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THIRD REPORT OF WORKING GROUP

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Norges Bank

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Foreword by the Governor

A central bank digital currency (CBDC) is electronic money issued by the central bank for general purpose users. Such money is a claim on the central bank denominated in the official unit of account in the same way as cash.

Norges Bank and a number of other central banks are researching the introduction of a CBDC as a supplement to cash. For Norges Bank, the paramount question is whether introducing a CBDC is an appropriate measure for promoting an efficient and secure payment system and confidence in the monetary system.

Norges Bank's research into CBDCs is motivated by low and falling cash usage and application of the precautionary principle. Cash provides the payment system with a number of attributes that may be relevant to retain and develop further by issuing a CBDC: An independent backup for payment solutions based on bank deposits, a credit risk-free alternative to bank deposits that can foster competition in the payments market and legal tender that can be used by anyone.

At the same time, Norges Bank wishes to be prepared to introduce a CBDC if the monetary and payment system evolves in a different direction from the one currently foreseen. We must take into account changes in the payment solutions on offer, with different forms of money, structural changes in banks' payment infrastructure and the possible consequences of these changes for competition, contingency preparedness and national governance and control of the monetary and payment system.

This report by a Norges Bank working group summarises the third phase of Norges Bank's research into CBDCs and is based on the working group's previous reports, published as *Norges Bank Papers* 1/2018 and 2/2019. The working group discusses the characteristics any CBDC must have, relevant technical solutions and the impact of introducing a CBDC. The working group also discusses international developments in this area and how Norges Bank's research into CBDCs can continue.

Norges Bank has recently decided to continue this research for a fourth phase of up to two years, in line with the working group's recommendation in this report. This phase is to comprise experimental testing of technical solutions and further analysis of purposes and consequences of introducing a CBDC.

This work is intended to provide a basis for deciding whether Norges Bank will test a preferred technical solution. Any decision to introduce a CBDC will require a political decision. The question may also arise as to whether the introduction of a CBDC would require an amendment to the Central Bank Act.

Norges Bank's research into CBDCs has run for a good four years. Any introduction of a CBDC will still lie some time in the future. The time spent reflects Norges Bank's view that there is no immediate need to introduce a CBDC. This is a new and complex issue, and there is little international experience to draw on. There is therefore a need for more information to be able to conclude whether introducing a CBDC is an appropriate measure.

The purpose of publishing the working group's report is to provide information about its work, disseminate knowledge and foster dialogue among stakeholders. Norges Bank would be grateful for views on the analysis and input for the work ahead.

Øystein Olsen

Introduction and summary

A central bank digital currency (CBDC) is a digital form of central bank money denominated in the official unit of account for general purpose users. Like cash, a CBDC is a claim on the issuing central bank. In contrast, bank deposits are claims on private banks. A CBDC can take several forms with different characteristics, depending on its purpose.

Norges Bank and many other central banks are evaluating the introduction of a CBDC. A survey by the central-bank representative organisation BIS[1] has found that 86% of central banks in a broad-based sample are currently studying CBDCs, and that 60% are taking a closer look at technical solutions. Several central banks, including Sveriges Riksbank (the Swedish central bank) and the People's Bank of China, are running pilot projects. The European Central Bank is examining a digital euro. To date, however, only a few central banks in emerging economies have actually introduced a CBDC.

A Norges Bank working group[2] has now completed the third phase of a study on CBDCs, building on the reports on the first and second phases; see Norges Bank (2018) and Norges Bank (2019).

The purpose of the study is to establish a basis for assessing whether Norges Bank should plan to introduce a CBDC and, if so, what form the CBDC should take. Important questions include: "What problems could a CBDC help to solve?"; "What characteristics must a CBDC have?" and "Which solutions are most suitable?"

The working group has emphasised the functions of a CBDC as a means of payment and payment system, rather than its function as a store of value. In Norges Bank (2019), the working group concluded that a CBDC could be desirable to:

- function as an independent back-up solution if ordinary electronic payment solutions fail or confidence in the banking system weakens substantially. The contingency perspective may become more important if payment infrastructure becomes more international
- maintain or strengthen competition in the payment market
- deliver all the key characteristics of legal tender and, if desirable, expand the area of application.

In Norges Bank (2019), the working group also pointed out that the payment system may change considerably in the years ahead, in terms of new stakeholders, new monetary and payment systems, and the geographical location of systems. The working group therefore concluded that the precautionary principle also indicated that Norges Bank should continue its examination of CBDCs.

[1] See Boar and Wehrli (2021).
[2] The working group comprised Knut Sandal (chair), Ragna Alstadheim, Tom Bernhardsen, Kjetil Heltne, Arne Kloster, Helge Syrstad, Ylva Søvik, Leif Veggum, Peder Østbye, Terje Åmås and Steinar Årdal. Carola Müller and Magdalena D. Riiser assisted the working group with parts of the analysis. The project's steering group comprised Torbjørn Hægeland (chair), Ole Christian Bech-Moen, Olav Bø, Kasper Roszbach, Marius Ryel and Ingrid Solberg. Ida Wolden Bache participated in the steering group until 1 April 2020.

In Norges Bank (2019), the working group set out a provisional assessment of the characteristics which a CBDC must or should have in order to fulfil the objectives. In Phase 3, these characteristics were specified and assessed in detail. While the list of characteristics remains largely unchanged, this report discusses aspects of the characteristics which require further investigation and specification through technical testing.

In some instances, characteristics may conflict with one another. Some conflicts are inherent, in the sense that they are technology-independent. For example, opening up the CBDC register/account system to innovative solutions developed by other stakeholders would inherently conflict with the principle that Norges Bank should have ultimate control. Conflicts may also be technology-dependent, i.e. the relevant characteristics are linked with the technical solution to some degree. In other cases, the technology will be flexible enough to allow characteristics to be balanced in connection with system implementation or during system operation. The working group considers it expedient to select solutions which are sufficiently flexible to permit such trade-offs, and which are robust enough to withstand future revision of an established trade-off. The working group has proposed an approach for balancing conflicting characteristics.

The working group has also considered how technical solutions can deliver the characteristics and how they can be tested. In this context, the working group has examined solutions used in CBDC testing in other countries, in cryptocurrency systems and in different account-based solutions. Feedback on solutions, testing and user needs has been gathered through meetings with various external stakeholders.

Potential CBDC demand is highly uncertain. Among other things, demand will depend on as-yet unknown specifics of the CBDC solution design, the CBDC's areas of application and how CBDC users choose to manage their personal liquidity. In its analysis, Sveriges Riksbank (the Swedish central bank), has assumed CBDC demand of around 3% of GDP. In Norway, 3% of mainland GDP totalled some NOK 90 billion in 2020.

A guiding principle adopted in this report is that the existence and size of any CBDC should not materially undermine private sector provision of credit to firms and households. The working group has analysed potential effects on Norwegian banks of introducing a CBDC. The effect on bank financing structures will depend on how demand for bank deposits changes, and is uncertain. There is reason to believe that some deposits will be replaced and that demand for deposits will become more interest-sensitive. However, it is possible to limit the effect of a CBDC on bank funding and lending rates, provided that the central bank makes reserves available to banks when deposits are withdrawn from banks and replaced by a CBDC, and that there are no significant changes in banks' funding structures otherwise or in interest rate spreads in banks' wholesale funding markets. The above conclusion also reflects the assumption that the CBDC will not be particularly competitive as a store of value, but rather will meet a transactional need, for example because the interest rate on the CBDC is set at a low level.

There have been rapid developments in the digital money field over the course of Phase 3. One of these is the emergence of so-called cryptocurrencies incorporating stabilisation mechanisms intended to make the currencies more stable relative to national currencies or other benchmarks. One example is

Diem, whose backers include Facebook. Although such initiatives are unlikely to have material consequences for Norges Bank's tasks and goal achievement in the short term, the introduction of new digital money illustrates the potential impact of new technologies and new user needs on the function of money in future, and raises questions about who should be meeting such needs and fulfilling such functions. The working group has considered this question not least when assessing how a CBDC could constitute a platform for service innovation by third-party providers. In dialogue meetings, stakeholders highlighted the need for so-called programmable money, and the working group has assessed both risks and benefits associated with programmable money as part of the validation process. In addition, various central banks have intensified their CBDC-related work by launching tests and pilot projects, often incorporating technology which facilitates programmability and other functions. This development underlines the need to follow the precautionary principle identified in Norges Bank (2019) when studying CBDCs. The fact that a CBDC could provide future functionality may be important to counter the risk that money and payment functions could shift to new arenas and infrastructures which may undermine the efficiency and security of the payment system. Further consideration should be given to how a CBDC could help counter this risk.

The working group has recommended extending the CBDC study for a fourth phase. The group has not observed any circumstances indicating that the study should be concluded. On the contrary, the findings thus far and the developments occurring in monetary and payment systems indicate stronger grounds for continuing the work. The proportion of cash payments in Norway has fallen further, and is now thought to be the lowest in the world. If anything, the importance of applying the precautionary principle with respect to unanticipated structural changes in monetary and payment systems has increased. Plans for new monetary and payment systems have been launched, and the role of CBDCs in the response to this development has become clearer. Central banks and international organisations are paying closer attention to CBDCs. This offers opportunities for knowledge-sharing. In addition, any decision by other central banks to introduce a CBDC, and the chosen design, may affect how Norges Bank and other central banks fulfil their mandates, and may in isolation accelerate a decision on introducing a CBDC.

The working group has recommended that the fourth phase of the study should last up to two years and should comprise experimental technical testing and further analysis of the purpose and consequences of introducing a CBDC.

The purpose of technical testing is to generate new knowledge on how solutions can deliver the necessary and desirable characteristics of a CBDC, and to uncover potential unintended consequences of relevant solutions. Such testing should utilise tests performed by other central banks, and cooperation should be pursued with other central banks wherever expedient. Norges Bank's own tests will be an important factor in facilitating such cooperation. The working group has concluded that experimental technical testing will both provide information on technological solutions and help reveal and concretise relevant analytical issues in the economic and legal/regulatory fields which cannot be discovered through purely analytical work.

The fourth phase should produce a basis for deciding whether Norges Bank should test a preferred solution with the aim of being able to introduce a

CBDC. However, continuation of the CBDC study does not constitute a decision to introduce a CBDC. Further, any decision to introduce a CBDC will require political support, and the requisite statutory changes will have to be considered and implemented.

The working group has discussed the organisation of technical testing, and has recommended using external testing suppliers. Norges Bank should maintain close ongoing contact with selected suppliers.

The purpose and consequences of introducing a CBDC should be studied further. Relevant topics include supplementation of reserves and liquidity management using the CBDC, and consequences for Norges Bank's balance sheet and monetary policy in general. Consideration should also be given to what statutory changes will be needed before a CBDC can be introduced. Further, the working group has recommended further assessment of how the introduction of a CBDC could counteract the risk that money and payment functions may shift to new arenas and infrastructures. More generally, the introduction of a CBDC should be evaluated by reference to what can be achieved through regulation of privately-owned payment systems for privately issued money.

PART I: Characteristics and technical solutions

1. Validation of technical solutions by reference to characteristics

Norges Bank (2019) identified a number of characteristics a Norwegian CBDC must and should have. The working group has not come across circumstances indicating that this list of characteristics needs to be materially amended. The characteristics appear adequately flexible and robust. However, the framing of the characteristics has been expanded and adjusted to reflect the content of the characteristics and simplify validation of technical solutions. The substance of the characteristics has not changed significantly. In Norges Bank (2019), a distinction was made between necessary and desirable characteristics. The working group considers that this distinction is unnecessary going forward, since most of the characteristics appear to be necessary. In addition, some characteristics are so closely interlinked that they can be dealt with jointly. For example, the requirements of technical autonomy and offline payment functionality both relate to contingency preparedness. The full list of updated characteristics can be found in Table 1.

Table 1. Characteristics of a Norwegian CBDC

Claim on Norges Bank
Parity value with cash and bank deposits
Customer orientation
Adequate frictions in transfers between the CBDC and bank deposits
Controlled by Norges Bank
Capable of functioning as legal tender
Compliant with obligations under EEA law
Payments are immediate and final
Compliant with sound IT architecture principles
Satisfy requirements relating to technical independence and offline payment functionality
Customer communications and due diligence undertaken by third parties
Flexibility to accommodate different data protection solutions
Platform for third-party providers
Safeguard monetary policy efficacy
Information relevant to Norges Bank's macroeconomic monitoring
DLT compatible
Attractive niche solution

The working group has validated technical solutions by reference to the characteristics. The main aspects of this work are:

- elaborating on and particularising the characteristics
- investigating technical solutions in greater detail
- assessing whether the solutions can deliver the characteristics (validation)

- recommending implementation of and a system for pilot and other technical testing.

The main categories of technical solutions recommended in Norges Bank (2019) are shown in Table 2.

Table 2. Recommended technical solutions

Solution	**Explanation**
CBDC in the form of register-based token money	The CBDC exists in a register. The CBDC is accessed using cryptographic codes which are not linked to identity. In practice, a user interface (such as a wallet application[3] on a mobile telephone) may offer simple and secure access to the money. Such solutions have some technological similarities with current cryptocurrencies.
Closed account solution permitting local storage	An account solution which requires both the sender and the recipient to have an account in the system. This solution has similarities with current e-money solutions. The solution permits offline use through the downloading of money to a physical device (for example a card or mobile telephone).

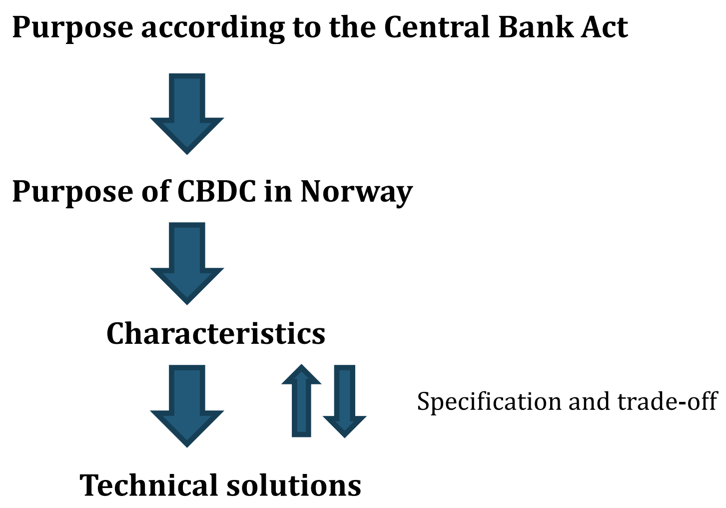
The working group has iterated between the characteristics and the technical solutions to evaluate:

- to what extent the technical solutions can deliver the characteristics; and
- to what extent specification of the characteristics in light of the technical solutions is needed.

The method used in the validation process is illustrated in Figure 1; see also Norges Bank (2020).

[3] Digital wallet and user interface for payments.

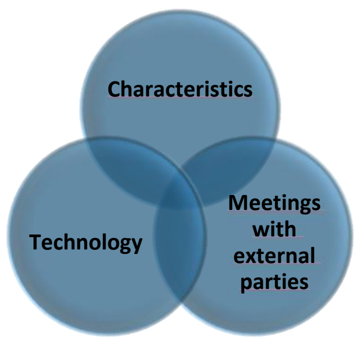
Figure 1. Methodology



Further, the working group has not found reason to reassess the two main categories of technical solutions identified in Norges Bank (2019). The distinction between the categories has proven to be fluid, and some of the most relevant solutions incorporate elements from both main categories. This report distinguishes between the main categories when this helps to highlight differences between extremes and the range of available options. As stated below, the working group sees no need to maintain a clear distinction between solution categories in the further validation process.

Validation work can be compared to “proof-of-concept” studies in which different concepts are evaluated by reference to a specification or characteristics. The working group has not conducted physical testing of solutions in Phase 3.

Figure 2. Workflows in the validation process



The validation process has been divided into three partially overlapping workflows, as illustrated in Figure 2:

- specification and validation of characteristics
- review of technical solutions
- meetings with external parties.

The workflows are discussed further in chapters 2–5 below. In the context of the different workflows, the working group has assessed how technical testing should be performed to ensure optimal investigation of how technical solutions deliver the characteristics. This is summarised in Part III, which contains recommendations on further work to be done.

2. Review of characteristics

To validate whether different technological solutions are in line with the required characteristics of a potential CBDC, the working group has reviewed each individual characteristic in detail.

Conducting this assessment necessitated detailed specification of the characteristics, including their core features and the purpose they are intended to serve.

The objective was to identify

- the number of compatible/consistent technical solutions which may fulfil all the characteristics,
- whether there are solutions which cannot fulfil all the characteristics simultaneously.

While many technical solutions/architecture solutions fulfil the characteristics to a greater or lesser degree, it may still be necessary to balance the characteristics when implementing the solution. The working group has identified potential necessary trade-offs, and has given primary emphasis to ensuring that selected solutions are flexible so that trade-offs can be made on an ongoing basis in accordance with applicable priorities at any given time. This can be supplemented with a concrete cost-benefit analysis.

The working group has not conducted a new systematic assessment of the list of characteristics in Norges Bank (2019). Nevertheless, the group has concluded that new CBDC priorities or specifications resulting from the validation process can be attributed to the previously identified characteristics, even though these factors were not necessarily assessed closely or in full at the time the characteristics were formulated. For example, interoperability issues have been evaluated in detail. Interoperability with the CBDC solutions of other countries in particular has increased in relevance as other countries have intensified their CBDC-related efforts. Interoperability may relate to several characteristics, including compliance with sound IT architecture principles, functioning as a platform for third party providers and DLT compatibility.

A summary of the working group’s review of the different characteristics listed in Table 1 above follows.

2.1. Claim on Norges Bank

The characteristic of cash as a claim on Norge Bank is best expressed as an *accounting principle*. Issued cash is shown on the liability side of a central bank balance sheet. The liability lapses when cash is withdrawn from circulation. In principle, the situation would be the same for a CBDC. The working group has assumed that a CBDC would be issued to banks for distribution to customers through conversion of bank deposits. This mirrors the functioning of cash. Accordingly, a CBDC would be shown – like cash – as a separate item on the liability side of Norges Bank's balance sheet.[4]

Norges Bank's balance sheet should clearly show the number of issued CBDC units and, correspondingly, how many units have been withdrawn from circulation – again like cash. Clear procedures should therefore be established for the issue and withdrawal of CBDC units, including for the technical handling of withdrawn units. For example, it will be undesirable for withdrawn CBDC units to be shown as an asset item in the central bank balance sheet.

Any CBDC should be structured in such a manner that Norges Bank is the formal issuer, and issued CBDC units should be expressly specified as a liability item in the bank's balance sheet. Banks and other parties should not be given the right to issue CBDC units, since this could create confusion about whether issued CBDC units should be recognised in the central bank balance sheet. In such case, it would also be unclear whether the CBDC can actually be deemed to be central bank money.

