared with no vaccination</th>
<th>80% vaccine coverage scenario compared with 40% vaccine coverage scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infections</td>
<td>11%</td>
<td>37%</td>
<td>29%</td>
</tr>
<tr>
<td>Severe/disease cases</td>
<td>11%</td>
<td>37%</td>
<td>29%</td>
</tr>
<tr>
<td>Deaths</td>
<td>10%</td>
<td>34%</td>
<td>27%</td>
</tr>
</tbody>
</table>

* Cumulative between February 14, 2021 and December 31, 2021
Impact of vaccine coverage on disease and mortality

Figure 6 shows the impact of various vaccination coverage levels on the cumulative number of averted severe/critical cases and deaths:

Naturally, any vaccine coverage reached by the end of the year will prevent hospitalizations and save lives.

However, as can be seen in Figure 6, the cumulative numbers of averted severe/critical disease cases and deaths between February 14 and December 31, 2021 increase substantially with higher vaccine coverage. They reach 23,600 cumulative averted severe/critical cases and 2,188 cumulative averted deaths in this year if the target 80% vaccination coverage is reached, compared with the no vaccination scenario.

Reaching 80% vaccine coverage will result in a 3-fold increase in the number of prevented hospitalizations and deaths compared with 40% vaccine coverage rate.

Figure 6. Impact of vaccine coverage on the cumulative number of averted severe and critical disease cases (A) and deaths (B) from February 14, 2021 (date of vaccine introduction) to December 31, 2021.

The model did not prioritize vaccination based on age, since younger individuals in the workforce are currently being vaccinated through the private sector. Given that the highest risk elderly population (>70 years) did receive the vaccine first, our estimates for the impact of vaccination are conservative and the number of averted disease cases and deaths may be higher than the ones reported in our study.
Impact of duration of vaccine scale-up on disease and mortality

We explored the impact of different durations of vaccine scale-up to reach the target 80% coverage, thus assessing here the importance of time and the speed at which vaccination is being rolled out in the community. Figure 7 depicts the number of averted severe/critical cases and deaths if 80% vaccine coverage is reached in 4 months, 5 months, etc... up to 11 months by December 31, 2021. Achieving the target vaccine coverage in the community in a shorter time duration will result in a substantial increase in the number of prevented hospitalizations due to severe/critical disease and number of saved lives. For example, reaching 80% vaccine coverage by August 2021 would prevent twice as many hospitalizations and deaths than if it were reached by December 2021.

Figure 7. Impact of vaccine scale-up duration to reach 80% coverage on the cumulative number of averted severe and critical disease cases (A) and deaths (B) from February 14, 2021 (date of vaccine introduction) to December 31, 2021.

What should we do to safeguard population health?

→ Scale up vaccination coverage to reach the desired 80% vaccine coverage rate the soonest possible.

→ Sustain certain levels of social distancing measures to obtain a more favorable impact of vaccination.
Impact of easing of restrictions schedule on disease and mortality

In all of the above scenarios, we assume that easing of all restrictions would occur over four months starting on April 15, 2021. In figure 8, we explore the impact of easing restrictions over longer durations on the cumulative number of averted severe and critical cases and death.

![Figure 8](image)

**Figure 8.** Impact of the duration of easing social and physical distancing restrictions on the cumulative number of averted severe and critical disease cases (A) and deaths (B) from February 14, 2021 (date of vaccine introduction) to December 31, 2021 (80% vaccine coverage)

→ As expected, we found that a longer duration over which restrictions are eased would result in a more favorable impact of vaccination.

→ Gradual easing of restrictions over 8 months (that is until end of 2021) would avert twice as many deaths than if social contacts are back to normalcy in four months, by August 2021.

What should we do to safeguard population health?

→ Scale up vaccination coverage to reach the desired 80% vaccine coverage rate the soonest possible.

→ Sustain certain levels of social distancing measures to obtain a more favorable impact of vaccination.
What is the predicted impact of vaccination on COVID-19 epidemic course in Lebanon?

1. At current population immunity levels, estimated by the model to have reached 40% on April 15, 2021, gradual easing of all restrictions and introduction of new variants of concern will result in a new epidemic wave, of larger scale than the one experienced in December 2020.

