Privacy and Transparency in CBDCs: A Regulation-by-Design AML/CFT Scheme

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***Abstract*—Central banks and governments all over the world are increasingly exploring digital versions of fiat money, known as retail Central Bank Digital Currencies (CBDCs). Most initiatives rely on Distributed Ledger Technologies and are presented as alternatives to physical cash. Consequently, anonymity-related regulatory questions have naturally started to arise in terms of Anti-Money Laundering and Counter-Terrorist Financing compliance. Against this backdrop, this paper provides a techno-legal taxonomy of approaches to balance privacy and transparency in CBDCs without thwarting accountability, but it also underlines cross-sectoral impacts. The contribution heeds regulation-by-design as its core methodological foundation, with Privacy-Enhancing Technologies as the relevant use case. Thus, it highlights that not only technology aids legal purposes, but also that some regulatory requirements ought to be designed into technology for one to reach agreed-upon results and/or standards.**

***Index Terms*—central bank digital currency, cryptocurrency, regulation, policy, anonymity, criminal activities, risk management, law and technology, anti-money laundering, compliance**

I. Introduction

Leveraging distributed ledger technologies (DLTs) into decentralized, tamper-resistant and trustless alternatives to traditional financial instruments has fascinated private and public sectors alike since the advent of Bitcoin in 2008 [1]. Over the last decade, the cryptocurrency-driven blockchain "hype" has sponsored collective participation of citizens and businesses in a new digital global economy as embodied by the concepts of "Internet of Money" (IoM) [2] and "Internet of Value(s)" (IoVs) [3]. Today, novel trends erupt in global cross-border "stablecoin" projects in the wake of Facebook's Libra/Diem initiative [4]. These efforts were preceded by exploratory trends of government-backed e-fiat currencies or *Central Bank Digital Currencies (CBDCs)*. This paper addresses CBDCs as institutional frameworks of programmable money investigated by many central banks [5], [6], [7], [8], [9], [10], [11], [12].

Evidently, this tech-steered socio-economic transformation has generated significant new legal and regulatory concerns. Notably, the perceived level of anonymity, ubiquity and smart contracts-driven opportunities presented by DLT-based ecosystems have fuelled fears of exploitation for borderless illicit transactions. This extends into the Anti-Money Laundering and Combating the Financing of Terrorism (AML/CFT) domain which is internationally overseen by the Financial Action Task Force (FATF).[1] AML-wise, CBDC issues differ from those in IoM/IoV, as they have different stakeholders. Nonetheless, with CBDCs usually advertised as "physical cash" substitutes, any desire for a certain share of anonymity needs to be balanced against the integrity of the underlying financial system.

[1]For brevity, in the remaining paper AML refers to both AML/CFT.

This paper attempts an introductory taxonomy of approaches in balancing privacy and transparency for CBDCs. It does this by underlining cross-sectoral impacts. Its contributions explore techo-legal questions of CBDC designs for AML compliance. *Regulation-by-design* is its core concept – once trade-offs are identified, they ought to be engineered into actual design plans. Although findings are set within the context of CBDCs, discoveries made here also offer insights to private "alt-coin" ecosystems. Additionally, this work heeds:

- The inherent cross-border dimension of CBDCs: interoperability between sovereign frameworks should be ensured, as well as transnational regulatory validity [13],
- A context-neutral approach immune to a jurisdiction: arguments are placed at a principle-level, and
- A flexible methodology: we focus on general frameworks, to be subsequently tailored to specific requirements.

The remainder of this paper goes as follows. Section II offers background information on the underpinning concepts and problem assumptions. Section III outlines the evolution of CBDCs. Section IV dives into AML and anonymity with Section V tackling trade-offs. Section VI examines regulation-by-design from a Privacy-Enhancing Technology (PET) standpoint. Section VII presents use-cases. Section VIII concludes the paper and pencils directions for future work.

II. Background

This subsection offers definitions and terminology [4], [5], [14], [15]. From a monetary viewpoint, let the following mean:

- *Central Bank Money (CeBM)* or *M0*: this can be physical money or cash (*i.e.*, banknotes/coins, general purpose money). It can also be reserve/settlement accounts (*i.e.*, e-CeBM's) to authorized institutions such as commercial banks and Payment Service Providers (PSPs).
- *Commercial Bank Money*: these are liabilities to the general public; that is, a claim against a commercial bank to pay CeBMs and thus an extension of the former.

Past literature classifies CBDCs as follows:

- *Wholesale*: a settlement mechanism between financial institutions for inter bank security transfers between participants by Real-Time Gross Settlement Systems (RTGSs) beyond the tier of physical-cash.
- *Retail*: offered to the public at large. This is also the most transformative subset of CBDCs construed as an evolution towards a more "democratic" public transmission channel to central bank monetary holdings/policies.

A. Core CBDC Architectures

Architecturally, a CBDC scheme can be either a *one-layered* system where the central bank directly manages all

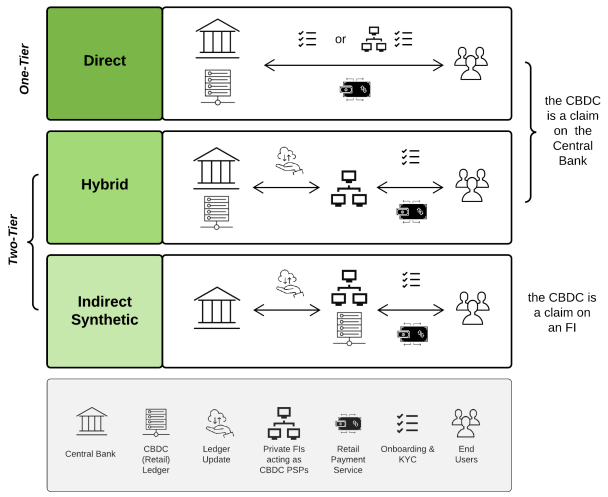

Figure 1: CBDC Architectures ([16], [20])

axles of its lifecycle (distribution, know-your-customer or KYC, settlement, etc.), or a *two-layered* one where non-governmental financial institutions (commercial banks, PSPs, NGOs, etc.) act as intermediaries for market placement, compliance, distribution or settlement. Accordingly, CBDC architectures have been labelled as *direct*, *hybrid*, *intermediated* or *indirect/synthetic* [16], and they may involve varied public and private stakeholders [9], [17].

Commonly proposed CBDC architectures are outlined in Figure 1. The *direct* structure is described as "one-tier" – only the central bank is involved (i.e., it initiates and maintains the relationship with end-users, which is not a traditional activity for central banks) and the CBDC is a direct claim of the general public. On the contrary, *hybrid* and *synthetic* CBDCs feature "two-tier" architectures. Similarly to traditional mechanisms, "two-tier" schemes require a cooperation between the government and private financial institutions (as they already hold reserve accounts with the central bank, and today they handle most AML/CFT tasks for the government) [18], [19].

Another classification is noteworthy to the needs of our contribution. On the one hand, a CBDC can be *account-based* where users open a current account, or "e-wallet", at a central bank or at a PSP – usually following some form of KYC. On the other hand, a CBDC can be *token-based* where the CBDC is a digital unit, such as a token stored in a physical device. This type of CBDC is a bearer instrument transferred with secure hardware/software units. Notably, one should be able to transfer CBDCs online but also offline. Just like cash, offline usage has the potential to serve minorities, international travellers and the unbanked [21].