These considerations apply irrespective of whether or not a CBDC is granted legal tender status. If the CBDC is granted such status, it must be clarified whether cash will remain legal tender and whether CBDC holders will be entitled to demand conversion into cash, or vice versa. See chapter 2.6 for further discussion.

2.2. Parity value with cash and bank deposits

Any CBDC must have parity value (1:1) with bank deposits and cash and other central bank money (central bank reserves). It is inexpedient for the same good or service to have multiple prices in Norwegian kroner depending on the legal tender used. Correspondingly, it is undesirable for conversion rates between different means of payment denominated in Norwegian kroner to fluctuate, whether in official marketplaces or unorganised markets. The parity value characteristic does not bar the charging of different fees for payments made using certain means of payment and payment instruments.

CBDC-cash parity is unlikely to be challenged. This becomes a certainty if CBDC units and cash are freely convertible. Moreover, if banks demand convertibility between the CBDC and central bank reserves, free convertibility in this regard will be a prerequisite for full parity between all the different types of central bank money. However, this will not block the setting of a lower interest rate on the CBDC than on central bank reserves and cash.[5] Both the CBDC and cash are claims on Norges Bank, and both will be legal tender; see chapter 2.6.

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[4] Norges Bank could potentially also issue a CBDC to banks by increasing the banks' central bank reserves, and in such case the CBDC would not appear as a separate liability item in the central bank balance sheet. However, this appears both inexpedient and undesirable, not least from the perspective of Norges Bank's liquidity management. The CBDC could potentially also be issued directly to the general public, i.e. without preceding distribution to banks. However, this solution appears unrealistic given the working group's conclusion that the CBDC should not be based on an open account solution. In any event, the CBDC would still appear as a separate liability item in Norges Bank's balance sheet with this solution.
[5] It is parity between the CBDC and other central bank liabilities which will prevent the emergence of multiple units of account in the economy, or several versions of the Norwegian krone.

Moreover, breach of CBDC-bank deposit parity[6] appears unlikely. However, parity may still be breached in an extreme situation where depositors are uncertain about the solvency and liquidity of the entire private banking sector. In this scenario, depositors may wish to transfer their funds out of the banking system and into CBCDs. CBDCs may appear more attractive than bank deposits, and may acquire a higher market value in the “grey market”. The effect on market value may intensify if CBDC supply is limited through volume restrictions; see chapter 2.4. Conversion from bank deposits into CBDC units will be simpler in practical terms and entail a lower risk of theft/loss than conversion from bank deposits into cash.

However, there are also factors which may promote parity:

- Banks may increase their deposit rates to compensate depositors for the perceived increase in credit and liquidity risk. In a major crisis, the interest spread relative to the CBDC may become substantial.
- The Norwegian deposit guarantee scheme protects deposits of up to NOK 2 million per depositor per bank. This sum must be made available to the depositor within seven working days. Comprehensive information on the guarantee scheme can help to limit depositor flight to CBDCs and reduce the pressure on parity.

It appears unnecessary for the requirement of parity value between the CBDC and bank deposits to confer greater protection than is currently available in the case of cash and bank deposits. Otherwise, the solution would eliminate credit risk linked to bank deposits.

The characteristic of CBDC-bank deposit parity is difficult to test. Nevertheless, it is possible to simulate a breach of parity, and assumptions regarding depositor conduct can be made based on sources such as historical data on banking crises.

2.3. Customer orientation

Any CBDC must have a customer orientation. This means that the CBDC must be accessible to a broad audience and that infrastructure must be in place to make the CBDC suitable for customer payments, including user-friendliness and security requirements.

A CBDC solution will only fulfil the purposes of functioning as a contingency solution and promoting competition if use exceeds the minimum level necessary for the solution to be both accessible and usable in practice. To achieve the minimum usage level, user interfaces for payers and payees must be attractive.

Core infrastructure[7] should be designed to be compatible with different payment instruments and different payment situations (such as physical trade, online shopping and transfers between private persons). The objective of

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[6] Central bank money (cash, CBDCs and central bank reserves) has a unique function as a unit of measurement in the economy. Banks use central bank money as a unit of measurement and thus promise parity between private bank deposits and central bank money; see White (2001), page 8.
[7] The primary core features of any CBDC system are the issuance and cancellation of CBDC units, the register/accounts system IT architecture and system rules/”protocols”.

contingency preparedness requires the CBDC to be compatible with use at physical points of sale.

To ensure a minimum level of use, it will probably be necessary to allow third parties to develop attractive new user interfaces or to link the infrastructure with existing payment solutions. Any test phase should investigate whether infrastructure can be linked to different payment instruments, such as mobile telephones and payment cards, including existing solutions in this field. Such investigation should also cover which standards can and should be used to ensure this.

Using third-party payment instruments and solutions may give rise to tensions in relation to other characteristics, for example that a CBDC should be controlled by Norges Bank and that the CBDC should be technically independent of banking systems.

Moreover, some parts of the population may find it difficult to use electronic means of payment, for varying reasons. Any CBDC should therefore have an IT architecture that allows Norges Bank or third parties to offer simple, accessible solutions. This is examined further in chapter 2.9 on IT infrastructure and in the discussion of user interfaces in chapter 3.

Consideration should be given to whether the CBDC should be available to tourists and others staying in Norway temporarily. However, it seems to make little sense for a Norwegian CBDC to function as a system for payments or as a store of value abroad. This will require a technical infrastructure and a regulatory framework that facilitate limited intentional use by foreign nationals while simultaneously eliminating undesirable consequences of granting foreign nationals access. Technical testing will shed further light on this issue.

2.4. Adequate frictions in transfers between the CBDC and bank deposits

The purpose of securing scope for introducing frictions is to prevent the immediate conversion of private bank deposits into CBDC units on such a scale as to cause or reinforce financial instability.

Both relevant literature and international CBDC discussion forums evidence uncertainty about the actual risk of major bank runs. The need for frictions in the context of conversion from bank deposits into CBDC units is therefore also uncertain, as is how substantial any frictions would need to be.

Nevertheless, it can be sensible to design a CBDC system to permit frictions, for example in the form of volume restrictions or through interest rate-setting. It is in any case unlikely that detailed management of CBDC demand will be desirable.

Money fulfils three main functions: legal tender, unit of account and store of value. In discussing the purpose of a CBDC, the working group has emphasised factors related to the payment function; see Norges Bank (2019). A CBDC should not be an independent unit of account (see discussion of parity value with cash and central bank reserves). Nor should a CBDC be a material store of value.

Frictions in the form of various volume restrictions may limit the storage of value in a CBDC, but should be designed so that they do not restrict the payment function.[8] An example of a friction that could affect the payment function and should therefore be avoided is transaction fees, including on transfers between bank deposits and the CBDC.

Frictions can have different designs. Two examples are limits on the number of CBDC units a person may hold or convert from a bank account during a given time period. Volume restrictions in connection with conversion from bank accounts appear to be a relevant instrument for limiting customer flight from bank deposits.

The “Sand Dollar” CBDC system in the Bahamas includes limits on the number of CBDC units a user may hold. Holdings in excess of the limit are automatically transferred to a private bank account specified by the user in advance. One relevant question is how large the maximum CBDC holding should be for firms, organisations and the public sector, which may need to maintain larger holdings to allow certain types of payment, and whether a distinction should be made between different user categories. For example, any cap on CBDC holdings should be generous if the CBDC is to be used for tax payments and receipt of payments from the public administration.

The selected technological solution may also feature “automatic” frictions, for example where users conclude that they may lose their deposits if they make a mistake related to storage of their money. However, if ownership and transactions are not anonymous (and there are strong indications that this will be the case at least for larger sums; see the discussion of data protection considerations in chapter 2.12), such a loss risk is likely to be limited.

Frictions may conflict with the characteristic of parity value between the CBDC and bank deposits; see chapter 2.2. The risk of a breach of parity is primarily linked to confidence in bank deposits. Frictions to prevent a bank run may increase this risk. Frictions represent a potential shortage of CBDC units which may result in the CBDC gaining greater value than bank deposits (and a higher value than it would otherwise have had) during a crisis. In such case, demand for the CBDC may far outstrip supply.

With a register-based solution, it is difficult to know whether frictions will impinge on other characteristics like data protection. This must be explored through testing.

2.5. Controlled by Norges Bank

Norges Bank (2019) states that, “Irrespective of the operational model chosen, Norges Bank must be able to issue instructions on all aspects of the system.” Further specification of the details of such control by Norges Bank is needed, not least because certain other characteristics involve the performance of functions by third parties. This applies particularly to the requirement that customer communications and due diligence must be performed by third

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[8] A fundamental equivalent to such CBDC frictions is found in Norges Bank’s liquidity management system – the quota scheme for interest on central bank reserves. Norges Bank ensures that holding reserves is not too attractive, and banks find other, more efficient ways of managing liquidity through inter-bank redistribution. Correspondingly, it should not be attractive to hold large volumes of the CBDC. Other means of payment and assets should be used as stores of value.

parties, the desire for the CBDC to serve as a platform for third-party providers and DLT compatibility. Statutory provisions that specify areas Norges Bank is required to control must also be taken into account.

The control requirement must also be evaluated by reference to the fact that operation of the system may be outsourced to providers who use their own systems. Issuing instructions on all circumstances under a supplier's control, such as employment conditions and equipment suppliers, is unlikely to be practicable. Steps therefore have to be taken to prevent the accumulation of power among suppliers that could in practice deprive Norges Bank of control. Such measures include restrictions on the use of suppliers' proprietary software and licences. Further, the system should be based on standards and specifications that permit easy replacement of suppliers.

Norges Bank must always have absolute control over the core of the CBDC system. This core primarily comprises the issuance and destruction of CBDC units, IT architecture for components like the register/account system, and system rules/protocols.

In addition, Norges Bank must implement measures to limit risks to users and society, such as wrongful loss of money and criminal uses, and to limit Norges Bank's liability and reputational risk linked to services delivered by third parties. Both technical specifications and regulatory/legal frameworks can help control services delivered by third parties. Statutory amendments may therefore be required. In the case of both a closed account solution and a register-based token solution, Norges Bank may add guidelines/restrictions on the services third parties may deliver and the transactions users may execute. However, such restrictions may hinder innovation.

In the case of a register-based solution that permits interaction with other registers, costs related to complexity and information-provision may be large if Norges Bank is to monitor all types of applications in which the CBDC may be used. It is therefore important to define an acceptable risk level that safeguards both innovation and user-friendliness. Technical solutions can be supplemented by a legal framework developed by Norges Bank. This framework could include both rules for third-party providers and user terms and conditions defining what users may and may not do.

It is important that technical testing generates additional information on the level of control Norges Bank can achieve through different technical solutions, and the extent to which such control could restrict user services and innovation.

2.6. Capable of functioning as legal tender

At present, only notes and coins issued by Norges Bank have the status of legal tender; see section 3-5 (1) of the Central Bank Act. The working group has not proposed changes to the legal status of cash. Accordingly, if a CBDC is granted legal tender status, Norway will have two types of legal tender.[9] Like cash, the CBDC will be denominated in NOK.

A CBDC may have potential similarities with both bank deposits and e-money, depending on the chosen solution. In either case, however, the CBDC will be an entirely new category of legal tender. Permitted CBDC use should be subject of legislation, and the legislature will have considerable freedom in this area. However, the working group has concluded that parties to a payment settlement should remain free to deviate from the legal tender provisions, i.e. the parties should generally be free to agree whether legal tender is to be used or not. Legal tender should thus be used in the absence of an agreement (a fall-back rule). Nevertheless, the possibility of the CBDC being made obligatory for certain types of payments, for example certain central and local government payments and receipts, should be kept open. The solution should at least allow for this, as the CBDC should be able to function as a niche solution for certain types of payment; see chapter 2.17.

Statutory amendments will be required if a CBDC is to be given legal tender status, primarily to section 3-5 (1) of the Central Bank Act. In principle, such a statutory amendment is unproblematic. Further, some adjustments will be required to section 1-5 (4) of the Financial Contracts Act, which defines "means of payment", section 2-1 on means of settlement, and section 2-2 on the time and place of payment.[10] The working group also anticipates a need for adjustment of section 16-4 of the Financial Institutions Act to make it clear that banks have a duty to accept and make customer deposits available in both CBDC units and cash. If the CBDC is to be used for central and local government payments and receipts, for example in the tax context, it will be necessary to amend a number of laws and regulations, since the current regulatory framework is primarily designed with bank deposit-based payments in mind.

If a CBDC is to function as legal tender, it must be generally and easily accessible, as well as relatively simple and cheap to use. A solution which is technically complicated to use or which requires the purchase of advanced or costly additional equipment will prevent the CBDC from becoming generally accessible money, and will therefore be incapable of functioning as a fall-back solution if the parties to a payment settlement fail to agree the means of payment. The user-friendliness of technical solutions is discussed in chapter 2.3 and chapter 3, and should be explored further through testing.

In practice, using a CBDC will entail the withdrawal of money from one bank account before use and its subsequent deposit in a different bank account. However, actual payments will be executed independently of such bank accounts, and the payer and payee are thus not required to have bank accounts. This mirrors the functionality of cash. The working group has

[9] Means of payment are not synonymous with payment instruments. The working group has not evaluated which payment instruments a payer may demand to use when paying with CBDC, or which payment instruments a payee may refuse to accept.
[10] A new Financial Contracts Act was adopted on 1 December 2020, and approved on 18 December 2020. It is not yet clear when it will enter into force. The working group has nevertheless decided to refer to the new Act. The new Act replaces the Financial Contracts Act 1999 (LOV-1999-06-25-46), which remains in force. The provisions referred to here reproduce – in substantively unamended form – section 12(d), section 38 and section 39 of the Financial Contracts Act 1999.

concluded that, in actual payment situations, it is less important whether the CBDC solution is register-based or a closed account solution.[11]

If a CBDC is to be legal tender alongside cash, it should be decided whether holders of CBDC units should be entitled to demand conversion into cash, or vice versa. The working group sees a reciprocal conversion obligation as a potentially expedient solution, i.e. that Norges Bank is given a duty to convert cash into the CBDC and vice versa. An obvious related step would be to impose a corresponding obligation on banks, based on the principle that banks must make legal tender available to their customers; see section 16-4 of the Financial Institutions Act. However, the establishment of a status hierarchy between the CBDC and cash – whereby CBDC holders can demand conversion into cash but cash holders cannot demand conversion into the CBDC, or vice versa – should be avoided.

2.7. Compliant with obligations under EEA law

Norway is bound by the EEA Agreement, and any CBDC design must comply with the fundamental principles of the agreement, including the four freedoms, state subsidy rules and competition rules. The working group has nevertheless concluded that these principles impose few practical hindrances to the issue and use of a CBDC.[12] Most matters with CBDC relevance are regulated by so-called secondary legislation – regulations and directives.

CBDC transactions may generate substantial volumes of personal data, and obligations under the Personal Data Act and the General Data Protection Regulation (GDPR) must be complied with. The scale of the obligations depends on where personal data is processed, and may vary depending on the type of solution. As the CBDC issuer, Norges Bank may be deemed to be a data controller under the rules, but the scope of the obligations will depend on what tasks are assigned to third parties. Irrespective of who is deemed to be the data controller, the principles of data protection by design and data protection by default in Article 25 GDPR will be key elements in designing the CBDC. This includes the objective of data minimisation. To some extent, the actual impact of these principles depends on the solution chosen; see further discussion of the desired degree of data protection in chapter 2.12 below.

As stated several times in this report, the CBDC design should ensure that the CBDC can be used as a platform for third-party providers. Platforms for payment services will often fall within the scope of the second Payment Services Directive (PSD 2). However, PSD 2 is not expected to entail significant obstacles for Norges Bank, as the directive does not apply when central banks act as public authorities; see Article 1(1)(e). Nevertheless, any third-party providers may be payment service providers under PSD 2 and thus be subject to relevant provisions of the directive, such as requirements related to authentication solutions. Indirectly, therefore, the CBDC may be regulated by PSD 2 to some extent.

[11] While some register-based solutions based on open blockchains may require conversion between NOK and a separate cryptocurrency, this conversion will be undertaken by Norges Bank and will be unrelated to individual payments.
[12] There is a possibility that state-subsidy rules may limit Norges Bank's ability to offer free user functionality where private parties are already offering such functionality on a commercial basis. The working group has not considered this issue further during Phase 3, and refers to the more detailed discussions in its previous reports.

Although central banks are not subject to the EU's money laundering directives, Norges Bank is subject to the Norwegian Money Laundering Act. The Act establishes extensive customer due diligence obligations which will also apply to any CBDC. Whether Norges Bank will have to conduct customer due diligence depends on whether Norges Bank is deemed to have a customer relationship with individuals or firms in connection with the issue and withdrawal/destruction of CBDC units. This applies irrespective of whether the CBDC is designed as register-based token money or a closed account solution. If Norges Bank is responsible for customer due diligence itself, section 22 of the Money Laundering Act is an important provision. It provides that Norges Bank may adopt customer due diligence conducted by third parties which are also obliged entities under the Act. In practice, this means banks.

Both the handling of personal data under the GDPR and the scale of customer due diligence pursuant to the Money Laundering Act should be explored further during technical testing.

Issuance of a CBDC falls outside the scope of the rules on virtual currencies and e-money.[13] This activity also falls outside the scope of the European Commission's proposed rules on cryptoasset markets.[14]

2.8. Payments are immediate and final

Payment immediacy

The recipient of a CBDC payment should be able to access the money immediately. This meets a user need and is a characteristic of both real-time payments using bank deposits and cash payments. The CBDC infrastructure must allow payments to be immediate. All else being equal, this is easier to achieve when both the payer and the payee are in the same register or account system (as in the case of a CBDC) than when the payer and payee are in different account systems (as in the case of payments using bank deposits).

At the same time, Norges Bank will be dependent on third-party suppliers of user-interface services. To ensure that all CBDC payments are immediate, payment immediacy must be a requirement in the rules applicable to stakeholders who want to provide payment services denominated in the CBDC, potentially with a power for Norges Bank to grant exemptions. It is likely that market stakeholders will have incentives to develop an adequate range of payment services featuring immediate transfer.

In principle, transfers between a CBDC and bank deposits should also occur immediately. In this context, Norges Bank is likely to be quite closely involved in controlling the operational structure. Moreover, it may be appropriate to implement frictions, for example that transfer immediacy is only required up to a certain amount; see chapter 2.4.

[13] See section 1-3(2) of the Money Laundering Regulations (FOR-2018-09-14-1324) and section 2-4(2) of the Financial Institutions Act.
[14] https://ec.europa.eu/info/publications/200924-digital-finance-proposals_en.