2. Yet, an 80% vaccination coverage by the end of 2021 will noticeably flatten the epidemic curve, resulting in a smaller epidemic.

3. Importantly, the 80% vaccination coverage would result in a 37% decrease in the peak daily number of severe/critical cases (needing hospitalizations on that day) and a 34% decrease in the peak daily number of deaths compared with the no vaccination scenario.

4. 80% vaccine coverage is expected to save more than 2000 lives and avert more than 23,000 severe/critical cases over the course of this year; a 3-fold increase in the number of prevented hospitalizations and deaths compared with 40% vaccine coverage rate.

5. The sooner we reach the target vaccine coverage, the higher the vaccine impact (e.g. reaching 80% vaccine coverage by August would prevent twice as many hospitalizations and deaths than if it were reached by December).

6. A longer duration over which restrictions are eased would result in a more favorable impact of vaccination.
How are countries speeding-up vaccine rollout?

The results of our analyses clearly highlight the need to expedite vaccine rollout to achieve herd immunity with the least deaths and hospitalizations possible, and with the least damage to the economy in the short and longer term. The below section summarizes lessons learned from the global COVID-19 vaccine rollout and key strategies countries/states followed to successfully overcome supply, demand, and administration constraints.

Supply

To overcome supply challenges, countries expedited vaccine approvals, procured the vaccines early on in production, diversified risk by purchasing more than one vaccine, prioritized the most vulnerable to maximize impact, ensured the efficient use of scarce vials, delayed the administration of the second dose, and are considering mixing and matching between different vaccines to provide further flexibility if the production of a vaccine decreases:

Vaccine approval

Delays in the national registration and approval of vaccines present a barrier to quick vaccine delivery. Emergency use of Covid-19 vaccines was approved by governments’ regulatory authorities in countries with the fastest vaccine rollout [51]. The United Arab Emirates, one of the top 5 countries in the world in percent population inoculated [52], granted Sinopharm approval for emergency use since September 2020 [53, 54]. Another example is the conditional marketing authorization (CMA), a regulatory mechanism that facilitates early access to medicines in emergencies, which was granted by the European Medicines Agency (EMA) for the use of Pfizer and Moderna in European countries [55].

Lebanon had approved six vaccines up until the report date; based on the World Health Organization, nine other vaccines are currently in the pipeline [56]. Lebanese authorities should closely monitor data released by manufacturers to ensure the prompt approval of promising vaccines and their early procurement.
Early Procurement

Understanding that companies will not prioritize them, small high-income countries ensured early vaccine purchases [57, 58], sometimes paying a premium reaching up to twice the initial price to ensure vaccine availability. The higher purchase cost paid is expected to yield a high return as the economy will be spared further lockdowns [57]. Countries also promised quick rollout to provide the manufacturers with data from the national vaccine campaign [57, 59, 60].

However, the issue of vaccine nationalism stands for many low to middle-income countries like Lebanon, where high-income countries reserved much more vaccine doses than what they actually need leaving little amounts for developing countries. This phenomenon even overshadowed the vaccine manufacturers’ efforts in expanding production and supply [61-63]. Consequently, some philanthropies and international humanitarian organizations are helping less-privileged nations like Lebanon in securing vaccines [62]. The World Bank Group issued a multi-million dollar grant from Lebanon Health Resilience Project to finance the procurement of COVID-19 vaccines [64] and COVAX has secured around 2.73 million doses enough to vaccinate 20% of the population [14]. Additionally, a significant number of vaccines were purchased through the private sector in Lebanon [16]. Other efforts include governmental endeavors to procure vaccines by depositing 4$ million to Pfizer and a total of 21$ million to COVAX. Such efforts should be sustained and further efforts should be made to secure funding for vaccine procurement even within the current foreign currency shortages as lockdowns resulting from slower vaccine deployment are expected to result in losses to the economy that outweigh vaccine cost [65].