B. Terminological Remarks

In the context of financial transactions, our contributions address the compound notions of anonymity, pseudonymity, privacy, transparency, and auditability. With no formal attempt to offer a comprehensive cross-sector techno-legal definition, and for the sake of conciseness, we set out the below [22]:

- *anonymity*: a subject is anonymous when it is not identifiable (*i.e.*, not distinguishable) within a set of subjects (its "anonymity set");
- *pseudonymity*: the use of pseudonyms as identifiers, where pseudonyms are identifiers other than real names;
- *privacy*: broadly intended as protection from unintended disclosure. Although the concept is manifold, details will follow with regard to DLT-based monetary instruments;
- *transparency*: without necessarily implying publicity in terms of "public availability" of some information, transparency enables (selected) third parties to have access to it. Thus, it relates to openness and accountability, as defined below. In a DLT context, it refers to the possibility to access data stored on the ledger. From an AML standpoint it relates to its availability and retrievability of specific information when legally required; and
- *auditability*: as presumed by [23], "*the understanding of transaction information by the authorised third parties, or the degree to which a given environment allows an authorised entity to audit confidential transaction information by viewing and interpreting the information*".

AML	Anti-Money Laundering
BIS	Bank for International Settlements
BoC	Bank of Canada
CBDC	Central Bank Digital Currency
CeBM	Central Bank Money
CDD	Customer Due Diligence
CFT	Counter-Terrorist Financing
DCEP	Digital Currency Electronic Payment
DLT	Distributed Ledger Technology
ECB	European Central Bank
FATF	Financial Action Task Force
IoM	Internet of Money
IoV	Internet of Value
KYC	Know-Your-Customer
MAS	Monetary Authority of Singapore
NGO	Non-Governmental Organization
P2P	Peer-to-Peer
PBoC	People's Bank of China
PET	Privacy Enhancing Technology
PoC	Proof-of-Concept
PSP	Payment Service Provider
RBA	Risk-Based Approach
RTGS	Real-Time Gross Settlement System
STR	Suspicious Transaction Reporting

Table I: List of Acronyms

For convenience, Table I lists the acronyms used in this paper.

C. Underlying Assumptions

The paper herein makes the following assumptions:

1) CBDCs are *programmable*, which means smart contracts are leveraged to embed them with specific features and capabilities. Although this work chiefly addresses how this state of affairs generates new regulatory opportunities, it is worth bearing in mind that novel sophisticated criminal pathways are opened up by this as well [24].
2) We focus on *retail-CBDCs*. In contrast, their wholesale counterparts are exclusively in the hands of financial institutions. They may spur reflections on cross-border interoperability, but generate less AML regulatory hurdles.

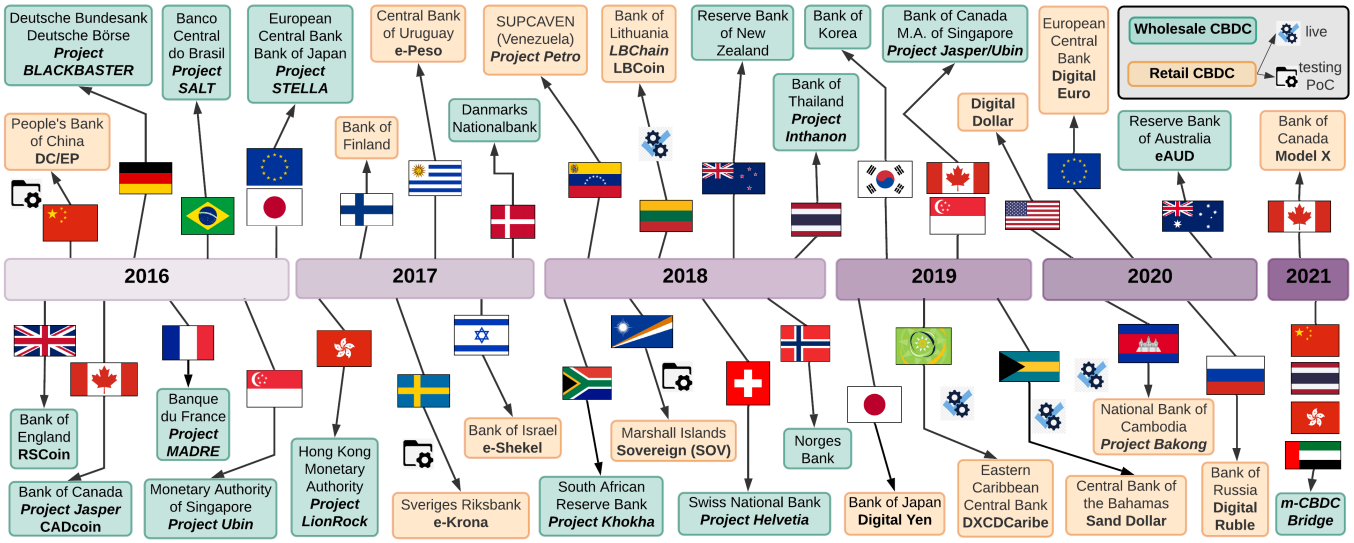

Figure 2: Global roadmap on major *wholesale* and *retail* CBDC projects

Henceforth, in the remaining paper the term "CBDC" means strictly "retail CBDC".

3) The principle of "tech-neutrality" is at the heart of regulation of new technologies. Moreover, retail CBDCs do not necessarily deploy DLTs. Nonetheless, as most initiatives are built on DLTs, this also pivots our work.
4) CBDCs pose a significant number of multi-faceted legal challenges. Here, we limit analysis to the AML sphere.
5) This work does not address cross-border CBDC (or, "m-CBDC") interoperability questions.

III. History and Current Efforts in CBDCs

The growing interest of central banks in programmable M0 money has had many drivers, and opinions on their origin vary [4], [7], [8]. In summary, two primary factors seem to have sparked this interest. Firstly, the use of traditional cash by the general public has been decreasing, in favor of digital claim-based alternatives such as card transactions, wire transfers and other means of electronic payment. As such, in some jurisdictions (like Sweden or Canada) the use of cash as a means of exchange has starkly declined in the past decade. At the same time, private altcoins and other tokenization initiatives are thriving. Today there are more than 5,000 cryptocurrencies in circulation. Further, attempts to limit their price volatility led to global stablecoins and, more recently, "mega-stablecoins" such as Facebook's Libra/Diem [25].

Against the backdrop of this FinTech-driven digitization and associated challenges to the traditional bank-based payment and monetary policy transmission mechanisms [15], central banks started heeding the idea of protecting their raison d'être and financial stability by tokenizing fiat currencies.

A. CBDC essence and goals

The author in [26] provides a tech-oriented definition of retail CBDCs as: *"A credit-based currency in terms of value, a crypto-currency from a technical perspective, an algorithm-based currency in terms of implementation, and a smart currency in application scenarios"*. More broadly, [27] highlights that *"CBDC is not a well-defined term. It is used to refer to a number of concepts. However, it is envisioned by most to be a new form of central bank money. That is, a central bank liability, denominated in an existing unit of account, which serves both as a medium of exchange and a store of value"*. Hence, *"A CBDC is a digital form of central bank money that is different from balances in traditional reserve or settlement accounts"* [6]. Notably, the composite nature of CBDCs set in the previous Section emerges in these definitions as well.