Payment finality

A payment becomes final when it can no longer be reversed, i.e. when ownership of the money has been transferred from the payer to the payee. In the case of cash payments, this occurs when money changes hands. Finality is also clearly regulated in the case of bank deposit and e-money payments, and is therefore unlikely to present any additional hindrances in an account-based CBDC system.

A register-based system featuring token money may present some special challenges. In a normal situation, a payment will become final once the cryptographic code required to exercise control of CBDC units is amended, i.e. when the money has been moved from one wallet to another. In an offline situation, the register will not be updated immediately, and it must therefore be clarified how payments which lack coverage or which are inconsistent are to be handled once contact with the register is achieved. Another question is whether separate finality rules are required for payments which are not consolidated with the register and/or whether a system must be established to eliminate or reduce credit risk for the payee/the payee's bank in connection with offline payments.

In a solution featuring local storage in the payment instrument/user equipment (i.e. where the money is not stored in an account system or a register), payments will achieve finality as soon as they are made, as in the case of cash.

Where a CBDC system is based on an open blockchain, it appears advisable to regulate liability contractually in case an attack on the blockchain is successful. Such attacks may also target "closed" blockchains; see chapter 3 on technology.

2.9. Compliant with sound IT architecture principles

"Compliant with sound IT architecture principles" encompasses a number of requirements and characteristics, including:

- Requirements concerning good software development and methodology, such as agility and modularity.[15]
- Security requirements, including compliance with data protection legislation and the Security Act. Security is often divided into confidentiality, integrity and accessibility. The CBDC architecture must cover all of these security elements.
- Capacity and transaction volume requirements, so that users can execute the payments they want without suffering inconveniences like latency.
- Requirements concerning accessibility for persons with disabilities, and compliance with related national guidelines.
- Facilitation of interoperability, and ensuring that the CBDC can function with other public and private registers. This includes the selection of appropriate standards for data representation.

[15] Modularity means that a system can be divided into "independent" modules which can be combined and recombined because a change in one module does not necessitate changes in another module. This reduces complexity risk.

- Special requirements related to the reliability of DLT systems, if the architecture incorporates these.

The use of open source code in software development can help reduce supplier dependence. However, doing this also has disadvantages in the form of less certain development incentives. Open source code may therefore be most suitable for modules where a user base exists and there are initiatives that ensure development. Many register-based token solutions are based on open source code, but standardisation work remains to be done. This could result in dependence on certain technologies.

Interoperability will be relevant to a CBDC in several respects:

- interoperability with existing infrastructure,
- interoperability with other public and private registers, including DLT systems, and
- interoperability between CBDC systems in different countries.

Technical testing will provide further information on the scope for interaction between registers. Moreover, cooperation and the exchange of information between central banks will be important for the development of appropriate standards for interaction between the CBDC systems of different countries.

As regards security requirements, the Security Act[16] may impose requirements relating to architecture, and in particular the location of physical infrastructure. End-user solutions affect system security, and deficient end-user service security may entail liability and reputational risk for Norges Bank. Security requirements and solutions developed in relation to third-party solutions pursuant to PSD 2 may provide guidance on which requirements should be imposed. Solutions used for cryptocurrency wallets may provide guidance on security solutions for register-based token solutions. Architecture and rules for third-party providers must be developed to reduce risk. Security at all infrastructure levels should be central in technical testing. The use of DLT will present separate security challenges. Increased DLT use in the public sector will generate more information on how DLT systems can fulfil national security requirements.

To satisfy the requirement of accessibility for persons with disabilities, it may be appropriate for any CBDC to be interoperable with existing solutions for fulfilment of the accessibility requirement, for example mobile telephones and user interfaces for visually impaired persons. This is discussed further in chapter 3 on technology. Technical testing will shed further light on whether the accessibility requirement is met and whether solutions can be based on existing technology that fulfils the accessibility requirement. A further option is for Norges Bank to finance a solution that ensures accessibility.

[16] Among other things, this will depend on whether the CBDC is identified as a critical national information system pursuant to section 6-1 of the Security Act. The working group has not evaluated the impact of the Security Act. This must be considered further at a later stage.

2.10. Satisfy requirements relating to technical independence and offline payment functionality

The focus of this requirement is that the system should function independently of bank payment systems, and also be usable for payments during temporary offline periods.

Any CBDC will include different components or sub-systems: core infrastructure, a conversion system between bank deposits and CBDC units and, finally, the interface for payers and payees. In principle, the technical autonomy requirement can apply to individual or multiple components. The greater the number of independent components, the stronger the back-up functionality of the CBDC. The requirements of technical autonomy and contingency preparedness should be balanced with the scope for third parties to be effective contributors in relation to different parts of the CBDC system, such as innovation, customer communications and customer due diligence.

Conversion between bank deposits and CBDC cannot be made independent of bank systems. It is therefore important that users have CBDC to hand in contingency situations.

It is reasonable to assume that at least the core infrastructure of a CBDC system must be technically independent of other stakeholders' solutions. A solution in which several independent third parties provide solutions to end users on top of Norges Bank's core infrastructure may ensure contingency preparedness even if the technical autonomy requirement is not met in literal terms. Another possibility is that Norges Bank itself develops and operates a technically independent minimum solution (for example an app) for end users in case the number of third parties involved in the CBDC system is too small or there is a risk that all third parties may experience simultaneous operational disruption.

The *technical autonomy* characteristic is not particularly well-suited to testing in a traditional sense. The technical independence of the CBDC system will be largely determined by the system design and structure. However, individual system components can be tested for independence.

Offline functionality
An offline payment can be defined as a direct payment between end users and their payment instruments in situations where there is no contact between the register or account system and the user interface. In such cases, the funds must be stored locally, and the transfer between users occurs while the users are in close proximity to one another.[17] This implies that the solution is appropriate for payments at physical user locations and, perhaps, also transfers between private persons. From a contingency perspective, the strongest emphasis should be given to facilitating payments for critical products such as groceries, medicines and fuel. In order for the module to be functional in an offline/contingency situation, funds have to be transferred in advance.

[17] The parties to the payment transaction must have access to a technical solution that transfers money securely between the users.

In the case of register-based solutions, consideration must be given to whether a payment can be characterised as final once it has been transferred from one device to another, or only once it has been consolidated with the central register; see chapter 2.8.

Offline payment solutions exist and have probably been tested by other parties. It should be possible to find such documentation. The difficulty with such solutions is the distribution of secure hardware or access to it (for example on iPhones).

2.11. Customer communications and due diligence undertaken by third parties

Outsourcing customer communications and customer due diligence to third parties serves several purposes and helps ensure an efficient division of work between Norges Bank and the market. Moreover, such a division of work and such cooperation can help secure private-sector support for the solution, broader use and improved functionality.

Most relevant reports and results from central-bank pilot projects have focused on solutions in which third parties bear primary responsibility for customer contact and customer due diligence; see also the discussion of different CBDC projects below.

As regards customer communications, it is necessary to find an appropriate division of work between Norges Bank and third parties. For example, it is appropriate for Norges Bank to provide some general information to the public while third parties are responsible for bilateral communications with individual customers.

Communications between individual customers and third parties can entail reputational risk and, potentially, liability for Norges Bank. The communications of individual customers with their service provider will form part of the overall CBDC user experience. Service providers and customers may also find it frustrating if customer communications concern matters outside the control and expertise of the service provider. To prevent this, both the technical architecture and rules and regulations should be designed to limit negative user experiences. Technical testing can also generate further information on how the architecture should be arranged with this purpose in mind.

There will always be a possibility that individual customers will contact Norges Bank directly, and Norges Bank will have to adopt procedures for dealing with such enquiries. Norges Bank may also become party to disputes related to individual customers' use of the CBDC, for example damages claims where a customer has lost money. A regulatory framework should be developed that limits Norges Bank's involvement in such disputes.

Customer due diligence encompasses a range of different checks, including identity checks when on-boarding users, transaction checks and the reporting of suspicious transactions. The extent to which these tasks can be outsourced will depend on the design.

If all due diligence measures are to be carried out by third parties, it will have to be technically possible for third parties to monitor transactions, as is currently the case with respect to bank deposits. In other words, providers of user interfaces must be able to access information identifying CBDC transferors and transferees. This information must be available either directly in the register or through the exchange of information between third parties, corresponding to current transaction-verification procedures. In an account-based solution, personal data will be linked to the account, thereby facilitating checks. In a token-based register solution, there appears to be little benefit to entering identifying user information directly in the CBDC register, since this could create security and data protection challenges. If such a solution is chosen, identifying information will have to be stored in external registers.

New regulatory technologies – “regtech” – are being developed to make customer due diligence more effective. Regulatory technology is discussed further below. One question is whether a CBDC can make effective use of such technologies. A potential solution is for the CBDC register to be made compatible/interoperable with other registers capable of delivering such “regtech” solutions for customer identification/due diligence. A separate register of this kind could also clarify the division of responsibility between Norges Bank and other stakeholders, and thereby limit liability and reputational risk for Norges Bank. However, it will still be necessary to develop customer due diligence rules, regulations and standards to limit reputational risk. These questions can be explored further through technical testing.

As regards rules, regulations and technical standards for third parties, some inspiration can be taken from the revised Payment Services Directive (PSD 2), which permits third parties to provide payment solutions for bank deposits. However, the transfer value of PSD 2 may be limited by the fact that account providers bear primary responsibility to customers and compliance with applicable rules and regulations; this is not necessarily a suitable solution for any CBDC.

A final issue is the handling of customer communications and due diligence if Norges Bank is only to provide a minimum-level payment service for use by the public. One possibility is to select a market solution by means of a competitive tender, i.e. for Norges Bank to pay a supplier to develop and operate the solution.

2.12. Flexibility to accommodate different data protection solutions

Flexibility to adapt a CBDC system to different levels of data protection is limited by data protection rules which impose minimum data protection requirements, as well as by regulatory rules designed to ensure monitoring and combating of payments linked to criminal activity. Data protection rules contain a number of principles any CBDC will have to follow.[18] In addition, the rules grant users rights, for example to receive information, file

[18] Such as the basis for processing, transparency, data minimisation, accuracy, time and volume restrictions, integrity and confidentiality (security, privacy by design, etc.), as well as management and control.

objections/complaints, access data and have data deleted, and with regard to data portability.

A closed account solution links identity with holdings. This type of solution therefore undoubtedly includes personal data.

A token-based solution will offer greater flexibility in data protection terms than a closed account solution. In a closed account solution, any holdings will be linked to an identifiable person. Norges Bank can control the release of information to different stakeholders, but there will be no inherent anonymity. Since this solution will also feature local storage, anonymous pre-paid cards can ensure anonymity within permitted quantitative limits.

A token-based solution does not entail a direct link between identity and monetary holdings. The register will link cryptographic addresses with money which can be controlled using cryptographic codes. Such a solution is "pseudo-anonymous", since money is not linked directly with individual persons.

Customer due diligence requirements[19] may nevertheless mean that tokens and identity have to be linked, for example when on-boarding new users or in connection with large or suspicious transactions. This will also necessitate registration of the link between identity and tokens, and retention of this link in relevant registers. Different models for organising such registers are described in the discussion of customer due diligence in chapter 2.11.

Even if there are no registers that directly link identity with tokens, different quantitative techniques, such as network analysis, can be used to link persons to holdings. Such techniques can be utilised for compliance purposes, but also mean that the register may indirectly contain personal data which trigger GDPR requirements. This depends on the specific design, which can be adapted as desirable. Technical testing may shed further light on links between a CBDC register and personal data.

Nevertheless, different technical solutions may facilitate anonymity by complicating the linking of tokens with individual identities. Cryptographic techniques can be used to conceal both the payer and the payee, as well as the sum involved. This is further described in the discussion of technology in chapter 3. Such solutions should be studied further through technical testing.

When considering flexibility with respect to the data protection characteristics of a CBDC register, the question arises of who should decide these characteristics. This could be decided by Norges Bank, politically through regulations or – to some degree – by the market through private solutions that facilitate concealment of transaction information. The latter may be a good solution for meeting user needs, but may simultaneously entail liability and reputational risk for Norges Bank. It is therefore necessary to examine the extent to which different technical solutions, rules and regulations can give

[19] As regards restrictions on the power to provide anonymous payment functionality, the EU money laundering rules are generally inapplicable to central banks. Nevertheless, Norges Bank follows the rules pursuant to national guidelines; see discussion in section 2.7. Third-party providers of CBDC-related services may be subject to the rules, for example banks, e-money suppliers and virtual currency service providers.

Norges Bank control over developments. This will be further explored through technical testing.

In the working group's experience, it is helpful to amend the specification of this characteristic to "flexibility to accommodate different data protection solutions" to clarify the content of the characteristic.

2.13. Platform for third-party providers

Norges Bank (2019) states that it is desirable for any CBDC to constitute a platform for third-party providers. The objective is to allow third-party stakeholders to innovate and develop services on top of the CBDC. These may include payment applications, solutions based on programmable money and offline solutions.

A CBDC can function as a platform in various ways. It can provide a basic infrastructure for the development of value-generating services. It can also be regarded as a platform for the realisation of network advantages.[20] Both perspectives are relevant in the CBDC context. If a CBDC is to realise network advantages across different solutions, it is important to avoid the development of solutions that, in practice, reserve network advantages for a small number of stakeholders. Both the technical architecture and applicable rules and regulations should safeguard this consideration. Technical testing will shed further light on how technical architecture can serve this objective.

A closed account solution based on traditional technology can provide API solutions[21] that facilitate third-party stakeholder involvement in accordance with the same principles as apply to third-party access under PSD 2. This can promote innovation with regard to payment solutions and user interfaces.

A token-based register solution may facilitate greater innovation through so-called programmable money and new cryptographic developments. Programmable money and cryptography are discussed further in chapter 3 on technology.

It will be possible to add programming functionality directly to the CBDC register, or alternatively to facilitate limited but sufficient programming functionality that allows the CBDC to be locked cryptographically in other registers offering greater programming functionality. The latter variant is considered more appropriate because full programming functionality in the CBDC register could give the CBDC register functions and roles falling outside the central bank's remit, such as tokenised securities and real estate. Use of the CBDC in external registers may create challenges with regard to Norges Bank's control, and may entail liability and reputational risk for Norges Bank. This must be balanced with the benefits of innovation. Risk can be restricted through rules, regulations and technical architecture. Technical testing will provide additional information on the scope for Norges Bank to exercise control.

[20] Both direct network advantages through the user base and indirect advantages through the development of value-generating services.
[21] An API ("Application Programming Interface") involves the provision of a communication interface that allows different applications to communicate with one another.

One question related to the CBDC's role as a platform for third parties and innovative solutions is what the purpose of this role is. A CBDC can serve as a platform for innovation in the field of payment systems in a narrow sense, with the aim of developing secure and efficient payment systems. A CBDC can also promote the development of services in the financial sector more generally, by facilitating and supporting digitalisation of the financial system, including decentralised solutions. In an even broader sense, a CBDC can help realise wider societal benefits from digitalisation, such as digitalisation of the public sector and the Internet of Things.[22] Even though a secure and efficient payment system lies at the heart of the CBDC concept, it is difficult to separate this from other digital infrastructure involving the payment system.

When conducting technical testing, therefore, it will be sensible to examine different services for which a CBDC could provide a platform or in which it could play a role, even if these services are not necessarily on the primary test agenda.

2.14. Safeguard monetary policy efficacy

The efficacy of monetary policy is dependent on the public using Norwegian kroner for payments, borrowings and savings. A well-functioning payment system denominated in Norwegian kroner will help safeguard the position of the Norwegian krone. To the extent that a CBDC is important for ensuring a well-functioning payment system denominated in Norwegian kroner, the existence and design of the CBDC system also holds indirect monetary police relevance.

In addition, it is important to prevent any CBDC from undermining monetary policy efficacy; see Norges Bank (2019). Both this and the desire to influence CBDC demand in the interests of financial stability (see chapter 2.4) indicates that it must be possible to set a variable rate of interest for the CBDC.

The CBDC interest rate will constitute the floor for all interest rates if everyone can hold CBDC units. The effective floor for the policy rate is currently considered to be somewhat less than zero, but will be zero if the CBDC is given a fixed rate of zero and there are no costs or frictions associated with holding CBDC units corresponding to those currently applicable to cash.

A CBDC carrying a fixed, low rate of interest (for example, zero) may reduce the impact of monetary policy. On the other hand, a fixed and sufficiently large (negative) margin between the policy rate and the CBDC interest rate is likely to insulate monetary policy relatively effectively against the introduction of a CBDC.

The possibility of a variable interest rate is more about avoiding negative effects on monetary policy and financial stability than about increasing monetary policy scope. Some articles have argued that introducing a CBDC will increase monetary policy scope in some respects,[23] that a CBDC offers an opportunity for the state to provide effective crisis support to the population,

[22] The Internet of things (IoT) describes the network of physical objects—"things" or objects—that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the Internet"; see https://en.wikipedia.org/wiki/Internet_of_things. The Internet of Things may also allow objects to initiate payments on behalf of users.
[23] See for example Bordo and Levin (2017).

and that a CBDC can potentially function as an additional monetary policy instrument if interest rate-setting and other instruments prove ineffective. However, the significance of these potential benefits has not been fully studied, and it is unclear whether these benefits can be achieved while simultaneously limiting the impact of a CBDC on banks.

If a CBDC has similarities with cash and is used primarily for payments, rather than as a store of value, it would be possible to start off with a zero rate of interest on the CBDC while still establishing technical and contractual scope for a variable interest rate. Given that the policy rate is already zero and the reserve rate is less than zero, it may be best to set the CBDC rate below zero, and no higher than the reserve rate. Bindseil (2020), Bank of England (2020) and Norges Bank (2018) have pointed out that the concern that deposits may be withdrawn from banks can be addressed by supplementing the variable CBDC interest rate with a dual interest rate system whereby customers achieve the best CBDC interest rate subject to a quota limit and a lower interest rate on deposits exceeding the quota. In such case, the CBDC system must facilitate this technically.

Interest-rate terms and quota systems must be designed so that they do not disrupt the implementation of monetary policy. Banks should be prevented from holding “stocks” of CBDC units and/or from transferring between CBDC units and reserves to exploit any interest rate spreads. The interaction between CBDC units and reserves, and the consequences of such interaction for liquidity policy, should be studied further.

The working group has concluded that it is possible to have interest rates (including negative rates) in both main solutions. A closed account solution with local storage must include a system for handling interest rates when money is used locally, for example in an offline situation (or when anonymous payments are desirable). There are two options:

- No interest payable on money which is stored locally.
- Applicable agreements clearly specify who will be paid interest in such situations, for example the person holding the money at the end of the offline period. In the event of intra-day use of locally stored money, the balance and interest calculation can be updated daily, as done by banks at present.