Procurement of more than one vaccine

Many countries reduced risks by procuring more than one vaccine. For instance, the United Kingdom procured both its local Oxford-AstraZeneca vaccine and Pfizer-BioNTech’s [66]; similarly, the United States and Canada both procured Pfizer-BioNTech and Moderna vaccines [58, 67]. As of the third week of March 2021, the United Arab Emirates had managed to vaccinate over 20% [52] of its population by procuring both Pfizer-BioNTech and the Chinese Sinopharm vaccine [53]. The Emirate government launched a phase 3 trial for the latter in July 2020 before authorizing it for emergency use in September of the same year [68].
Countries in the Eastern Mediterranean Region, Europe, and the United States are prioritizing the most vulnerable populations such as healthcare workers and older residents [51, 69, 70] to maximize the impact of their vaccination campaigns. This has translated into a remarkable decrease in the number of deaths in the United Kingdom reaching a low of 17 cases on the 22nd of March 2021 [71], approximately a month after the UK government hit its target by vaccinating all its vulnerable population and health and social care workers [72].

In a country like Lebanon having a history of political corruption and weak implementation of policies, it is crucial to safeguard and enforce the prioritization criteria for vaccine reception. This is aggravated by the fact that the private sector is procuring vaccines separately and which may be allocated based on nepotism, political affiliation and to serve political interests at the expense of the community’s health [73-75]. Also, vaccines should be equally deployed to all residents of Lebanon, including refugees and migrant workers which make up around 30% of the population [65, 74]. Xenophobic prioritization of Lebanese nationals and excluding refugees from getting vaccinated defeats the vaccination campaign’s purpose of lowering the infection incidence curve [65].
Efficient utilization of vaccines vials

The European Medicines Agency (EMA) approved utilizing each Pfizer vaccine vial for up to six doses instead of five, the number of doses it was originally designed to provide, as long as the amount remaining in the vial after the fifth dose can provide a full sixth dose. This was possible by using dead-volume syringes to increase the number of doses available for administration [69]. More recently, the WHO released a guidance document clearly endorsing this practice in the event when an additional full dose can be withdrawn from a single vial without combining residual vaccine from multiple vials [76].

Furthermore, countries having successful vaccine deployment programs have an efficient strategy in using leftover vaccine doses from the no-show appointments of the day. Individuals willing to get vaccinated earlier than their scheduled dates are contacted through advanced digital communication platforms and called in to get the vaccine [57]. Although some hospitals in Lebanon are using this approach there is no standardized policy to inform vaccinators of how to handle the remaining doses [77].
**Delaying the second dose**

Amidst the global shortages in vaccine supply and the challenges in its distribution, United Kingdom’s chief scientists decided to delay the second dose of the vaccine from the recommended 3-4 weeks interval to up to 12 weeks. The rationale behind their decision was to provide primary protection to the largest number of the UK’s vulnerable population, therefore alleviating pressure on its health system and decreasing the number of deaths [78]. The evidence behind this decision was the combined results of two clinical trials done across the UK and Brazil showing that the efficacy of the Oxford-AstraZeneca vaccine increases when the administration of the second dose is delayed by 6+ weeks [33]. Public Health England also justified the decision by the high short-term protection for hospitalizations observed following the administration of the first dose of Oxford-AstraZeneca vaccine [78]. Based on Public Health England’s Greenbook, the efficacy of the first dose of Pfizer-BioNTech can reach up to 89% (95% CI 52%-97%) between day 15 and 21 days following its administration [79]. Additionally, a Lancet pre-print describing a prospective cohort study on healthcare workers in the UK demonstrated that a single dose of Pfizer-BioNTech’s vaccine has 72% (95% CI 58-86) efficacy 21 days after its administration [80]. Public health authorities in the United States are also advocating for delaying the second dose for low-risk individuals while following recommended practice for high-risk individuals and healthcare workers until the supply of vaccines becomes sufficient [67].