Empirically, CBDC plans offer a diverse set of designs. Most literature agrees that a CBDC is a digital representation of a fiat currency, hence a digital liability of the central bank. Frequently, CBDCs are devised as an "enhanced" version of cash in terms of universal accessibility and transaction capabilities, thus placed in between physical cash (CeBM) and commercial bank money. Pursued goals vary according to the specific needs of the jurisdiction, generally advanced economies rank their goals differently to those by emerging ones. Overall, the underlying idea behind all initiatives is to mimic M0 cash while overcoming its existing inherent need for physical handling and portability limits. In parallel, CBDC plans also envision their potential to foster payment efficiency (including new monetary policy transmission channels), financial inclusion, safety, privacy and compliance [5], [15], [28].

B. Overview of Proof-of-Concepts

CBDC Proof-of-Concepts (PoC) have gained prominence over the last years and extensive commentaries were published by diverse stakeholders [6], [7], [8], [9], [10], [11], [12], [29]. The work of [28] classified central bank projects as early adopters, followers and new entrants. In this subsection we give a historical summary, as also illustrated in Figure 2.

In **2014-16**, research pioneers started exploring CBDCs, albeit by addressing wholesale interbanking use-cases. Notable references are led by the Bank of England (*RSCoin*) [30] and the People's Bank of China (PBoC), the latter coined as *Digital Yuan* or *Digital Currency Electronic Payment (DCEP)*. Around the same time, the Bank of Canada (BoC) piloted the four-phased *Project Jasper*, one of the most comprehensive efforts up to date. In Europe, the Deutsche Bundesbank and the

Banque de France put forward projects *BLOCKBASTER* and *MADRE*, respectively. After the Banco Central do Brasil set up *Project SALT* and the U.S. Federal Reserve started scouting the CBDC realm, two initiatives climaxed the first wholesale CBDC era in late 2016: the Monetary Authority of Singapore (MAS) launched *Project UBIN* and *Project Stella* was piloted by the European Central Bank (ECB) and the Bank of Japan.

Between **2017** and **2018** retail CBDC projects started to evolve. While *Project LionRock* of the Monetary Authority of Hong Kong still addressed interbank settlements, other central banks started to explore general purpose CBDCs and their relation to cash, most notably the *e-Krona Project* by the Sveriges Riksbank in Sweden. Other research/pilot initiatives also followed in this period, shown in Figure 2, around diverse –sometimes– CBDC concepts [9].

In early **2019**, around 70% of central banks responding to a survey of the Bank for International Settlements (BIS) declared to be engaging in some PoC CBDC-related activity [15]. Although only 30% voiced an intention to issue such instruments within the medium term, that year was arguably a breakthrough one in which research in CBDCs reached a new level of maturity, but also this of news headlines, in part due to the spark by Facebook's announcement of the Libra coin in late June 2019. Following the reports of the Bank of Korea and the Bank of Japan, the first cross-border interbank settlement mechanism between two different DLT-based currency platforms was concluded by the BoC and the MAS in the fourth joint phase of project *Jasper/Ubin*.

In 2019, the ECB started to analyze the implications of cryptoassets on monetary policy [31] and in October **2020** a report [32] was issued on principles and configurations for a candidate retail *Digital Euro*. At the beginning of 2020, central banks working on CBDCs had risen to 80% with nearly half of them at the PoC phase, and a lower number of pilot projects [33]. In May the *Digital Dollar Project* released a whitepaper and in June congressional hearings took place in the U.S. with regard to CBDCs. In July the Bank of Lithuania issued the first state-backed digital collector coin, LBCOIN, which can be transferred Peer-to-Peer (P2P). LBCOIN is no legal tender (the Bank of Lithuania belongs to the Eurosystem) and can only be exchanged into a physical collector coin.

Later, October 2020 saw the launch of the first CBDC by the Central Bank of the Bahamas through the *Sand Dollar* platform. The *Sand Dollar* is pegged to the Bahamian dollar, which in turn is pegged to the U.S. dollar on a 1:1 basis under currency board-like rules. This move also validates claims that smaller countries may want expedite implementation of their respective CBDCs due to risk of competition by CBDCs from larger foreign economies. That is, if foreign CBDCs are easier (or more "stable") to use, they may intermediate or present a risk of displacement to "local money" with whatever dramatic impact this may have on said domestic monetary/fiscal policies for those smaller economies. Meanwhile, Brazil's central bank launched the Pix instant-payment platform, and the Bank of Russia unveiled interest in a *Digital Ruble*.

Finally, the early months of **2021** testify not only to the wide interest in CBDCs, but also to their growing maturity. Notably, 86% of central banks surveyed by BIS are exploring CBDCs, where 60% of them at an advanced experimental or PoC stage and 14% at a pilot phase [34]. In January the European Commission and the ECB announced a cooperation on a possible *Digital Euro* upon the conclusion of the relevant public consultation. A decision whether to launch a project is expected by April. In February, the *Digital Dollar* debate rekindled significantly in the U.S. and the Swedish *e-Krona Pilot Project* was granted a one-year extension [35]. In China, the testing scope of the *Digital Yuan* was widened. A beta version is expected to launch in the second half of 2021. Meanwhile, the PBoC joined a cross-border payment project with the central banks of Thailand, United Arab Emirates and Hong Kong to develop a Multiple CBDC Bridge (*m-CBDC Bridge*) [36], [37]. Concurrently, in February the BoC unveiled three design proposals under their Model X challenge for a CBDC denominated in Canadian dollars (or, a *Digital Loonie*) by three universities [38]. Later, in May 2021 the Bank of Korea issued an open competition for a PoC of a CBDC system, addressed to the private sector.

IV. The Quest for AML/CFT Compliance

The term "AML/CFT" describes a set of laws, regulations and procedures aiming to protect the integrity of the financial system by preventing criminals from enjoying illicit profits. The goal is hindering concealment of the origin of ill-gotten proceeds through preventive measures and sanctions. From 1989 onward, international efforts have been coordinated by the Financial Action Task Force (FATF). The FATF is an intergovernmental, policy making, monitoring and enforcement organization that sets standards and provides comprehensive guidance, *e.g.*, through its Recommendations. In 2001 CFT was further added to FATF's mission.

Although most countries and supranational organizations provide their specific frameworks, the general structure of AML measures is fairly harmonized. In most cases, a set of regulated entities is required to give "active cooperation" to the authorities in light of their perceived oversight capacity. These obliged/reporting entities range from commercial banks and financial institutions, to professionals (such as lawyers and notaries), to casinos and art galleries. Virtual Asset Service Providers, such as a subset of providers of exchange and wallet services, were later added to the list. Illustratively, cryptocurrencies are at the core of the EU 5$^{\text{th}}$ AML Directive [39].