In a “dual-layer” token-based register solution, banks will convert reserves into CBDC units and pass these on to end customers in return for bank deposits. The end customers can access their CBDC units through their wallets. In principle, holdings stored in wallets do not have to be linked with an identity.[24] However, identification will be necessary to provide information on holdings and interest income to relevant authorities. If interest rates are differentiated depending on holdings, identification may also be necessary to prevent evasion of differentiated solutions by splitting holdings between multiple wallets/register entries. Such identification must be weighed up against reduced flexibility in terms of data protection and anonymous payment functionality.

[24] Since access to the money is governed by cryptographic codes.

2.15. Information relevant to Norges Bank's macroeconomic monitoring

It is desirable for any CBDC system to generate information relevant to Norges Bank's macroeconomic monitoring. If the transaction volume of a CBDC system is low, and particularly if the CBDC's share of the payment market fluctuates substantially from year to year, this information may be of limited value for this purpose.

The most relevant information will be the number and value of payments, in total and divided into payments between different types of stakeholders (private persons, businesses, public sector). From the perspective of macroeconomic monitoring, payments from private persons to businesses and payments between businesses are probably of the greatest interest. Among other things, the transaction-registration system will provide access to sector codes for payers and payees.

Relevant applications include "nowcasting" – i.e. estimation of current and future economic development – and information on economic reactions to changes in interest rates. The conversion of large sums into CBDC units may indicate financial turbulence.

Data from the CBDC system can only be analysed if the system includes a statistics module or, at least, a tool for retrieving information in a form suited to analysis using other software. Moreover, the CBDC rules and regulations must include provisions on the use and security of and rights attaching to CBDC data.

Further, a system is required for customer access to data and third-party stakeholders' access to customer data via APIs, if customers want this. The CBDC regulatory framework must include terms, conditions and requirements related to the standards applicable to third-party stakeholders, as well as a system for handling situations where customers believe that CBDC system data is incorrect; see also chapter 2.12 on data protection.

In a register-based solution, no identity will be stored in the core register. If relevant, this information will be stored in a separate register containing the identity information, which is then linked with the core register. This permits analysis of data in the core register without knowing user names.

2.16. DLT compatible

There are numerous DLT variants. A distinction is often made between "permissioned" and "permissionless" systems. Permissionless systems are ones in which there are no formal restrictions on who may perform functions such as validating transactions. Systems can be permissioned in the sense that functions may be reserved for certain stakeholders and that there are restrictions on which stakeholders have access to different information in the register. DLT technology is discussed further in chapter 3.

The CBDC pilot projects of many central banks, including Sveriges Riksbank (Sweden), are based on variants of a permissioned DLT system. One question arising in relation to permissioned systems is what roles may be assigned to participants other than Norges Bank, and what risk attaches to doing so. This can be explored further through technical testing and validation of specific technical solutions.

A CBDC solution does not necessarily have to be based on DLT architecture in order to be DLT compatible. A CBDC register can be based on standards that make it interoperable with other CBDC registers. In such cases, programmability and other functions offered by these external registers can be utilised. One method for doing this is to lock the CBDC cryptographically in external DLT registers and to consolidate it with CBDC registers pursuant to the rules (protocols) applicable to them. Other DLT registers will then function as a secondary register or overlay solution for the CBDC register. This is discussed further in chapter 3.

A challenge in this context is the lack of standards for ensuring interoperability when there are many available solutions. How data is represented can therefore have a lock-in effect to certain systems, and exclude others. Various standardisation processes are ongoing to ensure interoperability, and there are different methods for building bridges between different systems. Technical testing will shed further light on this topic.

If a CBDC register is made interoperable with external registers, this may create control challenges and entail liability and reputational risk for Norges Bank; see chapter 2.13. These challenges can be limited through rules, regulations and technical architecture. Technical testing will provide further insights.

2.17. Attractive niche solution

It is desirable that any CBDC functions as a niche solution that meets users' special payment requirements. This can help ensure a certain level of continuous use.

If a CBDC can function as a niche solution for users, it can also function as a catalyst for broader use. However, the CBDC must facilitate broader use from the start. For example, if payments from public authorities are made using the CBDC, it should also be possible to use these funds through the CBDC system from launch. It seems clear that if the CBDC is to function as a back-up solution and promote competition, the CBDC system should facilitate broader use and not only function as a niche solution.

In principle, a niche solution can be developed, and can function, independently of the technical platform. However, it seems clear that solutions capable of delivering additional functionality beyond the scope of account-based solutions (the current banking system) may attract more users seeking expanded functionality.

Demand for expanded functionality should be clarified through dialogue with potential users such as the tax authorities and the Norwegian Labour and Welfare Administration (NAV). Whether expanded functionality as demanded by users can actually be developed should be examined through technical testing. Functionality for bulk payments (for example payroll and benefit transactions, which often involve numerous simultaneous payments), should potentially be developed and tested.

2.18. Balancing the fulfilment of characteristics

As shown in the above review, certain characteristics may conflict with one another in the sense that satisfactory fulfilment of one characteristic may result in poor fulfilment of another. Examples of potential conflicts include:

- If customer communications and due diligence are to be performed by third parties and the CBDC is to function as a platform for third-party providers and be DLT compatible, this may mean less control for Norges Bank than if it controls the entire value chain.
- Some frictions with bank deposits intended to promote financial stability (for example quotas for holdings of or conversion into CBDC units) may reinforce breaches of parity between the CBDC and bank deposits which have arisen as a result of high uncertainty about the financial position of the banking sector as a whole.
- Some frictions (such as interest rates) may require expanded customer identification for reporting reasons, thereby rendering solutions that provide better data protection less relevant.
- Different frictions may also reduce user-friendliness and thus the customer orientation of the CBDC.

Conflicts between characteristics may take different forms. Some conflicts are inherent in the sense that they will arise regardless of the technology used. For example, opening up the CBDC register for innovative solutions will inherently conflict with the objective that Norges Bank should have control.

Conflicts may also be technology-dependent. For example, an account-based solution may offer advantages in terms of control and frictions related to bank deposits, but may also be less flexible with respect to different degrees of data protection and innovative third-party solutions.

This also means that, to some degree, characteristics have to be balanced when selecting a technical solution. In other instances, technology will offer sufficient flexibility to allow characteristics to be balanced, so that the trade-off can be made when implementing the system and/or while the system is in operation. The working group considers it important to adopt solutions that are sufficiently flexible to permit trade-offs of different characteristics and sufficiently robust to incorporate new trade-offs decided in future.

The working group has concluded that where characteristics conflict with one another, the following approach may be helpful:

- Identifying how the characteristics conflict with one another, i.e. identifying relevant mechanisms.
- Assessing whether a conflict is inherent, whether it concerns specific technical solutions and/or whether it depends on implementation of a specific technical solution offering flexibility to incorporate different characteristics.
- Preferring flexible solutions if they can be justified in cost terms.
- Conducting a cost-benefit analysis if conflicts cannot be avoided through design measures.

The working group has not conducted a detailed assessment of how such cost-benefit analyses should be conducted. One method may be to rank and categorise characteristics. When balancing different characteristics, primary emphasis can be given to ensuring fulfilment of characteristics that contribute materially to achievement of the purposes of the CBDC.

3. Review of technical solutions

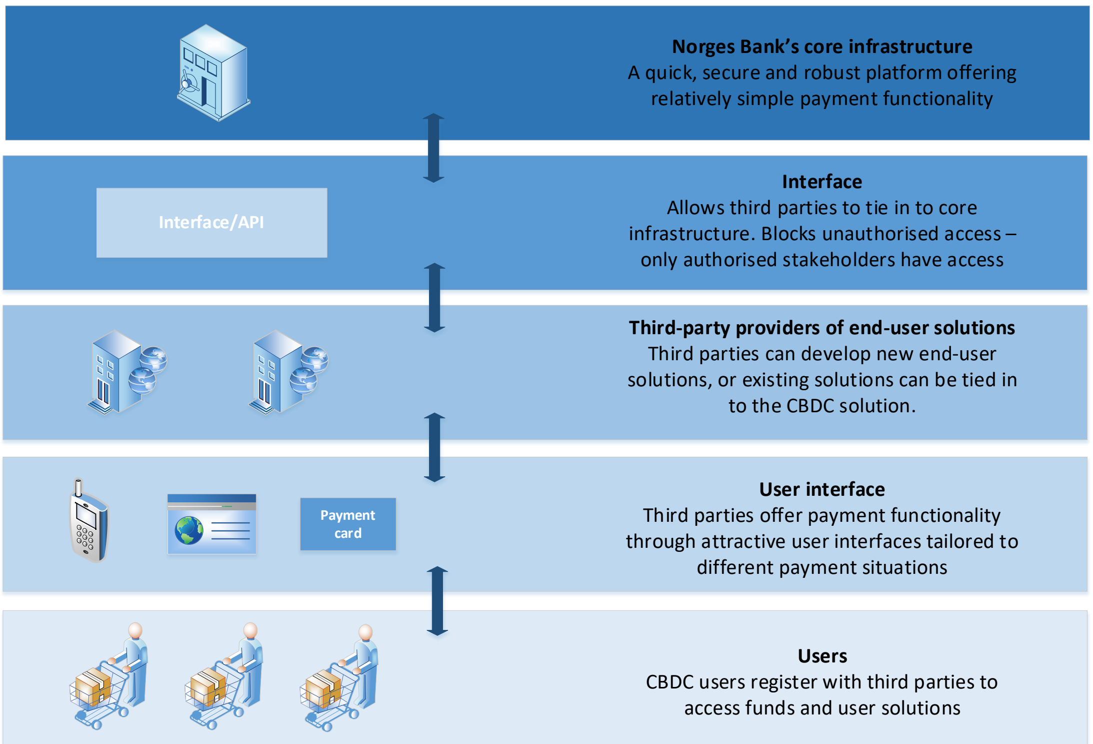
The working group has evaluated technical solutions based on the conclusions in Norges Bank (2019). In this work, the working group has:

- conducted a detailed assessment of technical solutions used in CBDC testing in other countries
- examined solutions selected for cryptocurrency systems and different account-based solutions
- reviewed other technologies about which greater knowledge was required.

The objective has been to develop further insight into how technical solutions can deliver the characteristics and how technical solutions can best be tested.

Figure 3 shows a general overview of how a CBDC system can be organised. The different elements are discussed in greater detail below.

Figure 3: Overview of CBDC system architecture



3.1. Technical solutions with potential utility for CBDC use

3.1.1. Technical solutions used in CBDC testing in different countries

Several central banks have tested or are currently testing technical CBDC solutions.[25] The purpose varies. Some central banks are conducting experimental testing without concrete plans to introduce a CBDC. Others aim to develop a complete solution suitable for introduction to the market.

Most of the central banks involved have organised this work as a pilot project, entering into an agreement with one supplier or group of suppliers. Far fewer central banks are using a technological sandbox. A sandbox allows many stakeholders to develop/experiment with new services within a given set of parameters; see chapters 4.1 and 11.1.

Particularly projects targeting a complete solution have included private banks and other third parties in testing. Other bodies, such as digital ID systems, are also involved in testing or are being developed as part of CBDC projects. Among the stakeholders who appear to be pursuing a complete solution, it is also more common to test technological solutions in limited geographical market segments. Examples of this include the central banks in the Bahamas and the eastern Caribbean.

Most projects are focused on register-based token money, i.e. elements of distributed ledger technology. Many of the concepts are based on R3's Corda technology. Some central banks, for example in Ukraine, have tested a CBDC in the form of a contract on an open blockchain.

However, some central banks have not opted for distributed ledger technology. The central bank of Uruguay, for example, used wallets operated by a state-owned telecommunications company for its pilot "e-peso" project, while the Ecuadorian central bank – which has both introduced and discontinued a type of CBDC system – used central bank accounts which users could access through their mobile telephones.

Most projects have retained the traditional structure in which banks – in some cases via various types of intermediary – are responsible for conversion between bank deposits and central bank money.

Technology projects are more prevalent in emerging economies than developed ones. The latter category includes the pilot project run by Sveriges Riksbank (the Swedish central bank), which was launched in February 2020 in collaboration with Accenture; see Riksbanken (2020a, 2020b). The project's aim is to demonstrate how an "e-krona" could be used by the general public. A test environment will be used to simulate user deposits and withdrawals of CBDC units from a digital wallet, and different types of payment transactions. Users will be able to use a mobile app, "wearables" like smart watches and payment cards.

[25] For an overview of technical testing by central banks, see The Block (2020), IMF (2020), Boar et.al (2020), and Boar and Wehrli (2021).

Several central banks in developed economies – including the Eurosystem, the Swiss National Bank, the Bank of Canada, the Bank of Japan, the Monetary Authority of Singapore and the Hong Kong Monetary Authority – have tested technology for so-called "wholesale" CBDCs. In collaboration with the Swiss National Bank and the SIX[26] securities settlement system, the BIS Innovation Hub has run "Project Helvetia" to test a wholesale CBDC for use in securities settlement. Although the solution is not accessible to the public, such projects generate useful information on test methodologies. Technical testing is not simply an instrument for testing technology, but also reveals economic and legal issues that require further investigation.

Several of these central banks are also studying customer-oriented CBDCs, but thus far the primary focus has been on general CBDC principles and characteristics. This is also true of a cooperative project involving seven leading central banks and BIS, see BIS (2020), as well as Iceland's CBDC project; see Sedlabanki (2019). The Bank of England has also published technology-related analyses and issues; see Bank of England (2020). Moreover, the US Federal Reserve is engaged in cooperation with MIT to study technical CBDC solutions; see Federal Reserve Bank of Boston (2020).

Some central banks have evaluated technology related to limited aspects of a CBDC solution. One example is the Eurosystem, which has examined technology to facilitate anonymous payments; see ECB (2019). In ECB (2020b), the Eurosystem indicated that it was accelerating its work on a digital euro and would decide whether to initiate technical testing and further study of a CBDC by mid-2021.

The People's Bank of China is developing the Digital Currency Electronic Payment (DC/EP) system. In December 2019, the central bank and a number of state-owned banks and telecommunications companies agreed to conduct a pilot test, with testing starting in several Chinese cities in 2020. The People's Bank of China does not appear to have published much information on the DC/EP, and the underlying technology is therefore unknown to us. The working group understands that the CBDC will be distributed through the largest banks and e-money companies, and that mobile apps will be the primary user equipment.

3.1.2. Technical solutions used in cryptocurrency systems

In the course of its work, the working group has investigated the technical and organisational solutions used in cryptocurrency systems, particularly cryptocurrencies featuring stabilisation mechanisms. The purpose has been two-fold: to evaluate the utility of these solutions with respect to the objective of the CBDC and to assess the extent to which technical and organisational solutions can be incorporated into the CBDC system. The latter is discussed below.

Distributed ledger technology has developed considerably in recent years. This development has focused primarily on improving capacity and efficiency in open decentralised systems, as well as data protection, security and functionality of decentralised systems more generally. To some degree, solutions and innovations used in cryptocurrency systems can be regarded as testing of technology which may also be relevant in a CBDC solution.

[26] See BIS (2020).

As regards the capacity and efficiency of open systems, this has limited direct transferability to a CBDC system, since open decentralised systems currently appear to be insufficiently mature for use as CBDC infrastructure. Nevertheless, this development is relevant in the sense that such systems may become more relevant as overlay registers for services incorporating a CBDC. This is also a development that should be monitored to allow ongoing assessment of whether different open systems could serve as CBDC infrastructure.

Developments in the fields of security, anonymity and more general functionality are more directly relevant to a CBDC. Developments linked to different types of consensus mechanisms can make it more realistic for CBDC architecture to utilise variants of closed decentralised systems. Technology that promotes the security of user interfaces may also be useful in a CBDC system. As regards anonymity, different means of facilitating anonymity can serve as inspiration for data protection solutions in a CBDC system; see the discussion of cryptography above. Developments in the fields of programmability and the possibility of building bridges between different registers may be relevant to a CBDC, particular if these advances can help Norges Bank to achieve adequate control while still exploiting the opportunities offered by programmability.

Organisational structures incorporated into different cryptocurrency systems to promote compliance with regulatory requirements and exploit third-party ecosystems may also provide inspiration for the organisation of a CBDC. For example, the Libra Association's revised White Paper[27] contains an overview of how the distribution of Libra (subsequently re-named Diem) is organised, and of regulatory issues associated with this organisational structure.

3.1.3. Closed account solutions featuring local storage

A bank account is an updated overview of a customer's receivables from or liabilities to the bank. The account balance is updated with payments and receipts in chronological order. The bank account is linked with a customer's identity and is assigned an account number for identification purposes. By definition, a bank's account system is closed, as receivables from one bank cannot automatically be swapped for receivables from another bank. In Norway, the different closed account systems are settled through settlement accounts at Norges Bank or other settlement banks.

The system must permit the transfer of funds between a customer's ordinary bank accounts and CBDC accounts. This can be achieved quite easily using Norges Bank's settlement system. However, it should not be possible to transfer money between ordinary bank accounts and CBDC accounts belonging to different owners. The reason for this is to ensure that the CBDC system does not become too similar to the ordinary payment system, so that the CBDC can achieve the purposes of an independent back-up solution and competition, and so that CBDC volume can be managed, not least for financial stability purposes.

[27] See Libra Association Members (2020).

An account system featuring such restrictions will have much in common with an e-money system that only permits payments between accounts within the system. Examples of such solutions include PayPal and AliPay.

The working group sees the possibility of combining the account system with a local storage module. The primary purpose of such a module is to secure capacity to execute payments and settlement when the centralised account system is inaccessible, i.e. in contingency situations. This model can be characterised as a hybrid model involving an account-based main system (which must be online to function) and a token-based local storage module (which can function in offline situations).

Storage in the local storage module is based on secure hardware such as smartcards or sim cards/the secure element in a mobile telephone. In this local module, payments can be made directly between end users without authorisation by a third party or the account system. Individual users are free to transfer money back and forth between the account system and the token module. An example of such a system is Hong Kong’s Octopus travel money system.

3.2. Details of individual technologies

3.2.1. Distributed ledger technology (DLT)

The working group has reviewed different DLT technologies and evaluated opportunities and challenges relating to the use of DLT.

One possibility is to structure a CBDC as a program on an open blockchain (i.e. as a smart contract[28]). The working group has concluded that this solution is currently difficult to reconcile with the necessary characteristics of a CBDC. This is due particularly to the lack of control for Norges Bank, risks associated with immature technology and challenges related to scalability and speed.