**Mixing and matching between vaccines**

Researchers have launched clinical trials to assess the possibility of mixing and matching different vaccines to address possible vaccine shortages and misdistribution and to scale up vaccine rollout. Two clinical trials are on their way, one assessing the effectiveness of mixing Sputnik V with Oxford-AstraZeneca [81], and the second Oxford-AstraZeneca with Pfizer-BioNTech [82]. Until more evidence is available, the Center for Disease Control in the USA and Public Health England in the UK advised against combining different vaccines except in exceptional circumstances, such as a shortfall in the vaccine the population received the first dose for [81] or a change in guidance and recommendation for the population who received the AstraZeneca vaccine which is being redirected or withdrawn from some countries [83]. Nonetheless, some experts argue that it is safer to provide partial protection through one dose than mixing between vaccines, at least not until more evidence is available [84].
Demand

To overcome demand challenges, countries are addressing vaccine hesitancy and misinformation through tailored campaigns, providing financial coverage for their residents, leveraging strategies to indirectly impose vaccine uptake, and ensuring access, especially in hard-to-reach areas.

Addressing Vaccine Hesitancy and spread of misinformation

Any successful vaccine deployment plan relies heavily on the public's trust. As such, transparent communication and combating the spread of disinformation and misinformation are vital [52]. Monitoring the public’s vaccine tolerance and uptake, and the factors underlying them through community engagement, helps understand the public’s doubts, concerns, and expectations [52, 85, 86], and in turn, helps address them through effective communication responses (Figure 9). For instance, vaccination centers in Lebanon are reporting a high rate of missed immunization appointments for candidates eligible for the AstraZeneca vaccine. This is due to the increasing distrust of vaccines in light of the recent emerging side effects which may hinder the already slow vaccine rollout process [77].

Figure 9. Tailoring communication to address public doubt and vaccine hesitancy
An efficient communication plan provides clear and properly aligned communication messages and responses that help prevent the spread of myths and misconceptions through tailored public messaging, awareness campaigns, public dialogue, and/or public engagement [52, 85, 87]. In either case, the messages shared with the public should provide a clear understanding of the vaccines’ efficiency, authorization, safety, availability and accessibility, and potential side effects to allow informed decision-making [52, 85, 87]. Details about the national vaccination program including progress reports, decisions, prioritization, deployment, storage, and surveillance should also be transparently shared with the public to avoid suspicion and misapprehensions [52, 87, 88].

Common strategies to address vaccine hesitancy and misinformation include:

→ Public dialogue and community engagement campaigns [85]
→ Public messaging and awareness campaigns [52]
→ Engaging community leaders to address cultural and religious aspects of vaccination [85]
→ Publicizing vaccine uptake by political leaders and other influential figures [53, 54, 86, 89]
→ Leveraging healthcare professionals, who are viewed as a trustworthy source of information by the public, to promote the acceptance of the vaccine [87]
→ Publicly accessible web-based portals of the national COVID-19 vaccination campaign containing progress reports and vaccination trackers [52].

The Lebanese ministry of information collaborated with the Ministry of Public Health, the COVID-19 Vaccine National Coordinating Committee, and various international organizations to establish an awareness campaign on the virus, the vaccines, and the vaccination program. The ministries of information and public health also cooperated with the WHO to provide the public with FAQs, facts, and information through their websites in addition to releasing various new websites specific for addressing the public’s concerns and combating misinformation and rumors [90]. Moreover, the National Deployment and Vaccination Plan for COVID-19 Vaccines established a risk communication and community engagement strategy [14].

Yet, the vaccine registration platform still recorded clear disparities in registration among regions and nationalities, exposing clear gaps in the campaign’s reach. For instance, 63% of registered individuals are residing in urban areas such as Beirut and Mount Lebanon while less than 5% are residing in rural areas such as Baalback and Akkar. The vast majority of the registered individuals (~90%) are Lebanese (vs. 5% Palestinian and Syrian refugees combined) [42]. Additionally, as per the head of the National COVID-19 Vaccination Committee, more than 40% of the population are still anti-vaxxers, or undecided, or do not know how to register [17].

The aforementioned issues are raising concerns over vaccine acceptance, access to and use of the online registration platform, misinformation, and awareness of the general public of the urgency of timely vaccination, among others. As such, Lebanese officials should work on increasing the public’s confidence in vaccines and in the national vaccination program through the provision of transparent and accurate data on vaccines, and the national immunization strategy. Targeted outreach initiatives are also essential to enhance the willingness of the public to get vaccinated and especially the most marginalized communities like refugees and migrant workers [74].

