Renewable and Sustainable Energy Reviews 158 (2022) 112162

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Pioneering a performance-based future for energy efficiency: Lessons learnt from a comparative review analysis of pay-for-performance programmes

Dimitra Tzani [a,b], Vassilis Stavrakas [a,b], Marion Santini [c], Samuel Thomas [c], Jan Rosenow [c], Alexandros Flamos [b,*]

[a] Institute for European Energy and Climate Policy Stichtung (IEECP), Amsterdam Sloterdijk Teleport Towers, Kingsfordweg 151, Amsterdam, 1043GR, Netherlands
[b] Technoeconomics of Energy Systems Laboratory (TEESlab), Department of Industrial Management and Technology, University of Piraeus, Karaoli & Dimitriou 80, Piraeus, 18534, Greece
[c] Regulatory Assistance Project (RAP), Rue de La Science 23, B – 1040, Brussels, Belgium

A R T I C L E I N F O

Keywords:
Energy policy
Energy efficiency
Pay-for-Performance
Incentive programmes
Finance business models
Evaluation, Measurement & Verification

A B S T R A C T

Energy efficiency targets and funding for reducing energy consumption in buildings play a significant role in the international policy landscape. Energy efficiency can deliver both sustained reductions in energy usage by improving baseline efficiency as well as targeted peak demand reductions. However, despite the many benefits, energy efficiency faces barriers to achieving its full potential. The economic effectiveness of energy efficiency programmes is often doubted because of the evaluation, measurement, and verification practices currently used. Calculation of potential energy savings from different interventions may be unreliable due to various types of uncertainty, resulting in a performance gap between predictions and actual energy consumption. On the other hand, calculation of trustworthy savings remains critical for convincing investors and regulators of the cost-effectiveness of energy efficiency programmes and their ability to defer supply-side capital investments. Yet, incentive programmes continue to heavily rely on the robust calculation of energy savings. In this article, we lay out guidance for designing and implementing pay-for-performance schemes that reward end-users or aggregators for delivering energy savings tracked through metering and established against a business-as-usual scenario, also describing several potential obstacles and questions that utilities and regulators should consider. Through investigating eleven such programmes around the world, we summarise key design features, performance assessment methods and payment agreement processes. In addition, we provide a set of key implications and policy recommendations, which, if acted upon, could accelerate the deployment of renovation strategies and spur cost-effectiveness.

1. Introduction

The Paris Agreement requires strong and rapid global action to reduce greenhouse gas (GHG) emissions and demands a fundamental reorientation of the way energy is used and produced [1,2]. Energy efficiency interventions address both climate and energy security challenges while providing multiple other benefits, including lower energy bills, improved comfort and health for occupants, and increased real estate value [3,4]. However, despite its potential, energy efficiency ranks at the lower end of the spectrum of realised sustainable energy investment opportunities [5,6]. Alam et al. (2019) identified lack of funding, uncertainties over financial gain and lack of metering to be frequently cited as the main barriers that limit energy efficiency investments [7]. Energy efficiency programmes constitute an effective way of scaling up the number of interventions in the buildings sector [8]. To date, almost all energy efficiency programmes have mainly relied on subsidies that are paid upfront and are based on a predicted result [9]. Thus, although energy efficiency programmes may provide financial incentives, which partially resolve the funding problem, the actual energy and cost savings may still differ from the predicted ones due to the uncertainties involved with the assumptions of key parameters [10]. The latter makes building owners reluctant to invest in retrofit projects [11,12]. At the same time, for energy efficiency to be attractive to institutional investors, it must be associated with consistent returns and stable long-term cash flows. This requires innovative energy efficiency financing that can be regarded as an effective market-based approach to attract private capitals in the energy renovation market [13,14].