Further, such a solution would require payment for use of the blockchain in the form of cryptocurrency native to the blockchain. For example, if a CBDC were to be organised as a program added to Ethereum, payment would have to be made in Ether in order for participants in the system to process the programs. Although solutions can be designed so that users do not need to see this, Norges Bank would have to acquire the necessary cryptocurrency holdings. The cost of doing so is uncertain, particularly due to the volatility of cryptocurrencies. To some extent, this can be compared to paying for the electricity used to operate a system. However, the relevant markets are less mature and there are fewer derivatives markets available for hedging risk. This may change over time. Even though the solutions do not appear particularly applicable at present, they can still be included in testing, particularly if stakeholders want to demonstrate – at their own cost and risk – that they can deliver the CBDC characteristics.

[28] Programs that provide for transactions to be triggered automatically based on a pre-defined code are often referred to as smart contracts. Among other things, smart contracts allow one transaction to be made conditional on another, for example that an asset may only be transferred if both parties to the transaction perform as agreed. Further, a condition can be added that an investment shall be liquidated if the value of the assets drops below a specified level. Smart contracts are not necessarily contracts in a legal sense.

If a CBDC is to be based on DLT architecture, it will be more relevant to use a closed DLT variant that gives Norges Bank full control over the system rules (i.e. the system protocol). Such a solution will enable Norges Bank to maintain control, but will also allow certain functions to be decentralised. This solution can make the system more robust and facilitate third-party development of solutions. Many pilot projects in different countries, including the project run by Sveriges Riksbank (the Swedish central bank), are based on such DLT variants. Often, a variant of R3's Corda is used; see chapter 3.1.1. It is therefore logical for technical testing to include closed variants of DLT technology.

Even if a CBDC register is not based on distributed ledger technology, this does not prevent the CBDC from exploiting advantages offered by DLT. So-called "overlay", "layer 2" or "side-chain" solutions allow devices in a basic register to be locked in for use in a different register and subsequent consolidation with the basic register in accordance with adopted rules.[29] One potential solution is for users to lock CBDC units from a basic register kept by Norges Bank into a DLT overlay register to facilitate use of services in this register. The fact that activities occur in an overlay register does not necessarily eliminate liability or reputational risk for Norges Bank in connection with those activities. Accordingly, Norges Bank will have to use technical solutions and/or develop rules for use of the CBDC or CBDC representations in external registers.

If DLT is used either for the basic register or indirectly through other DLT platforms, interoperability will be a key issue. At present, there is no standardisation of DLT systems, and different systems operate under different data processing and representation principles. To some degree, this can mean becoming locked in to a given technology, with the consequence that one cannot choose other technologies to realise the advantages offered by other technological solutions. Standardisation is being pursued by both private and public bodies. Cooperation between central banks may also promote standardisation. The development of different superstructure solutions can increase system interoperability. This work should be monitored as Norges Bank's CBDC study progresses, and technical testing will provide further data on interoperability.

3.2.2. Programmable money

Programmable money (through smart contracts) is a topic closely related to DLT, although programmable money is not DLT-dependent. Programmable money entails the addition of programming functionality on top of a register so that transactions can be made dependent on certain events, for example that at least two of three persons must sign off on a transaction in order for it to be valid.

Programming optionality can be more or less extensive. A complete general programming language can be provided (so-called Turing completeness) on top of the register, or restricted programming functionality.

Programming functionality promotes delivery of the characteristics. For example, third parties can be enabled to provide solutions for offline payments and payments with different degrees of data protection, and to develop niche

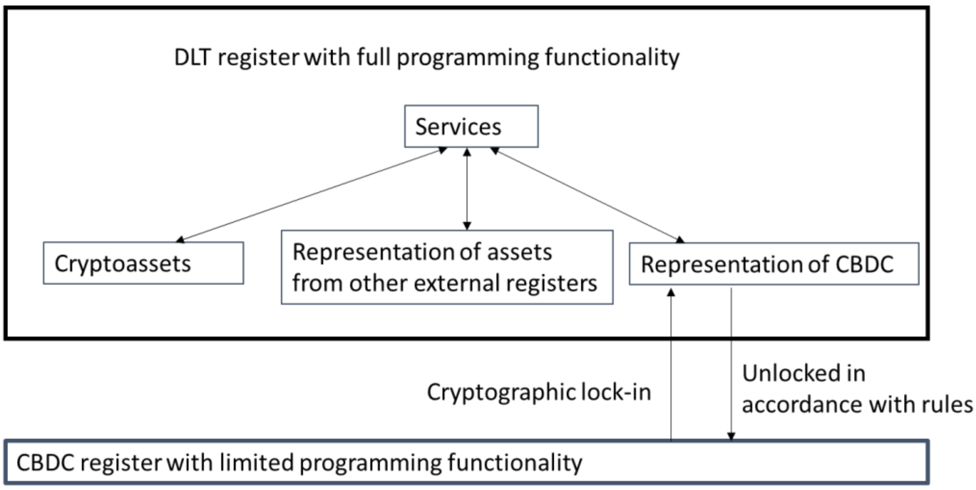
[29] See Gudgeon et al. (2020) and Bank of England (2020).

solutions. Tokenisation can be facilitated by creating a digital representation of certain types of assets – such as shares – in the register.

Programming functionality has advantages, but may also entail risk and other unintended effects. If extensive programming alternatives are provided on top of the CBDC – such as facilitating tokenisation of assets on top of the CBDC register – this could in practice make Norges Bank responsible for matters falling outside the scope of the Central Bank Act. In addition, many different stakeholders and authorities from outside the payment system may have views on the architecture of the register and how the register is operated, and this could potentially conflict with Norges Bank's efforts to promote an efficient and secure payment system.

The working group therefore considers it expedient for the CBDC to offer limited programming functionality sufficient to ensure interoperability and interaction with other registers, so that "packaged"[30] CBDC variants can be used in other registers offering different and/or more extensive programming options; see Figure 4. However, this may also present challenges related to the use of overlay solutions as discussed above. Use of a CBDC or CBDC representations in other registers will not necessarily eliminate Norges Bank's liability for occurrences in these registers, and may create reputational risk for Norges Bank regardless.

Figure 4: Full programming functionality – overlay solutions for CBDC



Source: Norges Bank

3.2.3. Cryptography

Cryptography is a key technology in all digital currencies. As a rule, the cryptographic elements are incorporated into underlying infrastructure without users having to deal with the technology. In a sense, register-based token solutions bring cryptographic infrastructure closer to users.

Monetary transactions are executed through cryptographic codes controlled by users. In practice, this is done through user interfaces (wallets), so that users do not have to deal with codes directly, but rather with passwords and other

[30] Often referred to as "wrapped".

substitutes for the cryptographic codes. Wallets are discussed further below. However, users may have to deal with the loss of cryptographic codes which are only stored locally and, potentially, a resulting lack of control over registered units.

Nevertheless, bringing cryptography closer to users may also create new opportunities. Cryptography is a central aspect of programmable money, and is important not least in relation to implementation of payments which are conditional on signature by several persons, the inter-dependence of transactions to eliminate counterparty risk in connection with payments versus settlement, and locking CBDC units into third-party service platforms. For many of the latter functions, so-called “hash-time locked contracts” (HTLC) can be used. These only allow money to be unlocked with the correct cryptographic code until a specified time period has expired.[31]

Cryptography will be particularly relevant for fine-tuning the CBDC to achieve the desired degree of data protection. By controlling registered units using cryptographic codes instead of identification, users can retain some degree of anonymity. Cryptographic techniques like “zero-knowledge proof”, “ring signatures” and “stealth addresses” can further reinforce data protection; see ECB (2020a). Cryptography can also facilitate automatic differentiation of the information accessible to different stakeholders. In some cases, keys can be generated so that authorised stakeholders can unlock information in accordance with specified procedures. Such solutions are in development.

Allen et al. (2020) have concluded that many cryptographic technologies remain too immature for use in a CBDC solution. Technical testing can provide further information on the usability of such technologies.

3.2.4. User interface technology (wallets)

Regardless of the selected technical solution, users will need an interface for controlling and implementing transactions involving their CBDC units. Given current technology, a wallet – i.e. a user interface/digital wallet – on mobile telephones appears to be the most applicable option. However, it should also be possible to pay using a card or other physical equipment.

Solutions are also being developed for payments without physical equipment, where users can identify themselves and make payments using solutions based on biometrics, artificial intelligence and other technologies. Although payment functionality that is entirely independent of physical equipment offers some benefits, it cannot be a complete solution because it will require reconciliation with a register that may be inaccessible in an offline situation.

Payment user interfaces will largely be developed by third-party providers. However, the fact that such solutions are delivered by third parties will not preclude liability and reputational risk for Norges Bank. It is therefore likely that a regulatory framework will be required for the development of such solutions, and that technical solutions will have to be implemented to give Norges Bank control. Norges Bank’s liability in connection with cash usage represents one potential approach, but Norges Bank must evaluate whether its liability is technology-neutral.

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[31] See Gudgeon et al. (2020) for further information on the technology.

Wallets and other user interfaces must fulfil the requirement of accessibility for special user groups. General accessibility technology already exists which users could utilise, such as browsers that make internet information available to user groups with particular needs.[32] It would be advantageous if a CBDC solution could utilise such general technology to eliminate the need for separate development of special CBDC system solutions. One question is whether the market will supply user interface solutions that cover all applicable needs and expectations, or whether Norges Bank will have to supply or finance some solutions. To deliver the characteristic that customer communications and due diligence must be performed by third parties, it will probably be most expedient for Norges Bank to finance the development of any such third-party solutions, rather than providing them itself.

In a closed account solution with local storage, third-party providers can supply wallets through API access to an identified user's account with Norges Bank in accordance with the same principles as apply under PSD 2. Implementing such a solution appears to be unproblematic from a technological standpoint. Nevertheless, several challenges arise in relation to local storage interfaces; see the discussion of offline solutions below. The technical solution for local storage, and the regulatory framework, must facilitate customer independence of a specific provider's user interface when accessing locally stored CBDC units.

Two types of wallets can be used in a register-based token solution.[33] The first involves a user storing codes needed to execute transactions. The user interface/wallet will typically organise the user's cryptographic codes and communications with the CBDC register. This may mean that third parties will use proprietary solutions to represent data granting users access to the CBDC. This may make it difficult for a user to dispose of CBDC units if the solution delivered by the relevant stakeholder fails or the user otherwise wishes to use a different user interface. There are many standardised solutions for organising cryptographic codes, including one utilising standardised "seeds".[34] In technical and regulatory terms, a CBDC solution should ensure that users are not locked into a user interface.

This solution also has weaknesses. If a user loses access to the code or suffers a malware attack, the user's funds may be lost or stolen. Different solutions are available for reducing such vulnerability. Customers can choose to store their codes on devices which are not online, and to transfer smaller sums for online use as and when required. Customers may also use secure hardware, i.e. isolate certain hardware components in their user equipment, to complicate access for malware.

The second type of wallet solution is "custodial wallets". With this solution, a user's cryptoassets are stored by a third-party stakeholder. The user can control his assets by logging into the third-party stakeholder's user interface. A drawback of this solution is that the user may lose access to the CBDC if the stakeholder's system fails or is attacked. It is also difficult for users to switch suppliers. In addition, problems may arise in relation to ownership of CBDC units protected by such keys unless this is adequately regulated. Finally, if a third-party stakeholder becomes too large, such failures may also have

[32] See Miedema et al. (2020).
[33] See Karantias (2020) and Allen et al. (2020).
[34] One such solution is that all of a user's keys can be generated based on a series of different words. The user then has to use this word series to regenerate his/her keys in a new wallet.

systemic consequences because many persons will be unable to access their CBDC holdings.

If distributed ledger technology is to be used, the different wallet solutions available for cryptocurrencies may provide inspiration.[35] In principle, cryptocurrencies are based on the principle that every node in the system contains an updated and complete version of the register. A wallet serves as a user interface with the register. The wallet allows the user to view his/her holdings and other information stored in the register, and can generate/sign off on transactions sent into the network following user authorisation. It appears inexpedient for each user to be in possession of the entire CBDC register. This has also become less commonplace among cryptocurrency solutions. Instead, it has become more common for users to have a so-called “light wallet”, where the wallet communicates with and retrieves information from nodes containing the entire register, or information needed to demonstrate that a transaction has been implemented in the register. This also constitutes a security mechanism to prevent users from utilising a user interface that is communicating with “false nodes”. Cryptographic solutions can help users to maintain data protection while communicating with such nodes. Technical testing can generate further information on such solutions.

3.2.5. Offline solution technology

An account-based solution with local storage functionality must incorporate an offline solution. In principle, a register-based solution must communicate with a register in order to execute a payment. An offline solution must allow transactions to be implemented, at least temporarily, without communication with the register. Overlay solutions as discussed above represent one way to achieve this, i.e. by locking CBDC units into a secondary system that organises transactions for consolidation with the CBDC register once it becomes available.

External DLT solutions represent another possible approach. One disadvantage is that if the chosen solution is based on continuous communication with a register, the customer must be able to communicate with the register. This would not be a complete solution. For example, if telecommunication lines fail, an alternative register would not compensate for lack of access to the CBDC register.

Like solutions for local storage of money, overlay solutions can be based on storage on a local device incorporating secure hardware. This solution allows the user to control funds on a “peer-to-peer” basis. In a register-based token solution, transactions must be consolidated with the CBDC register when at least one of the parties has access. The technology used in such offline solutions makes it difficult for users to manipulate the solution technically so that they can use the same funds for multiple payments (double-spending). However, there are no solutions that provide a guarantee against such manipulation. One possible solution is to manage the risk of technical manipulation through legal liability. For example, it is possible that if the system permits anonymous payments, this functionality may be unavailable in offline situations. This means that a user may be held legally liable later if the solution has been manipulated to allow the same funds to be used several times. This may effectively dissuade users from manipulating the technical

[35] See Karantias (2020) for an overview of technical solutions.

solution themselves, but may be less effective where a user's technical solution is manipulated by third-party malware. Secure hardware technology is under development, and it has been argued that the technology is immature.[36] Technical testing can provide further insight into this technology and the extent to which risk can be reduced through legal liability.

Overlay solutions as discussed above are based on subsequent consolidation with the CBDC register. In other words, transactions in such registers will not be immediate and final in the sense that transactions are registered in the CBDC register immediately. This issue can be resolved by accepting that payments are not final in certain situations, or through regulations that allow certain transactions which have not yet been consolidated with the CBDC register nevertheless to be deemed final.

3.2.6. Regulatory technology (regtech and suptech)

Developments in the so-called "regtech" and "suptech" fields are effectivising and automating regulatory activities.[37] A CBDC register may contain substantial information relevant to both Norges Bank's exercise of authority and other authorities. Among other things, the CBDC register may provide Norges Bank with real-time information on economic activity that can be used for monetary policy and macro-supervisory purposes; see chapter 2.15.

According to the necessary characteristics, customer communications and customer due diligence must be undertaken by third parties. In principle, this means using the customer due diligence ("know your customer", or KYC) systems of individual stakeholders to check new users into the system (on-boarding) and to conduct AML/ATF (anti-money launder/anti-terrorist financing) transaction checks. A further development is the assessment of whether such tasks can be effectivised through consolidation of each institution's register in a joint register, for example based on distributed ledger technology. A CBDC solution should not hinder this type of effectivisation. In this regard, it can be questioned whether Norges Bank should take on new tasks to achieve such benefits in the CBDC context, for example by facilitating the integration of certain control functions into the CBDC register.

Programmable money may also serve official purposes in a broader sense. Other authorities – for example financial supervisory bodies and tax authorities – may benefit from information generated by a CBDC register. If the CBDC solution permits smart contracts, the CBDC may supplement social policy and economic policy by allowing funds to be reserved for specific uses. For example, CBDC units used to pay various forms of social support may be programmed to be usable only in certain circumstances, or only in defined areas of application.[38] Correspondingly, in the fiscal policy context where individual businesses may receive support for investment in environmental technology, conditions may be programmed into distributed CBDC units. This would also allow monitoring of how the funds are used.

Although a CBDC register should facilitate the realisation of benefits linked to regtech in policy areas beyond Norges Bank's remit, there are also reasons to approach such technology cautiously. The primary function of a CBDC is to

[36] See, for example, Allen et al. (2020).
[37] See, for example, FSB (2020) and Omarova (2020).
[38] The working group has not considered issues related to whether it is legally permissible to impose such conditions.

promote a secure and efficient payment system, and other functions may conflict with this purpose. If different authorities are permitted to monitor and steer transactions, the CBDC may become less attractive to users. This could also entail Norges Bank losing control, if other authorities want to influence the design and functionality of the CBDC. Such solutions could also render money in the system infungible.

4. Meetings with stakeholders

4.1. Meetings with technology companies

The working group met a number of technology companies during the course of its validation work. These included developers of relevant technology and providers of consultancy services. Some companies offer a broad range of services internationally, such as major audit and consultancy firms. Other companies specialise in technological solutions, including both blockchain technology/DLT and digital money solutions.

The meetings normally followed a fixed agenda whereby the working group presented Norges Bank's CBDC-related work (presentation sent ahead of time), including the working group's assessments of the necessary or desired characteristics of a CBDC. The companies who met with the working group were generally well-prepared, which helped keep the meetings highly relevant to the working group's efforts. In several cases, the stakeholders reviewed their technical solutions and argued how these could deliver, or help deliver, the characteristics.

Many companies argued for solutions based wholly or partly on DLT technology. Some argued that a CBDC should take the form of a program (a smart contract) in an open blockchain, including Ethereum, Algorand and Bitcoin SV, while others recommended the use of private variants of open blockchains like Ethereum or Bitcoin. Some companies also had opinions on how consensus mechanisms could be established to permit more stakeholders to participate in the validation of transactions while still allowing Norges Bank to retain control.

An issue raised during meetings with some companies is interoperability between technical solutions. Various standardisation processes are ongoing under the auspices of both private and public bodies, but at present there is no satisfactory interoperability between different blockchain solutions despite the fact that some types of interoperability are possible, including through different cryptography solutions and "bridges" between solutions. Other companies identified weaknesses in DLT and stated that other solutions could be more appropriate, such as local storage on physical devices.

Many companies presented solutions that enable customer due diligence and communications to be undertaken by third parties. The different solutions offer varying degrees of payment anonymity and varying scope for keeping money in the system without customer identification by a third party.

Some of the companies were also urged to express their views on technical testing methods. Most companies appeared to take a positive view of different sandbox models, which can encompass many different types of technical solutions and stakeholders. The general impression is that a number of companies will be interested in participating in sandbox testing. The usefulness of modular testing was also emphasised, as it would allow e.g. user solutions to be tested independently of underlying technical infrastructure.

4.2. Meetings with organisations and user representatives

The working group has met with various organisations, potential users and user representatives. Most of these parties have given positive feedback on Norges Bank's examination of the introduction of a CBDC, and Norges Bank’s decision to initiate dialogue with potentially affected parties. The ICT sector has welcomed the decision to advocate a clear distinction between public and private-sector activity, so that public expansion does not displace private solutions. The distinction between public core infrastructure and private innovation based on such infrastructure was also welcomed. An important measure in this regard is basing core infrastructure on established standards. Moreover, low costs are always a prerequisite for user interest in adopting a solution.