Key AML duties are outlined in Figure 3. They encompass licensing regimes, Customer-Due-Diligence (CDD) obligations such as Know-Your-Customer (KYC) – *i.e.*, identification and verification of customers' identities and recurring checks of related personal and business information according to predefined criteria – and ongoing monitoring (*e.g.*, transaction scrutiny), as well as record retention and Suspicious Transaction Reporting (STR). Most of these obligations are informed by the Risk-Based Approach (RBA), *i.e.*, preliminary risk assessments tune consistent controls. As enshrined by Article 33 of the EU AML Directive, the ultimate goal is for authorities to be informed when a regulated entity *"... knows, suspects or has reasonable grounds to suspect that funds, regardless of the amount involved, are the proceeds of criminal activity or are related to terrorist financing"* [39].

A. Illicit Transactions in the IoM

Since birth, the risk of cryptocurrencies being misused for illicit purposes emerged as a common thread [40]. Due to their purported anonymity/untraceability, they have been linked to transactions on the dark web, online gambling, money laundering, and to the financing of criminal activities and terrorism.

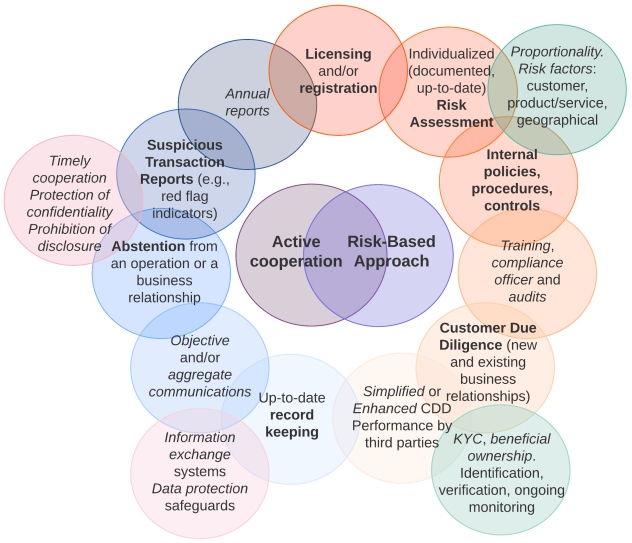

Figure 3: Overview of the major AML/CFT duties imposed on regulated entities

Popular controversies concerning the Silk Road case, followed by the shutdown of Darknet markets (*e.g.*, Alphabay, Valhalla, Wall Street Market), added to this skepticism and fear.

Even if the technology underpinning Bitcoin was acknowledged to shape a pseudonymous means of payment, a significant set of altcoins have evolved toward higher levels of anonymity and cryptographic complexities. Accordingly, the FATF acknowledged the growing money laundering concerns in terms of virtual-to-virtual "layering" mechanisms [41]. Later, "privacy coins" (such as Monero and ZCash) and transaction obfuscation mechanisms (such as mixers/tumblers) were complemented by P2P decentralized exchanges, unhosted wallets, and cross-chain atomic swaps or liquidity pools. In this context, the FATF identified anonymity as a "red flag indicator" of IoM-related suspicious activities [42].

Although the anonymity level is not sufficient to suggest a transaction is illicit, the FATF urged to be careful with some vulnerabilities inherent to specific Privacy-Enhancing Technologies (PETs) and/or enhanced decentralization. Likewise, Europol highlighted how privacy-enhanced wallets are currently among such top threats [43], while experts underlined the extent to which opportunities steered by CBDC-related programmability may be seized by criminals in innovative ways, *e.g.* through intricate money laundering strategies to evade AML checks [24]. In summary, regulators face major challenges and ubiquitous global-stablecoins worsen this fear.

B. CBDCs, Cash and Anonymity

Anonymity is inherent to the nature of physical cash: the level of privacy cash can reach is unparallelled and it is perhaps one of the purest examples of a fungible asset. Thus, the fight against financial crime has long faced the "anonymity barrier" against which identification and traceability have been heralded. If CBDCs are to replicate a similar situation, while at the same time overcoming material limitations, significant concerns may arise. Interestingly, however, cash being dangerous from an AML perspective is one of the reasons why e-money solutions, and the degree of control they can enable, were sponsored in the first place [5].

Nonetheless, one should not forget that anonymity is not a binary zero-sum property, but rather *ranges* within a spectrum. In [44] experts explored the difference between anonymous, identified and pseudonymous clients and also how this reflects on the underlying transactions with regard to AML rules. With the advent of "crypto" digital payments, we argue that the intrinsic complexity of this characterization has increased.

The issue of online anonymity is one of socio-technical nature [45], [46]. On the technical side, and within a DLT context, it is influenced by the available privacy tools (*e.g.*, PETs), by governance (*e.g.*, centralized vs. decentralized systems), and by the broader system architecture (*e.g.*, relationship with other on/off-chain layers). On the social side, it refers to (1) the actual possibility for identification/traceability and forensic techniques to "follow the (crypto) money" vs. (2) the backdrop of the public's skills to prevent this and its right in doing so.

As an example, pseudonymity implies to be neither anonymous nor identified. While the identity of pseudonymous users is unknown, that is, there are no direct identifiers, it may still be possible to link it when a warrant is issued with additional data to trigger identity associations. The same can be argued for records of transactions or the transactions themselves, as it is the case for commercial numbered bank accounts.

Further, as argued by [47], "*there is no "one" anonymity: anonymity is always, in fact, an anonymity with respect to a person or an institution. Consequently, it is susceptible to various configurations, which are therefore part of a general function of identification*". Relatedly, [47] suggests that the advent of non-State monetary assets has influenced the relationship between money and identification.

C. AML/CFT in CBDCs

In light of the foregoing, two remarks are necessary. If CBDCs are intended to mirror cash flexibility/usability, it might make little sense for procedures to resemble those of traditional bank accounts. Hence, it is not a surprise that token-based CBDCs could be argued as more conducive to financial inclusion than account-based ones. At the same time, if a CBDC design underestimates AML compliance, this does not also imply that users can operate beyond such principles. Instead, one would expect that compliance burdens would be shifted to the private entities offering CBDC product/services to the end-users — no different to what happens today with the "active cooperation" by commercial banks, etc. These observations lead to either a two-layered CBDC structure or one where the CBDC itself offers strong anonymity (thus making KYC impossible at this layer) but regulators require private service-providers converting CBDCs to other currencies to implement KYC on their customers. Of course, a central bank may also undertake the costly compliance effort herself and keep records anonymous if she is the sole processor of CBDCs' settlement.

It is important to note that although AML aspects of CBDCs have been extensively discussed, these instruments have so far not been treated as cryptocurrencies, which means AML for CBDCs is disjoint to that for cryptocurrencies. On the contrary, CBDCs are viewed as a form of fiat currency [8]. Rightfully though, several studies outline how different CBDC architectures may lead to various AML repercussions.

A key question relates to the responsibility for compliance duties, account management, and identity/transaction checks. To this end, two-tier structures may be favored by central banks, as those institutions do not traditionally interact with

public end-users other than a handful of private financial institutions. Hence, two-layer models allow to outsource compliance aspects to PSPs and commercial banks to be managed either directly or delegated. This intermediated access model is favored to leverage existing customer-facing services and avoid unnecessary duplication of KYC resources.