**Vaccine Financial Coverage**

Countries recording successful rates of vaccine roll out are subsidizing the vaccination for their residents [53, 91, 92], some of which achieve that through healthcare financing schemes in which all residents are registered [57].
Indirect Vaccine Enforcement Mechanisms

Countries worldwide, including those who managed to successfully deploy the vaccine, did not explicitly enforce the vaccination but rather strongly encouraged it [52, 53]. However, while enforcing vaccine uptake might be considered unethical, measures imposed by governments and businesses are expected to indirectly affect uptake. For instance, in the UAE, special precautionary measures such as bi-monthly PCRs, are required for government employees who choose not to get vaccinated [53]. In the USA, the Equal Employment Opportunity Commission (EEOC) states that organizations have the right to require vaccine uptake for all employees except in specific cases such as religion or disability. This is expected to have a positive impact on vaccine uptake as a recent survey in the US showed that 71% of CEOs support companies requiring COVID-19 vaccines [93].
Access to vaccines

Geographic barriers to vaccines are a common challenge faced during vaccine deployment, especially for large countries with decentralized healthcare systems, like Canada [92]. To enhance the public’s access to vaccines, ensuring the provision of many vaccination sites across the country is crucial. Governments have authorized vaccine administration in primary healthcare clinics, drugstores, health insurance facilities, elderly care facilities, and even workplaces [52]. Moreover, mobile vaccination teams are being established to reach people living in rural and distant areas, and governments are encouraged to establish vaccination centers in impoverished and marginalized communities [86]. Other high-income countries have put municipalities in charge of the outreach in their local communities to support the local hospitals in public immunization [52]. Another successful method of reaching the public to register for the vaccine than the digital appointment scheduling is through safety net organizations which can be used to reach out to their beneficiaries [86].

Reports from Lebanon show that mobility challenges to vaccination sites are the main reason for no-shows for booster dose appointments [77]. This highlights the importance of founding additional accessible vaccination sites especially with the anticipated increase in the number of eligible individuals awaiting their vaccines.
Administration

To overcome vaccine administration challenges, countries are relying on multi-disciplinary task forces to ensure real-time monitoring and continuous review of the vaccination program, expanding vaccine administration sites, optimizing human resources capacities, and increasing logistical capacities. As the country advances in its national vaccination program and more vaccines are being shipped and available for rollout, administration issues must be accounted for before their emergence.

Vaccination program management and monitoring

Governments that were successful in vaccine deployment referred to science, evidence, and surveillance data to inform their decisions and public health policies while preventing political views and interests from interfering with the process [87, 94]. Adjusting the vaccination strategies and policies during rollout is essential. Governments should continuously review and maneuver the dynamics of the vaccination program. The critical elements which affect the reassessment of the vaccination strategies during the rollout are the country’s epidemiological situation, the disease pathogenesis, newly emerging evidence about the virus and the vaccines’ safety and efficacy, vaccine uptake on-ground by target groups, supply chain capacities, and availability of the required logistics and human resources [52]. Accordingly, government officials should continuously monitor these changing factors locally and globally, and compare their operations and procedures to global best practices to keep their strategies aligned with the most recent evidence.

Vaccination delivery sites

Worldwide, existing healthcare structures are being used as vaccination sites [52, 54, 85, 92], in addition to specifically established sites such as drive-through vaccination and field hospitals in sports arenas [57, 86]. Some governments declared that vaccine administration settings will be based on the current phase of prioritization, whereby more vaccination sites and mass vaccination centers will be made available when a higher fraction of the country’s population becomes eligible for vaccination [52]. To promote vaccine delivery, many countries are making vaccines available in various places such as elderly care facilities, prisons, workplaces, primary healthcare clinics, and pharmacies, and by vaccinating healthcare personnel in the hospitals and clinics they work at [52]. As the population eligible for vaccination increases, it is critical to expand the locations where vaccines can be received. As such Lebanese officials should look into introducing the COVID-19 vaccines in primary healthcare centers and community pharmacies, both of which are available in significantly larger numbers than hospitals.
**Logistics**