4.3. Meetings with authorities

The working group met several official bodies which could have a particular interest in the potential uses of a CBDC. Several parties also provided feedback on CBDC design. The general impression is that public authorities are following Norges Bank’s CBDC-related work with great interest, and that the authorities have many questions about potential CBDC uses. None of the official bodies with which the working group was in touch have studied international CBDC developments in any detail, and their feedback therefore consisted primarily of general views on CBDCs and desired CBDC design features.

The working group gave the same presentation to both official bodies and other stakeholders, and this was followed by discussion. The feedback received reflects the differing tasks and responsibilities of the official bodies. The use of different technological solutions was discussed, including whether it should be possible to link the CBDC directly to public registers. User-friendliness for groups that tend to pay in cash was another highlighted concern. It was also emphasised to the official bodies that the introduction of a CBDC should not affect bank financing or reduce the robustness of the deposit guarantee scheme.

It was pointed out that liability in connection with CBDC use should be clarified by law, in the sense that there should be no doubt as to whether the payer, Norges Bank as issuer, or third parties bear liability for incorrect payments or incorrect register entries. In this regard, it was stated that it would be advantageous to draft such regulatory provisions in even clearer terms than the provisions applicable to bank customers and banks with respect to account deposits; see chapters 3, 4 and 5 of the Financial Contracts Act 1999.[39]

Data protection considerations are a key factor to which official bodies give varying emphasis based, not least, on their differing mandates and responsibilities. For example, some authorities emphasised designing the CBDC to make it easy to trace the origin of funds and to facilitate ongoing taxation. Other authorities gave particular emphasis to the principles underpinning the GDPR and other data protection considerations.

4.4. Meetings and cooperation with other central banks

Throughout all phases of the project, the working group has liaised with other central banks through various CBDC cooperation forums. Among other things, the working group has held regular workshops with Sveriges Riksbank (the Swedish central bank) and Sedlabanki (Central Bank of Iceland), and Norges Bank has participated in roundtable conferences involving a larger circle of central banks. Norges Bank is also involved in a Nordic BIS Innovation Hub to be established in Stockholm, which will be part of the BIS Innovation Hub network.[40] The hub network will study CBDC-related issues.

Cooperation with other central banks also includes the exchange of experience and information. One topic of discussion has been the need for standards for and interoperability between the CBDC systems of different countries.

5. Validation summary

Validation entails assessing whether and to what degree a technical solution can deliver the stated characteristics.

5.1. Validation of register-based token solution

In Norges Bank (2019), a register-based token solution was evaluated as a potential CBDC solution. The validation of solutions in Phase 3 has not altered this assessment.

In Norges Bank (2019), the technology was deemed to be insufficiently mature. This remains the case, albeit to a lesser degree thanks to ongoing technological development. Several central banks have decided to use the technology in pilot projects and other testing. Nevertheless, the validation work has clarified various challenges and the need for trade-offs:

- trade-offs linked to programmable money and control
- challenges linked to standards and interoperability
- challenges and trade-offs linked to offline solutions

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[39] A new Financial Contracts Act was adopted on 1 December 2020 and approved on 18 December 2020, but has not yet entered into force.
[40] For more information on the BIS Innovation Hub, see https://www.bis.org/topic/fintech/hub.htm.

- challenges and trade-offs linked to identification.

As regards trade-offs linked to programmable money and control, these relate particularly to the need for Norges Bank to retain control of the system while also facilitating innovation by third parties. Extensive programming functionality in a CBDC register will allow innovative services to be added to the register, but may also entail the addition of programs falling outside Norges Bank's remit, for example tokenised assets. This means that stakeholders – including authorities – from outside the payment system may have an interest in operation and development of the system that conflicts with Norges Bank's responsibilities under the Central Bank Act. Such a development could also entail liability and reputational risk for Norges Bank. The working group has therefore concluded that Norges Bank should use limited programming functionality and standards to facilitate interoperability with other registers offering such functionality. However, this will not eliminate liability and reputational risk for Norges Bank. It is therefore necessary to use technical infrastructure and a regulatory framework that secure an acceptable level of liability and reputational risk.

As stated above, interoperability with external registers is a useful function. Interoperability is important in a wider sense. The term encompasses interoperability with existing payment solutions, interoperability between different CBDC user interfaces and interoperability between CBDC solutions in different countries for the purpose of cross-border payments. Standards will promote interoperability. Few standards for register-based token solutions have been developed to date. Numerous public and private standardisation processes are ongoing in different areas, including EU initiatives to develop standards for registers based on blockchain technology. Various inter-central bank collaborative bodies in the CBDC field are also focusing on standards and interoperability. This suggests an eventual development of standards capable of promoting interoperability, and indicates that future CBDC efforts should be robust and agile enough to adapt to such a development.

In principle, a register-based token solution requires communication with a register to validate, process and register transactions, and such communications will usually be necessary to ensure payment finality. At present, some technology and concepts exist for so-called off-chain payments in overlay solutions, which allow payments to be made outside a register prior to later consolidation with the register, and thus potentially provide offline payment functionality. Secure hardware can be used for the latter. However, this technology remains fairly immature, and technical testing may provide further insights. Solutions based on subsequent consolidation with a CBDC register do not offer payment finality. Further assessment is needed of whether it is acceptable for payments not to be final in an offline situation, or whether a regulatory framework is needed to make such payments final.

In principle, a token-based register solution uses access to cryptographic codes, rather than identification, as the basis for monetary transactions. However, links have to be established between identity and register entries to comply with regulatory requirements. Such identification can be more or less direct, and more or less extensive, depending not least on the trade-off made between different characteristics. For example, a greater degree of identification will facilitate frictions related to bank deposits, such as interest rates and volume restrictions, but may reduce experienced data protection and reduce the friction effect of the possibility of losing money.

A further question is which identification solutions should be used. Existing third-party solutions could be adopted, or efficiency gains could be facilitated by using new regulatory technology. In principle, it would be possible to establish comprehensive links between register entries and identified persons. In practice, this would be very similar to an account-based solution. This also illustrates the fact that the boundary between register-based token solutions and account solutions is fluid. The working group therefore considers it unnecessary to maintain this distinction in the further validation process; see also chapter 5.3.

5.2. Validation of closed account solution with local storage

Generally speaking, the working group has not found any indications of incompatibility between the principles governing an account-based model and the necessary characteristics of a CBDC.

In some instances, an account-based model is likely to deliver the characteristics to a lesser extent than a register-based model. This is discussed further in chapter 2 on characteristics, and applies particularly to the characteristic regarding CBDC as a platform for third parties and the data protection characteristic. A closed account solution will not facilitate third-party innovation beyond what can already be expected under PSD 2. Moreover, it is likely that an account-based model will provide less data protection flexibility, not least because it will be (more) difficult to provide anonymity. The extent to which an account-based system is compatible with DLT is also uncertain.

On the other hand, an account-based system with a separate local storage module is likely to be most suitable for making immediate and final offline payments in a contingency situation.

5.3. Consolidation of the technical solutions in the further validation process

The distinction between an account solution and a register-based token solution has served a useful analytical purpose thus far. In an account solution, money is linked to an account owned by an identifiable person, and payments are made through API “calls” on the account solution. The solution is therefore technology-agnostic, and the underlying infrastructure can be replaced without material changes to the rest of the production chain. The integrity of the solution is dependent on the register of individual holdings.

In a token-based register solution, payments are made by transferring tokens in the register, and users must possess cryptographic codes to effect a valid transfer. In this case, the actual infrastructure plays a more prominent role in the production chain. The integrity of the solution is dependent on the register reflecting valid transfers in accordance with cryptographic codes, and the user interface must be compatible with such cryptography.

The distinction between an account solution and a register-based token solution is based on BIS (2018). This means of distinguishing between solutions does not appear to be subject to general consensus. In some instances, account solutions and token solutions are distinguished by how money is represented as data in the register from a technological perspective, without this being linked to user identity.[41] In other words, in an account solution money is represented as a holding in a specific register entry, whereas in a register-based token solution a user's right to dispose of a monetary unit in the register depends on the existence of a valid transaction sequence from the time a monetary unit is created until it reaches the user.[42]

Both account solutions and token-based register solutions can be based on DLT architecture. Moreover, the solutions overlap to some extent.[43] Users may regard a token-based register solution as an account solution if they have a user interface that is linked to their identity and a volume of tokens, where the user interface controls which tokens are used without the user having to decide this. On the other hand, it would also be possible to develop a system of anonymous accounts that are not linked to users' names. For example, certain e-money solutions in Asia are based on a user "giving away" his/her account by sharing the password that controls the account.

Although the distinction between solutions in BIS (2018) can be useful, for example when analysing economic effects, maintaining the distinction does not appear to be useful in further validation of solutions by reference to characteristics, particularly in the context of technical testing. In technical testing, it appears more appropriate to test different solutions and principles for establishing links with identity and monetary holdings, as well as different solutions for underlying technical infrastructure. Accordingly, no distinction will be made between the solutions in the proposed technical testing plan, and the working group has concluded that elements from both solutions should be tested by reference to necessary CBDC characteristics.

[41] See, for example, Bank of England (2020).
[42] The former is the solution used in the Ethereum blockchain, in which a user controls a holding linked to a register address, while the latter is used in the Bitcoin solution, where a user controls the right to use an "unspent transaction output – UTXO" transferred to him-/herself through a series of valid transactions subsequent to generation of the relevant Bitcoin unit.
[43] See, for example, Garrat et al. (2020).

PART II: Effect on Norwegian banks of introducing a CBDC

Summary

The effect of CBDC on banks' funding structures will depend on changes in demand for bank deposits, and is uncertain. There is reason to believe that some deposits will be replaced, and that demand for deposits will become more interest-sensitive.

The working group's primary conclusion is that it is possible to limit the effect of a CBDC on bank funding and lending rates, provided that the central bank makes reserves available to banks when deposits are withdrawn from banks and replaced by a CBDC, and that there are no significant changes in banks' funding structures otherwise or in interest rate spreads in banks' wholesale funding markets. A further assumption on which this conclusion rests is that a CBDC will not be highly competitive as a store of value and will instead meet a transactional need, achieved – for example – by setting the CBDC interest rate at a low level. Deposit rates will probably increase somewhat, and banks may also decide to increase their wholesale funding if residual deposit financing becomes more expensive and more volatile following an introduction of CBDC. This may further increase financing costs. The effect of an increase in financing costs on bank lending rates is likely to be limited by competition for borrowers in the Norwegian market, but this may then reduce the profitability of Norwegian banks.

The probability of a bank run is likely to increase somewhat if a CBDC is introduced. A bank run is highly destabilising for the financial system, and requires central bank action to prevent bank insolvencies, meaning that the direct impact on bank funding costs will be determined by the interest rate charged on loans from the central bank. Wholesale funding for banks is typically also very expensive during a bank run.

The introduction of a CBDC may have very significant consequences for Norges Bank's balance sheet, even in normal times. In the event of a bank run, the central bank balance sheet will increase substantially, and the central bank may be forced to take on substantial risk. This may lead to a trade-off between a small effect on bank funding and lending rates on the one hand and central bank balance sheet risk on the other. This may apply particularly during periods of financial turbulence and bank runs. This topic is not analysed in this report.

6. What do we know about demand for cash, deposits and CBDC?

Demand for any CBDC is highly uncertain. This is primarily because CBDCs represent a new asset class and necessary CBDC characteristics remain undefined. The working group has approached this question by reviewing empirical literature on demand for money and money-like assets, i.e. secure and highly liquid assets.[44]

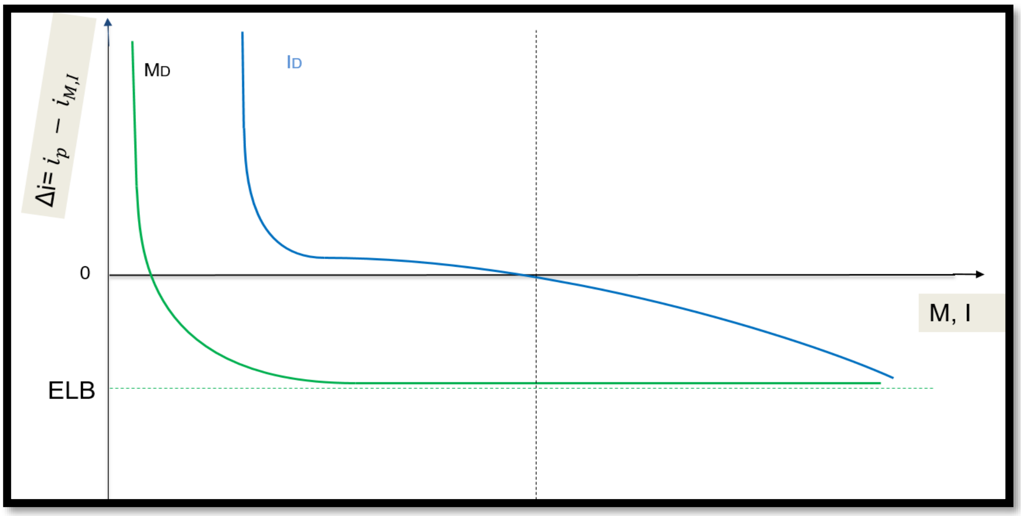
The main findings of the study are:

- Total demand for different secure liquid assets is fairly constant over time. Different types of secure liquid assets, like securities issued by banks and government bills, are substitutable. This likely reflects a relatively constant demand for such assets, due for example to the need to maintain liquidity buffers.
- Institutional investors account for a large proportion of demand for secure liquid assets, and their demand is quite interest-sensitive. This likely reflects a strong value-investment motive among these agents.
- Demand for money falls as the interest rate spread against other assets (the liquidity premium) increases. The return on alternative assets is therefore significant to demand for money.
- Demand from individuals and non-financial firms has low interest-sensitivity in the short term, likely reflecting the fact that these two groups value non-pecuniary benefits of the instruments, such as user-friendliness in connection with payments. This ties them to providers of liquidity services in the short term, but wide interest rate spreads are likely to cause them to switch to competitors in the longer term.

A CBDC will be closer in form to cash or deposits than short-term paper and bonds. Demand for cash and deposits, respectively, can be illustrated as in Figure 5:

[44] See Müller (2020). Money is normally defined as assets which function as a medium of exchange, a store of value and a unit of accounting. Müller (2020) discusses assets which have either the first two or all three of these characteristics. Central bank liabilities are unique in also functioning as a unit of account.

Figure 5: Stylised demand for cash (M_D) and bank deposits (I_D)



The X-axis shows the volume of cash *M* and deposits *I*, respectively. The Y-axis shows the interest rate spread against other instruments (the opportunity cost of holding M or I), calculated here as the difference relative to the Treasury bill rate or the policy rate (i_p). The interest rate spread falls when the deposit rate rises, and then demand for deposits rises too. In other words, falling Δi means that the interest rate on the alternative (i_p) falls or that the interest rate on deposits (i_I), or cash (i_M) increases. Normally, the interest rate on cash is 0.

Both cash demand (M_D) and deposit demand (I_D) have low interest sensitivity, partly because the public values the transaction properties and user-friendliness of these instruments so highly that it is willing hold a certain volume even with a wide interest rate spread against other instruments. This is the steep part of the demand curves, and the valuation of the transaction properties results in a lower required rate of return or high liquidity premium on such assets.

Once the demand for transaction services is satisfied, demand will turn to store of value and become more interest-sensitive. This is the flat part of the demand curves. Since the effective lower bound for the policy rate is assumed to be lower than 0 (see the ELB, or effective lower bound, in Figure 5), the working group has assumed that there will be some cost of holding cash compared with alternative investments, meaning that demand for cash will only level off and become high if the interest rate on alternative assets is negative.

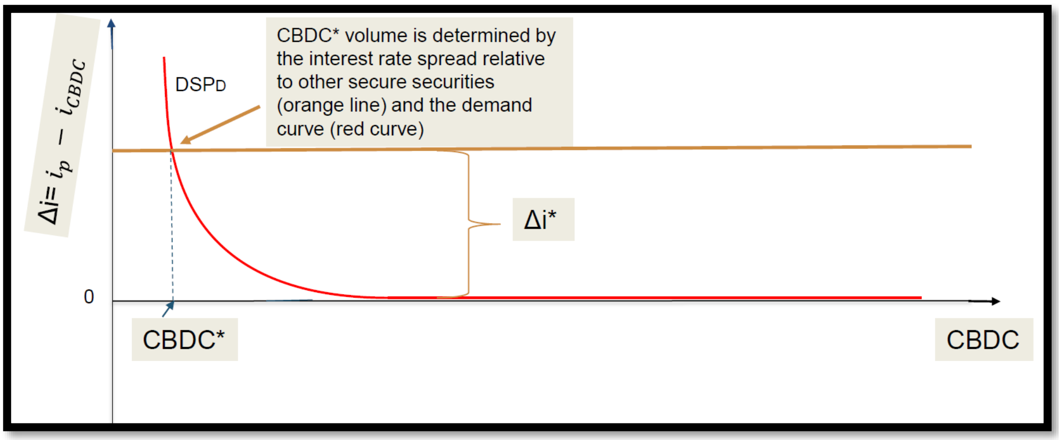
Since cash carries no credit risk, it is often assumed that demand will be almost unlimited at the effective lower bound.

As regards deposits, credit risk increases as volume increases beyond the secured deposit amount. Increased demand for deposits requires an ever-higher deposit rate (positive risk premium).

Figure 5 does not include supply curves for bank deposits or cash. Competition between banks will limit how low the interest rate on bank deposits in equilibrium becomes (how high the interest spread on the Y-axis can become), even when the demand curve for deposits is steep. As regards cash, the interest rate is zero and the interest rate on secure liquid investments therefore determines the liquidity premium on cash (the opportunity cost, or interest rate spread), while the cash volume is determined by demand.

The above has provided the inspiration for the stylised CBDC demand curve shown in Figure 6.

Figure 6: Stylised demand for CBDC (red curve). Interest rate spread between safe liquid assets (or policy rate) and CBDC on vertical axis, CBDC volume on horizontal axis.



The interest-inelastic (steep) part of the CBDC demand curve exists if the CBDC can meet a transactional need and there are no close substitutes capable of meeting the same need. This inelastic part of the demand curve is highly uncertain. If the CBDC is similar to deposits in terms of functioning as a store of value, demand will be highly elastic when the interest rate spread against similar investment alternatives (such as secure bank deposits or government bonds) approaches 0.