* Corresponding author.
E-mail address: aflamos@unipi.gr (A. Flamos).

https://doi.org/10.1016/j.rser.2022.112162
Received 8 November 2021; Received in revised form 27 December 2021; Accepted 15 January 2022
Available online 21 January 2022

Nomenclature

Acronyms & abbreviations

AHU	Air Handling Unit
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
BayREN	Bay Area Regional Energy Network
BES	Building Energy System
CEI	Continuous Energy Improvement
Con Edison	Consolidated Edison, Inc.
CDM	Conservation and Demand Management
DCSEU	District of Columbia Sustainable Energy
EC	European Commission
EERS	Energy Efficiency Resource Standards
EPP	Energy Performance Program
ESCO	Energy Service Company
ESM	Energy Savings Meter
ETO	Energy Trust of Oregon
EU	European Union
EM&V	Evaluation, Measurement and Verification
GHG	Greenhouse Gas
HVAC	Heating, Ventilation and Air-conditioning
IESO	Independent Electricity System Operator
IPMVP	International Performance Measurement and Verification Protocol
MUSH	Municipality, Universities, Schools, Hospitals
NJBPU	New Jersey Board of Public Utilities
NJCEP	New Jersey's Clean Energy Program
NYSERDA	New York State Energy Research and Development Authority
O&M	Operations and Maintenance
PG&E	Pacific Gas and Electric Company
PSE	Puget Sound Energy
P4P	Pay-for-Performance
SCL	Seattle City Light
SMB	Small and Medium-sized Business
US	United States
VAV	Variable Air Volume

So far, energy efficiency programmes have been typically developed either directly by governments, with funds raised through taxes or levies, or by mandatory saving goals (also referred to as *obligations*) set for energy providers (also referred to as *utilities*) to reduce their customers' energy use [9], as also depicted in Fig. 1. Different types of financial incentives have been used by governments to change consumer behaviour and persuade end-users to adopt innovative energy service solutions [15,16]. These incentives have been primarily delivered in the form of grants/subsidies, soft loans and tax incentives, mainly targeting residential, commercial, and public buildings [17]. In general, incentive programmes have assisted in increasing energy efficiency in buildings by removing financial barriers, supporting the penetration of innovative low-carbon technologies, and/or helping the implementation of other policy instruments (e.g., higher building performance standards, etc.) [18]. The development of incentive programmes has also been driven by the need to boost an economy in times of recession as governments have implemented incentive programmes to stimulate economic activity while also fostering innovation for sustainable growth [19]. In this context, and considering the economic implications of COVID-19, the impacts of existing financial instruments for buildings are expected to become even more important, since energy efficiency qualifies as one of the sectors with the greatest potential for the double dividend hypothesis, supporting both economic recovery and decarbonisation simultaneously [20,21]. Therefore, successfully utilising financial instruments in promoting sustainable growth is crucial to ensure minimum waste of national resources with maximum outcomes [22].

So far, the market has mainly been stimulated through the subsidisation of energy efficiency investments with grant schemes for households and businesses, which otherwise would not be able to bear the high upfront costs of energy efficiency interventions [23,24]. These schemes often constitute a solution to the finance gap, enabling a temporary shift in the market. However, they typically consist of limited resources, and can, therefore, neither offer a sustainable solution nor support massive market uptake programmes [25]. In this context, debt financing, such as loans and soft loans, can be a more sustainable means of scaling up energy efficiency investments as they can provide liquidity and direct access to capital [26]. Loans can be more relevant for energy efficiency interventions with high upfront costs, especially in deep renovation projects that comprise a package of multiple renovation measures [27]. Nevertheless, private debt financial products, specifically designed for energy efficiency measures are not currently fully developed as financial institutions are often unfamiliar with this subsidy type and perceive it as a high-risk investment [28]. Finally, tax incentives can increase demand for energy efficiency projects by reducing the cost of interventions through reduced taxes for households and businesses. They can be less costly than grant schemes and are considered a popular instrument promoting energy efficiency [29,30]. However, they often are subject to free-rider problems and can result to loss of tax revenue for governments [13]. Table 1 summarises the different