**Vaccine distribution**

Among the most common logistical obstacles faced by countries are difficulties in vaccine storage and supply chain capacity, especially for vaccines requiring extremely low temperatures which necessitate a functional cold chain. This has impeded the distribution of the vaccines, especially that each vaccine has its unique transport requirements [52, 92]. Smaller countries with digitized distribution networks have an advantage in vaccine transport and distribution [57, 92]. Centralized healthcare systems in which the government supervises vaccine storage and transport to different territories showed more promising outcomes than decentralized systems of distribution [92]. The experience of a small high-income country showed that receiving all vaccines at one site, specifically, the country’s main airport allowed better coordination and limited mistakes [57]. It is at this receipt site that big containers of vaccine vials were repackaged into smaller temperature-insulated boxes after which they are shipped to different locations within the country. This strategy allowed easier, quicker, and more coordinated shipping and ensured that each clinic received its required number of vaccine vials [57, 59].

In Lebanon, vaccine storage, management and distribution should also be centralized and looked over by national officials to ensure that no vaccine vials are wasted. They should also be distributed to distant area to reduce transportation barriers and be accessible to individuals living in these areas [73].

**Human resources and equipment**

In addition to the vaccination sites, a supplementary workforce will be required to deliver vaccines to the public as the vaccination campaigns progress and the fraction of the population eligible for vaccination increases [52]. Sufficient workforce capacity and equipment should be ensured while countries are still in the first phases of vaccination. Recruiting and training more healthcare workers to increase the human resource capacity is possible by engaging primary care staff and recruiting retired healthcare workers. Several European countries, such as Spain, Portugal, and Austria, are also deploying the armed forces’ medical personnel to provide rapid vaccination services [52]. Additionally, some countries’ vaccine administration teams are contributing to additional work hours to expedite the immunization process [59]. As for the availability of the required tools for vaccine administration, up-front procurement of personal protective equipment (PPE) and medical equipment such as syringes and needles is critical [52].
Digital infrastructure

Countries with centralized health information systems were able to better plan vaccine prioritization, scheduling, and follow-up tracking. The availability of centralized information on all residents allowed the development of data-driven prioritization and outreach strategies. Additionally, the digital infrastructure automated scheduling and communication between patients and providers. This helped in streamlining appointment scheduling for primary and booster doses [59] and enabled centralized follow-up tracking [92]. Larger countries with fragmented health information systems, such as the USA resorted to mobile applications and adverse events reporting websites for vaccine surveillance. However, such systems depend on public feedback instead of active data collection and may backfire if/when the public establishes unsound causal connections resulting in further misinformation and vaccine hesitancy [95].

The Lebanese government released an electronic COVID-19 vaccination platform before launching the vaccination campaign. Individuals can register using this platform which prioritizes the registrants based on the set eligibility criteria and notify them of their vaccination appointments [96]. Nonetheless, this platform does not track those who register for the vaccines through the private sector and should be adjusted to include those individuals. While the newly established platform (IMPACT) is a very well-received initiative, allowing individuals to track the vaccination campaign progress and the pandemic evolution, the absence of a unified healthcare information system between all healthcare facilities and the limited national capacity for surveillance and random mass testing still hinders the development of data-informed policies and actions [97]. This necessitates ensuring data integration between the health information system and the national vaccine registration platform [98].
K2P COVID-19 Series  Modeling COVID-19 vaccine rollout in Lebanon for better impact
How can Lebanese authorities speed up vaccine rollout?