V. The Privacy vs. Transparency Trade-off

Monitoring and/or limiting the use of cash is widespread across the globe as a way to combat money laundering, terrorist financing and tax evasion; thresholds for customs declarations are provided and cash transactions above a certain volume trigger compliance duties, among other measures. Pursuant to Article 11 of EU's 5th AML Directive, for instance, Customer-Due-Diligence (CDD) obligations are triggered for financial institutions either upon the establishment of a business relationship or when the customer carries out transactions that amount to EUR 15,000 or more (in a single operation or many seemingly interlinked). As another example, in Canada and in the US obliged entities must report transactions of CAD/USD 10,000 or more within 24-hours [48], [49].

Further, although five years ago a EU initiative to introduce restrictions to cash payments had no success [50], the recent 2021 "AML Package" is proposing a EU-wide limit of 10,000 EUR to payments in cash, including bearer-negotiable instruments, for professional purposes [51], [52]. This is an example of the application of the RBA to the threat posed by cash-intensive businesses. Meanwhile, however, EU Member States would still be able, if not encouraged, to maintain lower thresholds and/or adopt stricter provisions.

Indeed, a significant selection of countries are already limiting its use between private individuals if no regulated intermediary is involved in the said transaction [53]. Illustratively, this happens in Italy, where cash transactions between people that exceed EUR 2,000 are prohibited (this limit will decrease to EUR 1,000 in 2022), but also in France (EUR 1,000), Portugal (EUR 1,000), Belgium (EUR 3,000), Slovakia (EUR 15,000), Spain (EUR 2,500), Bulgaria (EUR 5,000), and Greece (EUR 500). In those jurisdictions, transfers of higher values must be made through regulated intermediaries. Outside Europe, a similar tactic applies to some types of transactions in Jamaica, Mexico, Uruguay and India.

A. A balance in the making

In light of the foregoing, there is a clear inherent tension in CBDCs between privacy and transparency. This *trade-off* however, is not a zero-sum game [45]. All means of payment provide varying degrees of privacy/anonymity, ranging from methods requiring the bank to monitor transaction and identity data (*e.g.*, wire transfers), to anonymous transactions in cash. In turn, digital cash allows to exert control, but it may also possibly expose other sensitive information [5].

Toward this direction, CBDCs can be designed to embed various privacy trade-offs. Further, DLT is inherently conducive to balancing the individual right to privacy vs. traditional public interests in AML compliance. The extent to which users' privacy is safeguarded, in fact, depends on the preferred balance between individual rights and public interests. Starting from extreme examples, if we imagine a fully-transparent CBDC with real-world identity transactions fully visible to law enforcement, the applicable solution(s) may violate human rights law on privacy and data protection. If privacy is provided without any limitation, so that no information can be revealed about transactions, this may invite misuse for illicit purposes that cannot be averted. This option is not viable to CBDC-regulated stakeholders, as it may generate dangerous societal impacts. History also shows how a regulated access of financial authorities to information on monetary/data flows resonates positively with citizens and businesses.

Luckily, nuanced solutions are available, and most CBDCs position themselves in the *middle*, offering some privacy to consumers and some visibility to authorities.

B. Privacy in Digital Currencies

Many CBDC PoCs are built on DLTs to leverage their programmability. For this reason, novel questions emerge at the privacy level [54]. For blockchain-based cryptocurrencies, this issue was tackled by breaking it down to pieces of information embedded in the blockchain to assess whether they are private or public. In this regard, this particular problem appears to be threefold. On the one hand, there is:

- *user-identity privacy* or *identity privacy*: it relates to transaction participants and concerns the ability (or lack thereof) to link an activity to the relevant senders or recipients; this is the area where *privacy* relates to *anonymity*. Arguably, the difficulty (or dilemma) to equip CBDCs with cash-like anonymity is mostly at this level, as pseudonymity proves to be insufficient;

while, on the other hand, there are:

- *privacy of transaction data/information*: it concerns transaction details (*e.g.*, amount) and the ability (or lack thereof) to learn its nature. This concept is malleable and handled through cryptographic principles [45]; and,
- *privacy of the global ledger state*: different attributes can be private at various degrees to the DLT parties involved (*e.g.*, PSPs, NGOs, end-users, etc.).

Furthermore, identity and transaction privacy levels within DLT-based ecosystems are influenced by multilayered solutions and by also storing different data on-chain or off-chain.

C. Privacy and Data Protection in CBDCs

One of the main drivers behind the advent of cryptocurrencies has been the desire to exchange money privately – *i.e.*, with no need of third-party intermediaries. Meanwhile, privacy and data protection concerns and anti-surveillance sensitivities have recently gotten the foothold in the law and technology domain. At times, these values may seem at odds with the fundamentals of AML frameworks. This possible contrast inspired many scholars to investigate the interplay between blockchain, privacy and data protection [55], [56], [57], [58].

In CBDCs, diverging questions arise from the presence of different public-private dynamics among the various designs proposed so far. Indeed, some information exchange models may possibly be detrimental to the individual privacy of end-users. Accordingly, AML aspects are often discussed in CBDC projects because they are seemingly opposed to privacy and data protection safeguards. The more information *is* disclosed or *can be* disclosed to obliged entities and law enforcement authorities, the more intrusive this is for end-users. This threshold led [59] to argue that transaction privacy is severely hampered by user-level payment history datasets, where the

latter are increasingly generated by commercial payments platforms. Further, the risk is amplified by the significant potential of CBDCs to impact on the individuals by intruding into their private life [20], [60], [61].

VI. A Regulation-by-Design Approach

As mentioned earlier, CBDC designs entail different trade-offs. Likewise, there is a correlation between those trade-offs and AML provisions when it comes to anonymity. The interlink between technical and regulatory compliance builds on the assumption that the latter can be embedded into technology itself. This concept is at the root of *design-based* regulatory techniques as a means to foster socially and legally desirable outcomes. This is in contrast to traditional "command and control" approaches such as prohibitions and sanctions [62].

Illustratively, if the latter refers to setting crypto-related AML duties and penalties for violations, *regulation-by-design* strives to devise inherently compliant instruments. The notion that compliance aspects not only can, but they *ought to* be taken into account from the early stages of the system design or process is gaining momentum among law and technology experts today. Embedding legal principles and values into technology lies at the core of privacy-by-design spilling into *compliance by* or *through design* [22], [63], [64].

Notably, design-based regulation has evolved from Lessig's "code is law" [65], claiming cyberspace behavior is controlled by software code. Although caution is recommended from a legal standpoint, this notion prompted the new understanding of *embedded regulation* [66]. Namely, regulation can be approached proactively (rather than reactively) by addressing the code itself [67]. Meanwhile, a branch of legal informatics known as *computational law* focuses on bridging the gap between legal knowledge/reasoning, natural language and machine-readable formats (*e.g.*, through formal semantic representation) [68], [69], [70].