CBDC volume is determined by the interest rate spread set by the central bank between the CBDC and other secure assets (the orange line, i.e. the supply curve), together with the demand function. This reflects an assumption to permit CBDC supply to be fully elastic and determined by demand, just like cash volume.[45] If the CBDC interest rate is set at 0, for example, the interest rate spread will be equal to the interest rate on secure liquid assets and the orange line will in practice be close to the policy rate. In a situation where the policy rate is 0, so that the orange line lies on the X-axis, the CBDC volume may become very large.[46] To avoid a very large CBDC volume, it has been proposed that a limited volume of CBDC can be provided with, for example, a 0 interest rate while CBDC in excess of a given volume can carry a lower interest rate. For a discussion of how a dual-price system for CBDC could work, see Bindseil (2020). A similar system is also discussed in the annex to

[45] Quantitative restrictions on a CBDC may impose separate limits on CBDC volume, and will appear as a straight vertical line in the figure, indicating the maximum number of CBDC units.
[46] For a discussion of how CBDC volume could be affected by changes in the policy rate when the CBDC carries a fixed rate of interest (for example zero), see the annex to Norges Bank (2018). If there is a fixed spread between the CBDC interest rate and the policy rate, CBDC volume will not be affected by changes in the policy rate, all else being equal.

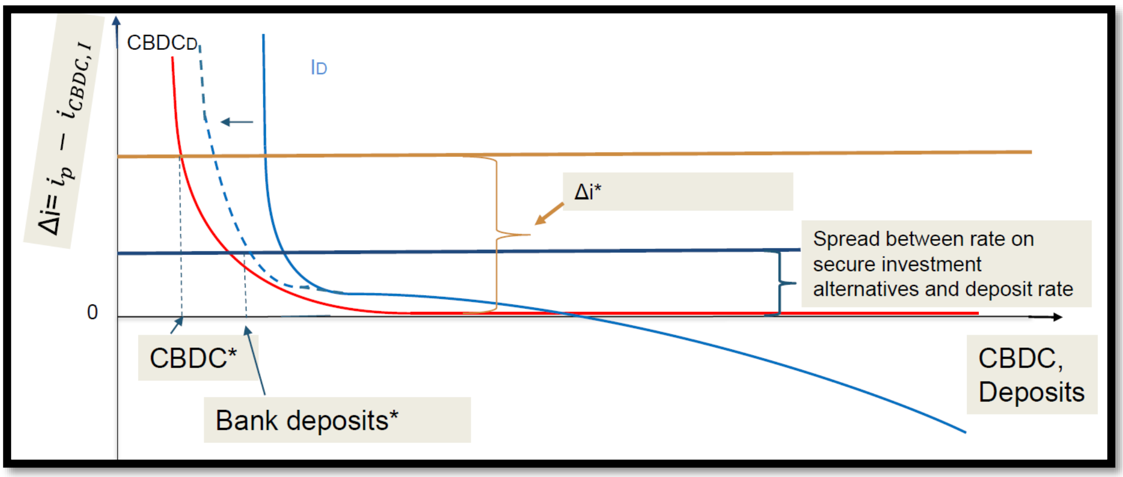
Norges Bank (2018), but further study is required to establish how manageable such as system would be in practice.

If, on the other hand, the CBDC does not function well as a store of value, CBDC demand will cease once the transaction need is met (and will not level off as in Figure 6). In such case, the distance between the CBDC interest rate and other assets (the orange line) will not be as significant for CBDC volume, and a low policy rate will not result in a high CBDC volume even if the CBDC interest rate is fixed and equal to 0.

It is safe to assume that, if a CBDC is introduced, the transaction-motivated part of bank deposits will fall somewhat if some of this demand is better met by CBDC, illustrated by a shift to the left in demand for bank deposits in Figure 7.

Moreover, the CBDC interest rate establishes a floor for bank deposit rates, for both transaction-related deposits and other deposits if the CBDC functions as a store of value. To compete with CBDC holdings, banks will always have to set their deposit margin against alternative secure assets (the blue line in Figure 7), so that it is lower than the orange line (the central bank-determined spread between interest on alternative secure assets and the CBDC rate).

Figure 7: Shift in demand for transaction-related deposits following introduction of CBDC.



Segendorf (2018) provides a rough estimate of CBDC demand following the introduction of a CBDC in Sweden. The estimate assumes that

- 10% of unsecured deposits will be replaced by CBDC,
- 2% of household deposits will be replaced by CBDC, and
- 10% of all transactions will be executed using CBDC.

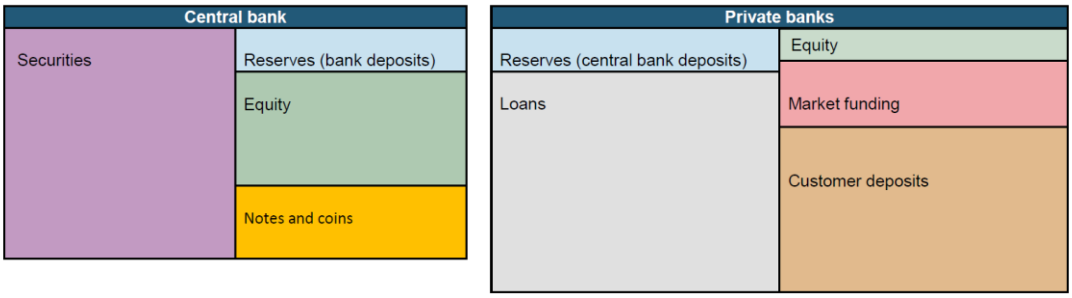
These assumptions result in a demand estimate of SEK 120 billion, corresponding to approximately 3% of GDP. In Norway's case, 3% of mainland GDP amounted to some NOK 90 million in 2020. This is a highly uncertain estimate for potential CBDC demand. Moreover, periods of financial turbulence may give rise to bank runs, and CBDC demand may then grow far larger. It is generally thought that demand for CBDC may be dampened during normal periods by setting a sufficiently low CBDC interest rate, see the discussion above. However, in very turbulent conditions CBDC may still appear attractive compared with assets carrying credit risk, even if the CBDC interest rate is very low. If investors only intend to hold CBDC for a few days, a low interest rate will have little impact.

7. Effect of CBDC on bank balance sheets, funding costs and lending rates

7.1. Balance-sheet effect

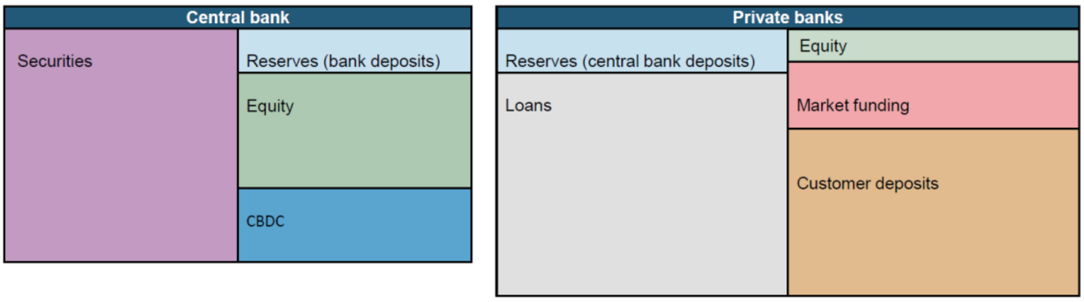
Figure 8 shows a stylised balance sheet for the central bank and private banks before the introduction of a CBDC.

Figure 8. Financial sector balance sheets, selected items



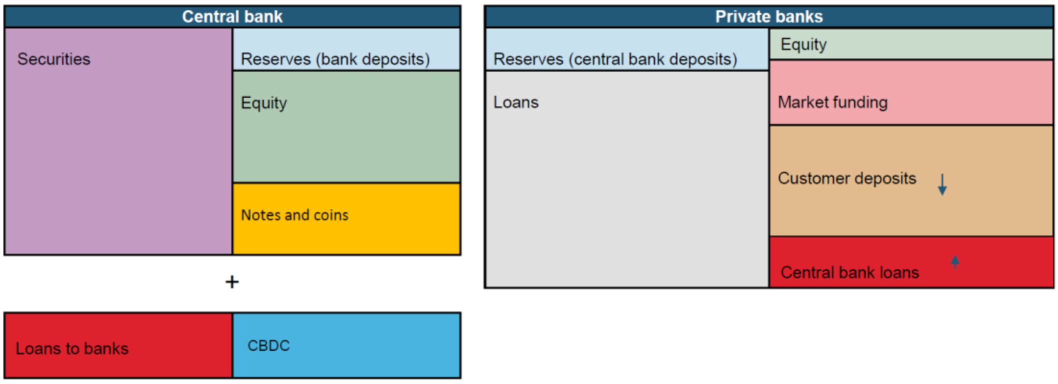
Private banks hold central bank reserves, which are used for interbank payments, and customer loans as assets. Assets are financed partly by market funding and partly by customer deposits. The central bank holds currency reserves and securities, accepts deposits from private banks and circulates notes and coins. If the public replaces notes and coins with CBDC units, the balance sheets of private banks will remain unaffected, and a situation as shown in Figure 9 will result.

Figure 9. The public holding CBDC units instead of notes and coins



If, on the other hand, the public wants to withdraw bank deposits to purchase CBDC, the balance sheets of both banks and the central bank will be affected. Potential balance sheets are illustrated in Figure 10, which shows Norges Bank providing liquidity in the form of lending to banks to compensate for the loss of deposits while the asset side remains unchanged. Here, banks are assumed to borrow sums from the central bank corresponding to the withdrawn deposits.

Figure 10. The public withdraws bank deposits and converts them into CBDC



The central bank balance sheet must increase if CBDC does not replace cash or other existing claims against the central bank held by private parties. However, the central bank balance sheet may be prepared so that lending to banks from the central bank does not have to increase. The central bank can purchase assets so that the banks' reserves exceed what is needed ahead of time. Then, banks can draw on their deposits with the central bank (reserves) instead of borrowing more from the central bank. Irrespective of whether the central bank decides to lend more to banks or to purchase other securities, the central bank balance sheet will still increase. This report does not assess how this should be done.

The central bank's lending to banks is collateralised, and banks have limited holdings of government securities and other assets that can easily serve as collateral. However, if Norges Bank buys securities from third parties, banks' holdings of assets not pledged as collateral will to a lesser degree be a limiting factor, see Bindseil (2020).

7.2. Effects on banks' funding costs

The direct effect on bank funding costs of the public replacing some bank deposits with CBDC (see Figure 10) depends on the spread between the interest rate on bank deposits and the interest rate on banks' borrowing from the central bank. Historically, this interest rate spread has been small or even negative. If the central bank sets a normal interest rate on loans, the effect of replacing deposits with central bank loans will therefore be quite limited. It is likely that the interest rate on central bank loans will be set higher than normal, partly on account of maturities and the collateral pledged. In addition, central bank loans are collateralized and banks may need to hold larger liquidity buffers to meet collateral requirements and hold sufficient liquidity buffers. See Bindseil (2020) for a specific calculation example of implications for European bank funding costs, and Alstadheim and Søvik (2021) for a corresponding calculation for Norwegian banks.

The remaining deposits may become more interest-sensitive and thereby more expensive for banks than before. However, the total volume of deposits + CBDC units will in the situation illustrated in Figure 10 not be higher than the previous total volume of deposits, indicating that the liquidity premium the public is willing to pay on the residual deposits will probably remain largely the same.

Nevertheless, a high CBDC interest rate may press down the interest margin on remaining deposits. A high CBDC interest rate corresponds to a situation where the orange line in Figure 7 lies close to the X-axis, setting a low ceiling on the deposit margin (blue line in Figure 7) banks can charge. Juks (2018) has calculated that the interest rate payable by banks on their remaining deposit funding may increase by up to 22 bp in a scenario where a CBDC carries an interest rate 25 bp below the policy rate. This effect on deposit rates will be reduced if the spread between the policy rate and the CBDC interest rate is larger (CBDC rate lower).

As stated, banks cannot replace withdrawn deposits with funding other than central bank loans (or drawdowns on central bank reserves). However, banks may make other adjustments if a CBDC is introduced:

- Banks may wish to reduce the outflow of deposits by bidding up deposit rates. Banks may want to do this if central bank funding becomes expensive compared with deposit funding (for example if the central bank charges a high interest rate on loans). Lower deposit funding may also weaken bank credit ratings and thereby increase other funding costs. Fulfilment of the LCR requirement may be a further relevant consideration, as fulfilment may become more difficult if a large proportion of banks' liquidity buffers have to be pledged as collateral for loans from the central bank. Such an adjustment could increase the interest rate on deposits to something approaching the interest rates paid on the alternative, unsecured form of funding - senior bonds. Smaller banks with a large proportion of deposit funding would face particular increases in funding costs.
- On the other hand, banks may wish to increase market funding for new loans. There are several reasons why this may happen. Firstly, deposits may become more volatile and/or interest-sensitive if a CBDC is introduced. Secondly, all else being equal, banks may reduce their LCR requirements by increasing long-term market funding. However, if the deposit-to-loan ratio falls substantially, unsecured market funding may become more expensive for banks. Smaller banks in particular may face higher funding costs.
- Covered-bond funding is the cheapest long-term form of market funding for banks, and thus probably the preferred source of market funding. Moreover, demand for covered bonds and other collateralised securities is likely to increase if a CBDC is introduced, since the central bank will either have bought up such securities or the securities will have been pledged as collateral in connection with the provision of reserves. Accordingly, banks may seize the opportunity to increase loan securitisation in this scenario. However, the scope for banks to issue more covered bonds or other collateralised securities will be limited by the available amount of collateral. In countries where securitisation is commonplace, as much as 96% to 97% of a lending portfolio is sold when it is securitised.
- The marginal investor in Norwegian securities is a foreign investor, and an increase in banks' market funding is also likely to include increased funding from abroad.[47] This limits the likely spread increase resulting from any increase in demand for market funding by Norwegian banks.

[47] Any increased bank funding from abroad will have other implications for equilibrium in the economy. Moreover, to achieve a new equilibrium, other sectors will have to invest more abroad, or the total net capital inflow will have to increase. While volumes may not necessarily change substantially, the possibility of securing funding abroad is likely to have a price effect.

However, the price banks have to pay in the currency swap market to convert foreign exchange funding into Norwegian kroner may increase significantly, particularly in the event of large, rapid increases in foreign currency funding. This would raise Nibor relative to the policy rate and increase the cost of banks' entire market funding. This increase would be more limited if the public simultaneously increased its international investments in such an equilibrium. Any increase in foreign currency funding may increase the risk that turbulence abroad causes future funding problems for Norwegian banks. However, banks will only choose to increase their market funding from abroad if doing so reduces their funding costs relative to the available alternatives.

7.3. Effect on banks' lending rates

The average deposit funding ratio of Norwegian banks is just under 40%. If the introduction of a CBDC triggers the replacement of some deposit funding with central bank loans and increases funding costs on the share of funding that was deposit funded, the effect on lending rates will be limited to 40% of this.

It is possible that banks will increase their share of market funding in response to deposit outflows, but only the central bank can replace the lost deposit funding directly. Accordingly, if market funding increases, it replaces remaining deposit funding. Market funding costs may increase due to lower credit ratings if a material proportion of deposits is withdrawn. Any increased market funding and higher market funding costs will pull in the direction of higher lending rates.

There is considerable competition in the Norwegian lending market. This may limit any increase in lending rates as a result of higher funding costs for Norwegian banks. Small banks often have a higher deposit funding ratio, and thus have a competitive disadvantage in the event of major changes in deposit rates. Foreign banks may gain a competitive advantage if deposit rates in other countries are less affected by the introduction of a CBDC.

7.4. Studies of a CBDC's impact on banks

Some international studies have assessed the impact of a CBDC on bank funding costs. The conclusions vary depending on the assumptions made. However, examining these studies can provide an indication of what to expect. A brief summary is provided below, with further details in the references.

In an analysis of Swedish banks, Juks (2018) makes the assessment that introducing a CBDC ("e-krona" in Swedish) would, under certain conditions, increase bank funding costs by up to 25 bp. The analysis assumes CBDC demand of SEK 120 billion. The 25 bp include a maximum effect of 22 bp linked to the CBDC establishing a floor for deposit rates. The increase in funding costs will be smaller the lower the policy rate, since the interest rate on market funding will track reductions in the policy rate more closely than deposit rates, and deposit funding is relatively expensive when the policy rate is low. Increased competition in the deposit market due to increased use of FinTech may reduce the cost increase further. Moreover, the effect of higher funding costs on lending rates will be limited by competition for loans from other sources of funding, but this was not quantified in the analysis.

Agur, Ari and Dell'Ariccia (2019) discuss trade-offs in a situation where a CBDC may increase the funding costs of banks and modify their ability to provide credit. A trade-off is described between the degree to which all economically profitable projects receive financing and increased efficiency of the payment system through the introduction of the CBDC. If banks are more important for the efficient allocation of credit, and if the CBDC's contribution to efficiency of the payment system is small, this suggests that CBDC volume should be more limited.

Andolfatto (2020) and Chiu et al. (2020) show that higher deposit rates in response to intensified competition between banks following the introduction of a CBDC may also trigger an increase in bank deposits after the CBDC is introduced. In principle, therefore, banks may increase their lending – subject to certain conditions – if a CBDC is introduced.

Brunnermeier and Niepelt (2019) show that bank lending rates may remain unchanged if a CBDC is introduced and central bank lending to banks replaces bank deposits:

"*Our framework suggests that some frequently-made arguments in the policy debate are questionable. In particular, it is unclear why the issuance of CBDC should reduce credit, crowd out investment or undermine financial stability. Whether this would be the case, depends on the monetary policy accompanying the issuance of CBDC and on the strength of the central bank's commitment to serve as a lender of last resort. With a strong commitment, a transfer of funds from deposit to CBDC accounts would give rise to an automatic substitution of one type of bank funding (deposits) for another one (central bank funding) – the issuance of CBDC would simply render the central bank's implicit lender of last resort guarantee explicit. By construction, a swap of CBDC for deposits thus would not reduce bank funding; it would only change the composition of bank funding."*

The authors establish conditions under which the introduction of a CBDC would not alter credit, output and price conditions in the economy, but only bank funding structures. They conclude that credit conditions can be unaffected only if the central bank offers banks funding on terms just as favourable as those which applied to the lost deposit funding. Collateral requirements for central bank funding under the current system means that Brunnermeier and Niepelt's conditions will not be met in practice, indicating that the introduction of a CBDC will increase bank funding costs.

Gross and Schiller (2020) study the effect on banks of introducing a CBDC, using a medium-sized general equilibrium model. Their findings are consistent with those of Brunnermeier and Niepelt. Gross and Schiller's conclusion is that as long as the central bank provides banks with sufficient liquidity, and if CBDC volume can be controlled using a low CBDC interest rate, the effect of the CBDC on bank lending activity and terms of credit offered to the public does not have to be large. In their model, a high level of central bank funding is not negative for banks.