Listed below are key strategies authorities can follow to overcome supply, demand, and administration challenges and speed up community immunization:

Supply

- Closely monitor data released by manufacturers to ensure the prompt approval of promising vaccines and their early procurement.
- Safeguard the early procurement of vaccines by providing manufacturers with needed national vaccination data for their ongoing monitoring and evaluation and purchasing the vaccines at a beneficial price for the producers.
- Secure various vaccine candidates, which puts the country ahead in its vaccine deployment campaign.
- Design a standardized policy to inform vaccinators of how to handle the remaining doses from no-shows.
- Promote the WHO-approved extraction of an additional jab than that indicated on the vial label for the maximal use of vaccine vials and provide the necessary guidelines for this use.
- Combat the limited availability of vaccine doses and the high disease burden by approving the delayed administration of the second dose when supported with scientific evidence.
Demand

→ Suppress the spread of misinformation and vaccine hesitancy through a strategic communication plan, clear and tailored awareness campaigns, and community engagement initiatives.
→ Organize targeted outreach initiatives to enhance the willingness of the public to get vaccinated, especially the most marginalized communities like refugees and migrant workers.
→ Ensure geographical accessibility of all populations to vaccine administration sites by establishing them throughout all Lebanese regions and forming mobile vaccination teams to reach the distant areas.
→ Ensure an equitable vaccine rollout by subsidizing vaccination costs for all residents through healthcare financing schemes and funding.

Administration

→ Establish the largest possible number of vaccination sites to optimize vaccination rates and accessibility such as drive-through sites, and field hospitals, and authorize administering vaccines in pharmacies and primary healthcare institutions.
→ Continuously monitor and adjust the vaccine strategies according to the emerging evidence and data on the vaccines’ safety and efficiency, the national epidemiological situation, and the vaccination campaign progress.
→ Recruit a sufficient number of healthcare workers to deliver the vaccination program. This includes deploying retired healthcare professionals and military healthcare personnel.
→ Procure the required PPE and medical equipment for delivering the vaccines.
→ Employ a centralized health information system to serve vaccine prioritization, outreach strategies, and monitoring.
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Annex 1. The use of the Effective Reproduction Number Rt as a guide to imposing and easing restrictions

Rt: basic principles and guide to decision making

What is Rt and how is it different from R0

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- **R0** (the basic reproduction number, R naught) determines the intrinsic potential of an infectious agent to spread in a population that is totally susceptible and where no control measures are in place, i.e. at the beginning of the epidemic.

- **Rt** (the effective reproduction number) determines the potential for an epidemic to spread at any point in time t in a partially immune population, that is where a fraction of the population have become immune either through naturally acquiring the infection and recovering from it or through vaccination.

- Rt measures the average number of secondary cases produced by one infected individual at any point in time throughout the epidemic in this partially immune population and where control measures could be in place.

One, the critical threshold for Rt

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- If **Rt > 1**, at this point in time more people are getting infected than previously: The epidemic is growing

- If **Rt < 1**, at this point in time less people are getting infected than previously: The epidemic is declining

How can we decrease Rt

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- Rt can be decreased by 1) control measures such as social distancing, mask wearing, and isolation of cases and quarantining of their contacts and/or 2) an increase in the proportion of immune individuals through natural infection or vaccination.

- The objective of public health interventions is to reduce Rt below 1.

- As long as the population is below herd immunity levels (at least 80% for SARS-CoV-2 new variants), lifting all control measures will result in an increase in Rt to a value larger than 1. Until herd immunity is reached, certain levels of social distancing must remain in place to maintain Rt below 1, otherwise the epidemic will surge.
Recommended control and monitoring strategies using Rt

- Quantifying Rt in different settings at regular and frequent times is needed to evaluate the effectiveness of interventions, to monitor epidemic trends, and to guide decision making for imposing or easing social distancing restrictions.

- **Rt = 0.7**, key threshold for lifting control measures: It is recommended that easing of restrictions starts only when Rt has been reduced to below 0.7 (for example through a lockdown), to insure a buffer against any increase in Rt following the easing of restrictions - that is to keep Rt below 1 even after some control measures are lifted.

- Easing of restrictions should be very gradual, starting at an Rt <0.7, with constant monitoring and tuning. As long as Rt is below 1, further restrictions can be eased. However, when Rt gets closer to 1, caution needs to applied with no further lifting of restrictions. With time, as immunity builds up in the community through ongoing incidence and/or through vaccination, Rt will decline gradually allowing room for further lifting of restrictions.

- Restrictions should be imposed when Rt crosses 1. Lockdowns, however, are not always necessary - The level of restrictions imposed will depend on the value of Rt and the overall epidemic situation in the country.