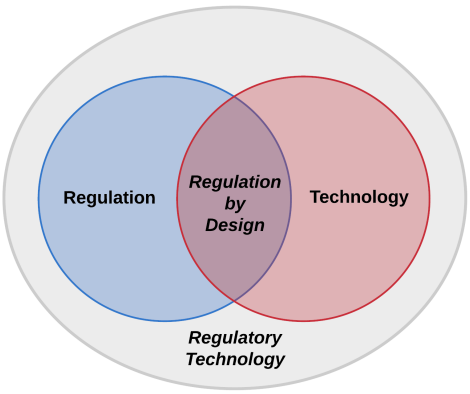

Figure 4: The interplay between regulation and technology in *RegTech* and *Regulation by Design* / *Embedded Regulation*

Outlined in Figure 4, as "design" and "code" are becoming regulatory instruments, this takes RegTech (*i.e.*, regulatory technology, generally leveraging new technologies to aid legal purposes) to the next level. This *forward-looking* approach requires preliminary engineering and standard setting as to said regulatory goals and available tools. Choices are seldom binary and need to be made early in the design cycle with interdisciplinary teams cooperating from the beginning.

A. Towards Accountability in Privacy Enhancing Technologies

Privacy-by-design was first formalized with regard to PETs [64], [71], so to exemplify how technology can be tailored to regulatory goals. This section outlines how privacy, just like anonymity, is twofold. On the one hand, PETs are implemented to safeguard individual privacy against intrusions. Likewise, it serves the purposes of data protection, where the application of the EU General Data Protection Regulation (GDPR) 2016/679 is now arguably ubiquitous. On the other hand, however, similar techniques have been exploited to pursue sheer anonymity in "privacy coins" such as Monero, ZCash, or Dash, whose degree of untraceability cripples the fight against illicit financial activities.

Data protection must be balanced with accountability and various PETs present different techno-legal compromises. Many of these tools can support privacy and transparency in manifold forms, but the balance is technically challenging. Further, trade-offs grow harsher when PETs are applied concurrently [11]. Consistently, experts have analyzed the ways privacy attitudes can be coded into blockchain systems [72] and the compatibility of diverse PETs with regulation. The goal is not only to enable proactive compliance, such as balance and payment limits, but also retroactive one (*e.g.*, data retention, auditing and mandated disclosure). Because not all PETs allow to retrieve information, some are deemed unfit.

More specifically, Phase 4 of *Project Stella* by the ECB and Bank of Japan [23] focused on the implementation of different PETs to balance confidentiality and auditability when sharing transaction information on DLT-based systems for purposes of payment and securities settlement. Indeed, transaction information to which PETs are applied is "confidential" – where "confidentiality" means unauthorized third parties are unable to view and interpret it – but PETs also impact on the relevant "auditability", as defined above, in different ways. In this respect, the report [23] offers the following systematic contextualization and classification:

A) Segregating PETs. Information is shared on a "need to know" basis, such as in:

- *Corda*: transaction information is protected at the network communication level, where each communication can be partaken solely by authorized and identified participants; network services, *i.e.* (validating or non-validating) notaries, receive (all or part) of the information to avoid double-spending;
- *Hyperledger Fabric*: transaction information is safeguarded by dividing the network into subnetworks and respective ledger subsets, with each channel requiring authentication and authorization; a network service, *i.e.* an ordering service, orders transactions;
- *Off-ledger (Layer 2) payment channels*: confidentiality is fostered by allowing a specific network to transact off-ledger, with relevant funds being temporarily held in escrow on the ledger for security purposes; this may become a payment channel hub when an intermediary is involved. Similar setups are offered by Bitcoin (Lightning, etc) and Ethereum (Raiden, etc).

B) Hiding PETs. Confidentiality is fostered at transaction level by implementing cryptographic techniques against unauthorised interpretation. This is the case of:

- *Quorum*. Besides public transactions, participants can opt for transacting privately; in the latter case, information is

stored in private ledgers with only the relevant one-way hash value being stored publicly;
- *Pedersen commitment*. Participants share, instead of transaction amounts, only relevant commitments. The latter are uninterpretable to third parties, while it is possible to verify equivalence between inputs and outputs;
- *Zero-Knowledge Proofs*. They enable third parties to verify information without participants revealing or disclosing the content. In particular, the zk-SNARK subset (implemented in Ethereum and Quorum, for instance) sees a trusted party setting up a secret parameter that generates two public parameters, *proving and verification keys*, where the first is used by senders and the latter enables validation. Improvements are constantly put forward.

C) Unlinking PETs. They allow concealment of either the *(i)* identity of transacting parties from pseudonyms stored on the ledger, or *(ii)* any transacting relationship. Notably:
- *One-time address*: different pseudonyms or addresses may be used for different transactions. Its implementation is common, with deterministic wallets mitigating address management drawbacks;
- *Mixing* and *Tumbling*: multiple transactions are shuffled for relationships to be unlinkable, with confidentiality degrees resting on the amount of mixed data. If *centralized*, service providers are entrusted with original information. This can be averted in *P2P* schemes, although they require to timely find parties willing to mix data. As transaction amount is still stored in the clear, this method is often combined with *hiding techniques*;
- *Ring- and multi-signatures*. They allow to prove a signer is part of a group of signers without disclosing its identity. To this end, transactions are signed with both private key and public keys of the group members. Again, transaction amount is still visible and other methods may be added.

	Segregating PETs	Hiding PETs	Unlinking PETs
Effective Auditability	Corda Hyperledger Fabric Off-ledger payment channel (with payment channel hub)	Quorum Pedersen Commitment (blinding factor and amount)	Centralised Mixing
		Pedersen Commitment (only blinding factor)	
	Off-ledger payment channel (no payment channel hub)		Peer-to-peer Mixing
Weak Auditability		Zero-Knowledge Proof	One-time address Ring signatures

Figure 5: Classification of types of PETs in terms of auditability as per findings in [23]

As outlined in Figure 5, the study shows how different types of PETs exert different impacts on the auditability of confidential transaction information. In this respect, the report measures "auditability" of a given piece of information by assessing *(i)* the accessibility to it, *(ii)* its reliability, and *(iii)* the efficiency of the auditing process. When all criteria are met, it is possible to speak of "effective auditability". According to the results, effective auditability may be allowed by segregating PETs, Quorum's private transaction, Perdesen commitment and centralized mixing. Hence, their implementation may enable balancing anonymity and transparency in a CBDC-wise desirable way. By contrast, Zero-Knowledge Proofs, mixers/tumblers, one-time addresses and multi/ring-signatures, they all prohibit accessibility of transaction information to auditors. Nonetheless, multiple PETs may be combined to deliver the desired balance(s).

VII. A Case-Study Taxonomy of Selected CBDCs

In light of the above, the way regulatory requirements are embedded into CBDC designs reveals trade-offs between privacy and transparency. Different use-cases are emblematic of diverging choices of sovereign institutions in the context of their monetary policy. The goal of this section is not to provide a taxonomy of how all CBDC projects have so far managed the balance at hand. Conversely, we highlight a few concrete examples of how technology is leveraged to reach various objectives. Projects are placed across a spectrum of conceivable privacy vs. transparency nuances, as outlined by Figure 6. In detail, we argue how full anonymity is difficult to achieve technologically and possibly inconsistent with established and essential legal principles. To reach full anonymity, users' identity should not to be verified upon access to a service – a practice that is subject to restrictions in AML-regulated jurisdictions.