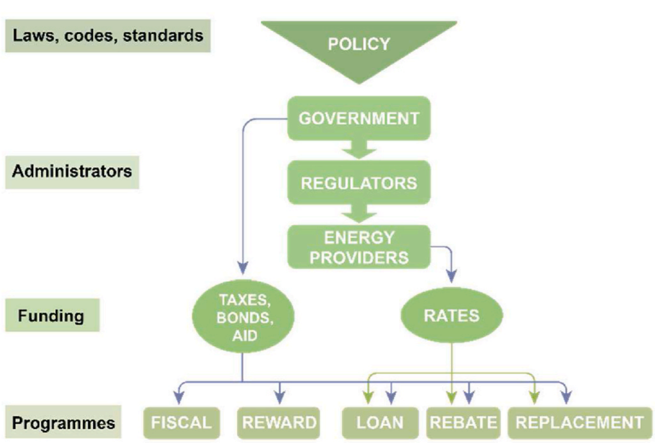

Fig. 1. Typical implementation framework of energy efficiency programmes.

Table 1
Subsidy types for energy efficiency investments.

Types	Description	Ref.
Grants	Grants mainly serve as direct monetary incentives that may partially or fully cover renovation costs and do not require to be paid back. Grants are usually used by governments to support the market diffusion of new technologies.	[9, 27]
Loans	Loan incentives are offered at a low-interest rate and are usually delivered through public-private partnerships, in which governments provide financial support to banks, which in turn offers a loan scheme with a preferential interest rate to its customers. The recipient institution then on-lends the funds to customers to invest in energy efficiency projects.	[13, 26]
Tax incentives	A tax incentive can be defined as monetary credit, deduction or exemption on the tax required to be paid if the energy target/energy upgrade is not performed for the building.	[30]

Table 2
Summary of the existing literature addressing the topic of pay-for-performance programmes.

Study	Type of publication	Description
Healey et al. (2010)	Proceedings of the 2010 American Council for an Energy-Efficient Economy Summer Study	The study focuses on the P4P programme launched by the New Jersey's Office of Clean Energy and presents first-year experiences and insights.
Egnor et al. (2016)	Proceedings of the 2016 American Council for an Energy-Efficient Economy Summer Study	The study analyses a P4P pilot project implemented in a building in Seattle. The analysis is focused on how the programme operates, how the baseline for a new building is modelled, and how actual savings are verified.
Szinai et al. (2017)	Technical report prepared for the Natural Resources Defence Council and Vermont Energy Investment Corporation	The study reviews energy efficiency and demand-side management programmes based on P4P business models. The authors also reflect on some energy efficiency P4P programmes running during the period of their study in the US.
Shaban et al. (2018)	Proceedings of the 2018 American Council for an Energy-Efficient Economy Summer Study	The study presents an analysis of the performance risk in energy efficiency P4P programmes. It explores how this risk is allocated among the different market actors and how these actors can mitigate it by measuring and controlling the performance.
Rinaldi et al. (2019)	Technical report prepared for the National Association of State Energy Officials	The study analyses the role of residential grid-interactive building technologies and policies towards a clean, affordable, and resilient grid. A brief discussion of energy efficiency P4P programmes as a financing enabler for such building technologies is also presented.

subsidy types for energy efficiency investments and provides a short explanation of the monetary aspects of each type.

Outside the traditional types of energy efficiency programmes, various market mechanisms, using data analytics and automated measurement, and/or evaluation, measurement, and verification (EM&V) practices, which reward performance, have been developed over the past few years [31]. These mechanisms reward end-users or aggregators for delivering energy savings against a business-as-usual (i.e., baseline) scenario, indicating the energy efficiency project's performance on an ongoing basis as the savings occur. Savings are based on metered energy consumption and beneficiaries need to achieve a certain level of operating performance to receive all or part of the incentive payment [32]. By focusing on the output (i.e., energy savings) rather than other indicators (e.g., number of technology units deployed, etc.), such pay-for-performance (P4P) schemes align incentives with policy objectives, incentivise the persistence of energy savings over time, and boost the energy service market [33]. However, scaling up such schemes has proven to be a major challenge, since their implementation and effectiveness depends on many parameters [34].