8. Risk of bank runs and frictions

8.1. What do we know about the risk of bank runs?

The introduction of a CBDC may result in bank runs and high demand for the CBDC. This means that the central bank may have to provide much of banks' funding (potentially equal to banks' entire deposit funding). This will have a destabilising effect on the financial system, and will increase the central bank balance sheet risk.

How substantial is the risk of bank runs? This is very difficult to judge, since practical experience with CBDCs is limited thus far. The issue of bank runs is discussed in the literature on demand for money,[48] and the working group would emphasise the following:

- While the existence of bank runs is well-documented, their actual occurrence has been materially restricted by deposit guarantee schemes, particularly in the past 10 years and in countries where state finances give credibility to the deposit guarantee scheme.
- During the financial crisis, there was a reallocation of deposits between banks in Norway, motivated by keeping deposits below the deposit guarantee cap. This indicates that the Norwegian deposit guarantee scheme is credible.
- There were no significant movements in bank deposits during the corona crisis in the spring of 2020.

The working group's primary assumption is therefore that the risk of a run on banks' secured deposits is small. Nevertheless, it is likely that the risk of bank runs will increase if a CBDC is introduced. Transferring funds to and storing them in CBDC may become far easier and more secure than in the case of cash. Even though the Norwegian deposit guarantee scheme is credible, deposits in excess of the guaranteed amount may be converted into CBDC, for example because redistributions previously made to secured deposits now flow into CBDC. Moreover, CBDC may become more attractive than guaranteed deposits, particularly if a large number of banks experience difficulties at the same time and the deposit guarantee fund is – or is at risk of becoming – depleted. This increased risk of a bank run may indicate that banks should maintain higher liquidity buffers than at present.

In the event of a bank run, the central bank will have to give loans to banks to prevent banks becoming illiquid. If the central bank charges a normal premium on such loans, the direct effect on bank funding will be limited. Since banks cannot pledge new collateral during a bank run, the central bank will have to accept expanded collateral. This suggests that a higher-than-normal margin should be charged on these loans. Banks' access to market funding will also be affected in this situation, and it is not unlikely that banks will face prohibitive prices for market funding. If the central bank does not intervene in a bank run, banks will fail and will either have to be resolved or placed under public administration.

[48] See Müller (2020).

8.2. Effect of different frictions on bank funding

To limit bank runs, incentives can be introduced to encourage the public to limit their CBDC holdings. These are referred to as frictions in the context of Norges Bank's CBDC project.

- The CBDC interest rate can be set significantly lower than the rate on deposits. This is most important if the introduced CBDC functions well as a store of value. This possibility was emphasised in Phase 1 of the CBDC project.
- As in the case of banks' deposits with Norges Bank, two different interest rates can be paid on CBDC units, with a higher rate (for example the policy rate) being paid on a given quota and a lower rate being paid on other deposits (corresponding to the current reserve rate paid to banks). This could help keep CBDC demand in the desired range, and help ensure that depositors have less incentive to run from deposits to the CBDC. This possibility was discussed in Phase 1 of the CBDC project (see annex to Norges Bank (2018)), and has also been proposed by Bindseil (2020).
- Permanent or situational restrictions can be placed on the volume of CBDC an individual or institution may hold or convert in a specified period of time. Generally speaking, such restrictions may entail breach of value parity, i.e. bring about a divergence between the value of one deposited krone and one CBDC krone.
- A CBDC can be given characteristics that limit its attractiveness as a store of value (in addition to a low interest rate).[49]

The central bank also has access to more traditional instruments for countering a bank run:

- The central bank can block the conversion of deposits into CBDC units, corresponding to a so-called "bank holiday". The disadvantage of this measure is that it may undermine longer-term confidence in the CBDC, and may increase incentives to run from deposits to the CBDC in the event of market turbulence, if the market anticipates such a shutdown. Correspondingly, restrictions on conversion volume during a set period of time may increase the incentive to convert as much as possible in each permitted period, if the limit is expected to be binding. A situation-contingent restriction on the volume of CBDC an individual or institution may hold can provide similar incentives.
- If the central bank provides banks with necessary reserves to counter the outflow of deposits, as assumed above, the central bank will be acting a lender of last resort (LLR). If depositors expect this, this expectation alone may already reduce depositors' incentives to run to the CBDC. The disadvantage is that if depositors do run, the central bank's lending to banks will increase and the associated problems will arise. In a stylised calculation, Juks (2020) has found that if a central bank applies a haircut of 30% on bank asset, bank liquidity can still be maintained even if 75% of all bank funding is withdrawn. Before any CBDC is introduced, further assessment is needed of what collateral

[49] A proposal made in Phase 2 is that the encryption key to a CBDC holding can be lost and that this will entail loss of the entire holding. This could stop the public from wanting to maintain large CBDC holdings.

the central bank could take for loans during a bank run and what haircuts should be applied.

Based on the expectation that blocking conversion between the CBDC and deposits could incentivise a bank run while LRR could reduce such incentives, the central bank may benefit more from communicating clearly its intention to act as an LLR in the event of a bank run, rather than keeping the possibility of a bank holiday or temporary quantitative restrictions on the CBDC open.

9. Effect on banks – assessments and recommendations

The introduction of a CBDC has several potential consequences for banks:

- If CBDC replaces deposits and functions well as legal tender, demand for bank deposits may fall and become more interest-sensitive.
- Deposit rates are likely to increase, but the increase will be small if the CBDC interest rate is set significantly lower than the policy rate, and if competition between banks for deposits was already high prior to introduction of a CBDC.
- If the outflow of deposits is limited and does not entail changes in bank funding structures beyond replacement of bank deposits with central bank funding, the effect on bank funding costs will be largely determined by the central bank, and is likely to be small.
- Any significant changes in bank funding structures (other than increased central bank funding) may increase bank funding costs, which banks will want to avoid. For example, banks will seek to avoid increased market funding if this makes all market funding more expensive. Moreover, the possibility of obtaining funding abroad may limit, at least to some degree, the increase in costs if banks conclude that they want to increase long-term market funding.
- Bank lending rates are unlikely to change significantly, reflecting that funding costs may see a limited increase. The potential for change is also limited by the extensive use of market funding by banks, and by competition in the Norwegian lending market.
- The risk of a bank run is probably small regarding guaranteed deposits, but will rise if a CBDC is introduced.

Based on the above, the introduction of a CBDC can probably be implemented without materially affecting access to credit in the Norwegian economy, and the central bank will have a strong influence on this effect through its provision of reserves in connection with introduction of the CBDC and its setting of the CBDC interest rate. This conclusion is supported by a number of published qualitative studies. However, there may be considerable effects on the central bank balance sheet and central bank risk, particularly if a bank run occurs.

PART III: Recommendations

10. Further CBDC-related work by Norges Bank

Norges Bank's CBDC project has progressed alongside rapid international developments. The attitude towards CBDCs among central banks has generally become more positive; see Auer, Cornelli and Frost (2020).[50] Many central banks have issued reports on the purpose, consequences and design of CBDCs. Several central banks are currently running pilot projects and other technical testing, and new arenas have emerged for cooperation between central banks.

In addition, the context of CBDCs has continued to develop. New private alternatives for the administration of digital monetary are under development, and technology of potential CBDC relevance has developed quickly. Cash usage in Norway has fallen further. The proportion of cash payments is now at 3% to 4% – probably the lowest figure globally.

When Norges Bank launched its CBDC project, the primary motivation was the central bank's desire to facilitate a secure and efficient payment system without negatively impacting the other objectives laid down in the Central Bank Act. The working group's own work and international efforts indicate that CBDCs can potentially also be used as an instrument for promoting other objectives in the Central Bank Act. It would be beneficial to have an increased focus on these aspects of CBDCs in the next phase of the project.

Overall, therefore, the working group has concluded that the motivation for examining CBDCs further has been strengthened.

Phase 3 of the project has generated greater knowledge about the characteristics of a CBDC, the consequences associated with introducing a CBDC and potential CBDC designs. Phase 3 has thus produced the desired results. Nevertheless – as expected – the working group sees a need for deeper insight into both how technical solutions can deliver the characteristics and the motivation for and consequences of introducing a CBDC (including the consequences of design choices). These insights are vital for establishing a sufficiently strong basis for deciding whether Norges Bank should introduce a CBDC.

As stated in Part I, technical testing can shed further light on many aspects of relevant technological solutions. This includes not only insight into technical issues, but also information on economic, financial and legal questions raised by the different solutions. This knowledge is needed so that the working group can make more precise recommendations on the choice of CBDC solution and on whether a CBDC should be introduced.

[50] For more information on the reasons why central banks are studying CBDCs, see e.g. Armelius et. al. (2020), Panetta (2020) and Kiff et. al. (2020).

Testing can be conducted in phases, with experimental testing appearing to be the most appropriate for the first phase. The working group is therefore proposing that experimental testing be carried out for a period of up to two years. The two-year duration reflects a trade-off between the shortest amount of time needed to engage external experts, conduct testing and write a report, and the desire not to wait too long before being able to make a recommendation regarding Norges Bank's potential further work on introducing a CBDC. Experimental testing will generate information and provide a basis for deciding whether to conduct further testing and, potentially, whether to implement a full-scale solution.

During experimental testing, Norges Bank will be able to draw on development work done by, and dialogue with, other central banks. However, relying on work done by others will be insufficient. As stated in Part I, there are certain factors the working group wants to explore further through testing, and it is not certain that the work of other central banks will meet this need. Moreover, testing may reveal economic, financial and legal issues that are particular to Norway. Table 3 summarises the characteristics alongside the modifications recommended in this report,[51] as well as testing needs.

Table 3 Need for testing of characteristics

Characteristic	**Testing need**
Claim on Norges Bank	Test how a CBDC is an ongoing claim on Norges Bank and how it ceases to be so in the event of destruction/withdrawal.
Parity value with cash og bank deposits	Test technical solutions that promote equilibrium of supply and demand.
Customer orientation	Test how a CBDC can be integrated into different user interfaces while still ensuring portability between different interfaces.
Adequate frictions with bank money	Test how different frictions can be implemented in technical solutions.
Controlled by Norges Bank	Test how Norges Bank can maintain control using DLT and third-party solutions, including the limitation of Norges Bank's liability and reputational risk.
Capable of functioning as legal tender	Test whether technical solutions have characteristics that allow a CBDC to function as legal tender.

[51] As stated in Part I, the working group is recommending that the distinction between necessary and desirable characteristics be eliminated, that the wish to include offline payment functionality should form part of the technical autonomy requirement and that the characteristic "provision of the desired degree of data protection (beyond the requirements imposed by EEA law)" should be reformulated as "flexibility to accommodate different data protection solutions".

Compliant with obligations under EEA law	Test data protection characteristics and fulfilment of KYC requirements, etc.
Payments are immediate and final	Test whether different solutions include technical functionality for ensuring irreversibility and complicating manipulation of technical solutions.
Compliant with sound IT architecture principles	Test security under different conditions, scalability and accessibility for persons with particular needs.
Satisfy requirements relating to technical independence and offline payment functionality	Test different dependencies in core infrastructure. Testing of portability at user level to prevent dependence on concrete user interfaces. Test how a basic interface delivered/financed by Norges Bank could look. Test different technologies for offline payments, particularly solutions requiring subsequent consolidation with a register.
Customer communications and due diligence undertaken by third parties	Test how different technical solutions can allow customer due diligence to be performed by third parties (while enabling Norges Bank to retain control of the system).
Flexibility to accommodate different data protection solutions	Test how different solutions can facilitate differing levels of payment anonymity subject to regulatory requirements.
Platform for third-party providers	Test how different technologies facilitate innovation by third parties while still preserving control.
Safeguard monetary policy efficacy	Test how interest rates can be implemented in different solutions.
Information relevant to Norges Bank's macroeconomic monitoring	Test how different items of information can be aggregated and visualised in different solutions.
DLT compatible	Test how technical solutions can be made interoperable.
Attractive niche solution	Test how a CBDC can be integrated with other public requirements and registers.

Public reports and presentations by other central banks rarely cover technical details in depth. Bilateral communication is required to gather such insights. The working group considers that other central banks will be more likely to prioritise such communication if Norges Bank conducts its own testing and generates experiences and findings which it can contribute to dialogues.

Further, there is a substantial "learning by doing" aspect to developing knowledge about technical solutions. The experiences shared by other central banks suggest that a considerable amount of knowledge about solutions will remain inaccessible without practical testing. See also the detailed discussion of testing in chapter 11. The objective of experimental technical testing is to generate sufficient knowledge to enable the working group to recommend a strategy for testing and potential implementation of a specific solution.

As stated in Part I, the working group is not recommending that a distinction be made between account-based and token-based e-money solutions, but rather that different solutions spanning the two main solutions be tested.

In addition to technical testing, Phase 4 should produce further knowledge about the motivations for – and consequences of – issuing a CBDC, including the consequences associated with different CBDC designs. Relevant topics include the supply of reserves and liquidity management using a CBDC, as well as consequences for Norges Bank's balance sheet and monetary policy in general. Moreover, consideration should be given to what statutory amendments will be needed before a CBDC can be introduced. The working group is also recommending a detailed assessment of how a CBDC may affect the risk of money and payment functions migrating to new arenas and infrastructures. More generally, the introduction of a CBDC should be weighed up against the potential benefits of regulating privately owned payment systems utilising privately issued money.

At the end of Phase 4, decision-makers should have a basis for deciding whether Norges Bank should test a preferred solution with the aim of being able to introduce a CBDC.

11. Details of experimental testing

11.1. Purpose of technical testing and test methods

Technical testing serves a number of purposes, and has several functions. The primary purpose is to investigate whether and how one or more technical solutions fulfil the system specification, i.e. whether they deliver the characteristics. Technical testing can also reveal unintended consequences and security risks, and show whether solutions can perform functions beyond delivery of the identified characteristics. Testing can also help identify economic, financial and legal issues requiring further study.

In Phase 3 of the project, the working group has examined whether technical solutions can deliver the characteristics at an analytical/abstract level. Technical testing can be used to validate these assessments in the framework of concrete technical implementation, and can produce further insights into how the characteristics can be delivered, both individually and collectively.

The objectives set for technical testing are highly significant with respect to selected test methods and how testing is organised. The working group is recommending experimental testing as discussed above. In experimental testing, it can be expedient to test a variety of technologies, and to test the least well-known solutions to reduce uncertainty. This is very different from so-called alpha and beta testing of solutions prior to launch, which covers all aspects of a chosen solution.

Technical testing can take a variety of forms. Some types of technical testing are better suited to certain characteristics, and can shed light on different aspects of the characteristics. Moreover, certain methods may be better suited to different modules, for example core infrastructure and user solutions. The different methods are both complementary and alternatives, and should therefore be combined. The range of technical testing options includes:

- Proof-of-Concept
- Prototype
- Pilot
- Sandbox/test network
- Simulation/modelling

Proof-of-Concept **(PoC)** involves testing whether different solutions can fulfil specifications/deliver characteristics in conceptual terms. This can be done at an abstract level, like the validation process which has already been completed, and can be supplemented by technical testing. Technical testing will provide further insights into whether technical solutions can deliver the characteristics.

A ***prototype*** is a delimited technical solution that can be used to test individual characteristics or individual system modules. Unlike PoC testing, which generates information on whether a technical solution can deliver a characteristic, a prototype provides additional information on how the characteristic is delivered. For example, core infrastructure prototypes could be developed to test security and capacity-related characteristics without simultaneously testing specific user solutions based on such infrastructure. Likewise, a delimited solution could be developed for the user interface without underlying infrastructure in order to test the user-friendliness of these solutions. This approach can provide information, but will not necessarily test whether the characteristics will be delivered in a full-scale solution that includes interaction between modules. It is therefore important to identify the characteristics and modules whose interaction has to be tested.

A ***pilot*** typically involves the development of a more complete solution in which all, or most, characteristics can be tested at the same time in relation to the same solution. Sveriges Riksbank (the Swedish central bank) and the People's Bank of China are among those currently developing CBDC pilots.

Sandboxes/test networks are often used to involve a diverse range of stakeholders in the testing of innovative new solutions.

In the context of technical testing of a CBDC, this will typically involve the central bank defining a number of fundamental conditions for participation. These may include relevant test cases that provide insight into solutions capable of delivering necessary CBDC characteristics, or conditions related to the technology to be used, for example that it must be based on open source code. Unlike a regulatory sandbox, such a sandbox will be a purely technical framework that is only run in a test environment. Accordingly, there will be no testing of a "real CBDC". To incentivise participation, funding can be provided in accordance with pre-defined criteria, and "hackathons", competitions or similar events can be arranged, potentially with prize money on offer.

It will be difficult to test certain characteristics using a prototype/pilot or sandbox because these are linked to events that are difficult to recreate in a test environment, for example how frictions will function in the event of financial instability or in other stress situations. ***Modelling and simulation*** can supplement other test methods in such scenarios. Mathematical representations of technical solutions can be used to analyse factors such as security. Agent-based simulation involves linking behavioural models with technical solutions. Virtual reality and augmented reality also offer some potential benefits. For example, "games" can be created in which users can test solutions in a virtual environment. Modelling and simulation will presumably function as a supplement to other technical testing methods.

Actual testing will require the preparation of tender documentation, funding and follow-up of external contributors, the arranging of competitions and, more generally, extensive contact with external stakeholders. It may be appropriate to engage an external project manager or adviser to assist with this work, including administration of the processes involved. The appointment of any project manager/adviser must be implemented as a public procurement.

11.2. Examples of potential test cases

Table 3 above provides an overview of different test needs related to each characteristic. Some examples of potential test cases and methods are provided below. These have been included for illustrative purposes only, and will not necessarily be incorporated into experimental testing.

Test of offline solutions
A technical solution is developed that allows offline, mobile-to-mobile transmission of payment information and fulfils good IT infrastructure requirements – including register consolidation once online functionality is restored. Prototypes may be appropriate for this type of test.

Test of portable integration with different user interfaces
This test will examine whether a token-based solution can be integrated with, for example, Vipps and other existing user interfaces, and how. This is conditional on willingness among user-interface operators to participate in testing. Portability/interoperability are important in such a test. It must be easy to replace a user interface if a user wishes to do so. Sandbox standards or requirements are often appropriate for this type of test.

Test of interest in a register-based token solution
How can users be credited with interest in a token-based register solution in different scenarios for linking tokens with identity? A combination of a prototype with modelling and simulation may be appropriate for this type of test.

Test of interoperability with DLT registers
How can a token-based register solution be designed to be data-compatible with DLT platforms and other registers, such as IoT payment solutions? How can Norges Bank retain control in such a solution? A combination of a prototype with modelling and simulation may be appropriate for this type of test.

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