Studies on identity privacy have focused on pseudonyms and on the elimination of pseudonymous identifiers. Even in these cases, a theoretically "bullet-proof" solution has not yet been found to make it impossible for attackers to gather information on the identity of senders/recipients if such information is collected and recorded on a CBDC ledger that is available publicly or selectively. Hence, from this perspective it may not be feasible to achieve full cash-like anonymity [5]. Meanwhile, experts have focused on achieving transaction privacy without preventing validators from verifying that transaction amounts are both consistent with account balances and compliant with predefined requirements. This is often pursued through computationally costly cryptographic techniques broadly labelled as Zero-Knowledge Proofs. Other solutions leverage secure multiparty computation, rotation of public keys and Trusted-Execution-Environment hardware-enclaved computing [5].

From a CBDC perspective, a way to offer anonymity while reaching a legally desirable level of privacy is to provide different solutions for different types of transactions – below we refer to these schemes as "mixed solutions". For instance, one may allow higher degrees of anonymity for transactions of low values. Indeed, in theory privacy can be tackled selectively, meaning certain types of transactions could be undertaken without the acquisition identity information on the payer or the payee. This type of CBDC model is usually token-based, being intrinsically more conducive to anonymity, as described earlier. Evidently, any trade-off will need to be identified at the beginning of the design cycle. Nevertheless, for reasons mentioned above, registration and KYC-related identity verification are still likely to take place when a user signs up. Further, in case e-devices are used, identity/verification checks can be biometrical.

A. Semi-anonymity

In 2019, the ECB explored the application of the concept of "cash-like" anonymity to CBDCs as part of the EUROchain

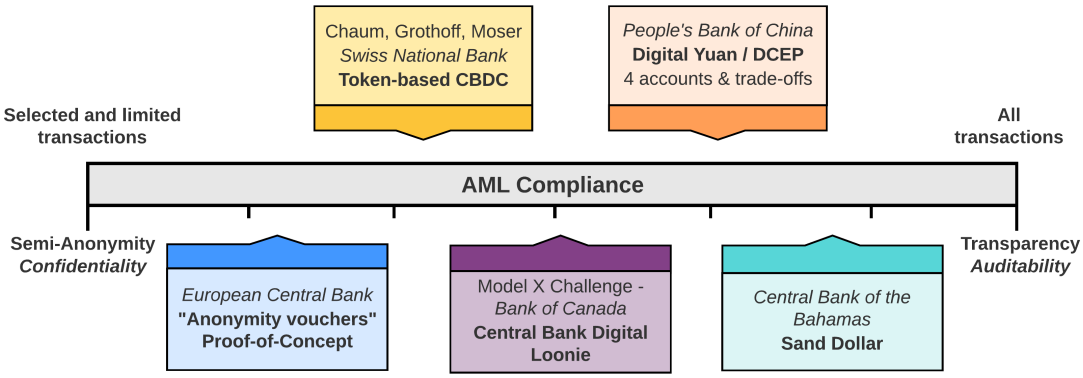

Figure 6: Selected CBDC projects from an AML compliance standpoint, from *accountable anonymity* to *transparency*

research network [73]. In this respect, the expert group conceived a DLT-based simplified PoC where a degree of privacy for low-value transactions is ensured (Figure 6) with no detriment to AML controls for higher values.

The PoC was developed on the Corda network and aimed to provide "*a digitalisation solution for AML/CFT compliance procedures whereby a user's identity and transaction history cannot be seen by the central bank or intermediaries other than that chosen by the user*". Within this scheme, end-users are on-boarded by an intermediary of their choice, and receive by the latter a pseudonymous identity that will be their CBDC network address. On top of this, end-users are equipped with limited and un-transferrable "anonymity vouchers", through which they can transfer a specific amount of CBDCs within a given timeframe with no AML oversight concerning transaction data. The relevant thresholds are automatically enforced at the intermediary level, while a specific AML authority is in charge of issuing the vouchers and of carrying out the associated checks for large-value transactions.

The mentioned features of enhanced privacy are based on Corda's "confidential party" mode, insofar as the latter allows to assign states to end-users by using a one-time key that does not reveal directly the user's pseudonymous identity [73]. Admittedly, however, "*notwithstanding the data segregation model of Corda, a participant can therefore build a knowledge graph based on information collected from the CBDC units it receives over time*", and the privacy level could be enhanced through the implementation of mechanisms such as rotating public keys, Zero-Knowledge Proof and hardware-enclave computing. Using rotating keys, which involves users generating new pseudonyms for every transaction, would limit nodes' ability to link transactions to individual users, since users would be using different identification over time.

B. Token-Based Transaction Privacy

As highlighted above, bearer-type token-based CBDCs may provide higher degrees of transaction anonymity. This is especially the case when the payment device is physical (*i.e.*, hardware-based or hardware-dependent), such as prepaid cards storing digital tokens whose transfers are P2P or for offline use when network access is not available. In this respect, [74] argues that token-based systems are the only avenue to reach a cash-like degree of transaction privacy. At the same time, however, the hardware-based subset presents some features that arguably do not suit well a CBDC scenario, chiefly in terms of online transferability and AML compliance. Notably, the authors claim the necessary fraud detection systems would not be compatible with transaction privacy.

In proposing a non-DLT-based CBDC design that is a "true digital bearer instrument", [74] maintains that a token-based mechanism is necessary for assets not to be associated with the relevant transaction history – contrary to what happens with account-based systems. Nonetheless, the authors shy away from a hardware-based model and argue for a software-based solution – thus enabling the central bank to meet the relevant requirements in terms of transparency and accountability.

In this architecture, payers and payees interact only with commercial banks. Customers/payers are identified when they withdraw CBDCs, and merchants/payees upon receipt. Other than this, no identification is needed to perform the transaction, which means customers' and merchants' identities are not unveiled to the central bank. The withdrawn coins – whose value resides in the central bank's RSA cryptographic signature on their public keys – are subject to an encryption performed by the smartphone that "blinds" the relevant number. When the merchant deposits the coins, the central bank can carry out anti-double spending checks without knowing which user withdrew it nor the total transactions amounts.

Building on E-Cash, GNU Taler and [75], the privacy of buyers is safeguarded by "blind signatures", thus preventing commercial and central banks from linking transactions to buyers. Meanwhile, conversion limits may be imposed for AML purposes, and the GNU Taler key-exchange protocol aims to ensure income transparency and consumer privacy. Hence, KYC and authentication services are performed by commercial banks. Finally, the authors specify the possibility to implement jurisdiction-specific limits on withdrawals/payments in the proposed design.

C. Mixed solutions: CBDL

We mentioned above how "mixed solutions" can provide nuanced privacy-transparency trade-offs that can better suit different types of transactions. In this way, the same CBDC model can offer a diversified service, to the benefit of all types of users. This concept is strongly related to a key feature for CBDC architectures: supporting offline CBDC transactions. A PoC developed by a team from the *University of Toronto* and *York University* [38] has tried to provide an effective model,

in the context of an academic competition-of-proposals issued by the BoC in April 2020 under the *Model X* title.

The proposed architecture is for a *Central Bank-issued Digital Loonie*, or *CBDL*, and enshrines a *two-phased* account-based KYC-backed approach. The overall mechanism sees eligible end-users obtain wallets addresses after under-going an e-KYC performed by an approved third-party authenticator. End-users do not remain anonymous if the homomorphically encrypted AML process triggers compliance flags, or if there is any court order to reveal certain information. Indeed, AML-related data is kept in a protected environment. Nonetheless, wallet addresses are represented by quasi-anonymous identifiers – *i.e.*, the latter is not built to identify and share users' identity or the respective transaction-data to other system parties [38]. All in all, CBDL's onboarding and transaction processes resemble India's Aadhaar UIDAI system [76].

In broad terms, it is proposed wallets have upper limits (*e.g.,* 10,000 CBDLs) sufficient for typical cash-like transactions, and special provisions, such as reduced functionality or preset-expiration dates, for tourists or business visitors. When it comes to off-line transactions (*i.e.*, when the user needs to perform CBDL transactions but has no access to the online world), the CBDL scheme relies on RF technology and provides for both (i) a quasi-token-like portable CBDL-card, and (ii) a smart-device-based functionality that can emulate it. In this respect, for AML purposes the authors suggest that non-traceable offline transfers via CBDL-cash-cards need to be for less than 1,000 CAD, and that in the context presented in tehir report there should be a much smaller limit per card in the proximity of 200 CAD. As they reason: *"these cards only mimic the use of cash for day-to-day transactions (gas, movies, food, etc) and [thus] mitigate the security risks that their low-cost hardware entails"*.

The report [38] foresees the application of PETs – "*such as mixers/tumblers or one-time-addresses (similar to the pseudo-random identifiers utilized by the Aadhaar system) with seeds that periodically change*", or Zero-Knowledge Proofs – in the advanced stages of the CBDL project. Indeed, as we argued earlier, in a subsequent phase the need may arise to obfuscate data (*e.g.*, the stream of transactions) from private validators.

D. Mixed solutions: DCEP

One of the most advanced CBDC projects is being piloted in China, where the PBoC is consistently expanding the testing scope of its *Digital Yuan*, currently dubbed eCNY but also DCEP. Although the launch is expected by February 2022, there is no comprehensive published research paper by the PBoC that explains all the technical architecture details behind the eCNY. Most information can be derived from public talks by Chinese officials, such as Mu Changchun (Director of the Digital Currency Research Institute (DCRI) of PBoC), or more recently by their first white paper released in July'21 [77]. In this respect, interesting comments pertain to their introduction of the concept of "*controllable anonymity*" or "*managed anonymity*". Indeed, the eCNY is informed by the principle of "*anonymity for small value and traceable for high value*" [77].

More specifically, PBoC's *DCEP* is reported to offer four or five different types of accounts/wallets. The decision on which account to assign to a specific user rests on characteristics such as CBDC amounts, anticipated use, and other information provided during the registration to the service. Reportedly, the two most anonymous types of account – *i.e.*, the "*least privileged wallets*" [77] – require very few identifying information and no real-name identity, which means they present a significant degree of anonymity. In turn, in these cases risks of money laundering and other criminal abuses are mitigated by imposing strict balance and transaction limits – a daily transaction limit and a relatively low balance limit.

On the contrary, depending on the provided information, the least anonymous types of individual or corporate wallets must be opened at a counter and can be linked to a bank account or even used as one. Further, the implemented restrictions (if any) vary, depending on the "*strength of customer personal information*" [77], with regard to both types of transactions that can be performed and relevant amounts.

The eCNY offers both software and hardware wallets [77]. Offline transactions are designed in a way that resembles the CBDL report [38]. Nonetheless, even in the most anonymous scenario among the account types, featuring minimal functionalities and strict balance limits, some identifying information is given when the account is opened. Hence, one may be expecting upon DCEP's mainstream introduction by early 2022, that the true identity of the user can always be retrieved. In any case, by implementing this multi-layered structure one can achieve a limited degree of user-to-user anonymity which is both controllable and tiered. Within this framework, commercial banks hold identifying information and they can de-anonymize suspicious transactions for AML purposes. Privacy and data protection issues raised by the two-layered structure of the e-CNY are addressed by [61].

E. Transparency

We noticed how it is impossible to ignore trade-offs and fully comply with regulation even in the mentioned anonymity-oriented scenarios. An alternative option is that of accountable anonymity (Figure 6). In the solution put forward by the ECB [73], an AML authority is still involved and anonymity is limited to a restricted number of untransferable vouchers. At the same time, privacy is provided to the extent thresholds are enforced automatically, with no need to record the amount. Even when users are identified upon the first access, both the central bank and intermediaries can grant them different degrees of privacy subsequently.

If one proceeds along the "anonymity to transparency" spectrum, we find transparency-oriented solutions that closely resemble current regulatory frameworks for electronic payments. Obviously, data protection requirements still need to be met, but transactions could be fully transparent to the entity operating the underlying infrastructure. A high level of transparency is already offered by one of the very few known CBDC projects already operating, launched by the Central Bank of the Bahamas (Figure 6) in late 2020. Its CBDC tokens represent a claim on the central bank and they are digital cash. They are recorded and transferred on a private and permissioned DLT with all parties being identifiable [33].

VIII. Conclusion and Future Directions

This contribution proposes techno-legal methods to balance privacy and transparency in retail CBDCs for AML compliance within a *regulation-by-design* scheme, *i.e.,* regulatory trade-offs are embedded early into technology design plans. It further argues that by leveraging PETs one can provide a selected taxonomy of how CBDCs are placed within a range

from accountable anonymity to transparency. To this end, the relevant technical approach of five case studies is briefly outlined, as well as they are positioned on an AML-specific privacy-transparency spectrum accordingly.

All in all, CBDCs show some limitations when balancing this trade-off. Namely, issues arise when the envisaged solution cannot concurrently provide the desired levels of privacy and transparency. To address this significant dilemma, this work shows how some existing CBDC projects split the problem into a compound design of two (or more) structures with different characteristics, pursuant to a risk-based methodology. Notably, they select to implement anonymity-oriented token-based solutions for small transactions, and a privacy-preserving transparency-oriented account-based system for higher amounts. In this way, transaction and volume limits seem to be held as compliance benchmarks. Although focused on CBDCs, the findings here have a wider application across other blockchain assets (cryptocurrencies, stablecoins, etc.).

A potential avenue for future work ponders over the multifold opportunities opened up by the *programmability* of CBDCs, chiefly in terms of smart contracts-driven – or simply put, embedded software-based – AML enforcement, but also new criminal-prevention strategies. Consequently, it may tackle the issue of techno-regulatory interoperability in a cross-border CBDC world, given that the current development of mCBDC projects show how standardization is reaching the limelight. Further, the arguments presented by this contribution could benefit from examining at length the technical role of PETs in CBDC compliance, and how they can be tailored to pursue different AML trade-off metrics.

Finally, in a world where AI, machine learning and IoT technologies are increasingly linked to the financial and AML sphere, this paper remains agnostic to them. Similarly, to a certain extent this contribution implicitly assumes that those we define as "auditors" do not abuse their powers. Hence, possible extensions could dive deeper into how *regulation-by-design* may foster citizen protection against potential "abuse" of CBDCs and their accompanying data for various harvesting purposes and risks this may entail.

IX. Acknowledgment

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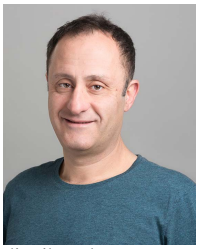

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