So far, studies in the scientific literature have extensively analysed P4P programmes in the fields of health policy and medicine, focusing on the assessment of the programmes' impact on health systems and outcomes for patients [35–39]. P4P programmes have also been investigated in research studies related to community pharmacy in the context of how the integration of such programmes and other factors may affect the pharmacy environment [40,41]. Finally, P4P programmes have been analysed in motivational science and their effectiveness in workplace settings has been assessed in different studies [42–44]. Nevertheless, despite their novelty, contributions providing deep insight on energy efficiency P4P programmes have been scarce in the literature so far. Table 2 provides a summary of the existing literature addressing the topic of energy efficiency P4P programmes.

In particular, Healey et al. (2010) and Egnor et al. (2016) provide a deep analysis of two energy efficiency P4P programmes implemented in the US, in New Jersey and Seattle respectively, and focus on their specific design and implementation aspects [45,46]. Szinai et al. (2017) present a thorough study of energy efficiency and demand-side management programmes [31]. The study includes P4P programmes but focuses on demand-side mechanisms such as demand-response and capacity auctions rather than on pure energy efficiency programmes. Shaban et al. (2018) explore how the performance risk is allocated among different actors in energy efficiency P4P programmes and how measuring and controlling can mitigate those risks and make such programmes a game-changer [47]. Finally, Rinaldi et al. (2019) devote a brief sub-chapter of their study on how energy efficiency P4P programmes can be a financing tool towards residential grid-interactive buildings and a clean, affordable, and resilient grid [48].

Research knowledge can also be found in the deliverables of the Horizon 2020 project "SENSEI[1]", funded by the European Commission (EC), which is the first project to study energy efficiency P4P programmes and their roll-out in the European policy landscape. However, to the best of our knowledge, there is no peer-reviewed study in the scientific literature that addresses the issue of energy efficiency P4P programmes, as existing studies are part of the grey literature, e.g., reports and research produced by organisations outside of academic publishing, conference proceedings that are not peer-reviewed, etc. In this context, thus, our article sets out to pioneer this field in the scientific literature by asking the question: "*What is an energy efficiency P4P programme and how could it be designed and implemented*?" To answer this question, we couple a thorough desk research and consultation activities with key stakeholders to present the main specifications and features of energy efficiency P4P programmes and to summarise experience and lessons learnt from real-world case studies, through the comprehensive analysis of 11 such programmes in North America and Europe. Overall, our novel contribution to the scientific literature is threefold:

- We establish the definition and main design features of energy efficiency P4P programmes in the scientific literature.
- Through a comparative review analysis, we identify and highlight the actions needed to bridge the gap between market needs, policy goals, and scientific research, also establishing best practices for the design of energy efficiency P4P programmes.
- We summarise experience and lessons learnt from real-world cases and we provide a set of key implications and recommendations for policymakers and other practitioners on designing a P4P pilot project.

2. Changing the way energy efficiency is valued: pay-for-performance programmes compared to traditional approaches

Although traditional financial programmes and mechanisms have helped to promote energy efficiency thus far, they provide customers with one-time, upfront incentive payments for interventions based on ex-ante saving estimations [49]. In practice, this means that for these programmes, the expected amount of the energy saved over each measure's lifetime is calculated, or deemed in advance, based on pre-specified unit saving values, or formulas with pre-specified parameter values as the basis for quantifying savings [50]. This approach has served well energy efficiency programmes for years, and in many sectors will also keep playing a vital role. However, these estimations lack standardisation, are prone to parameter errors, and neglect rebound effects. Moreover, compared to ex-post estimations, they are not systematically done [51–53]. Several challenges also come with payment

[1] https://senseih2020.eu/.

structures of traditional energy efficiency programmes, especially those with one-time rebates based on deemed savings (e.g., grants or subsidy programmes, etc.). First, once the rebate is upfront awarded, it is difficult to motivate and closely track sustained performance (persistence of savings over time), while the verification of savings after the implementation can be expensive and time-consuming. Second, pre-calculated, deemed saving values require well-defined, simple, and consistent energy efficiency measures and conditions. Deemed savings are, therefore, applicable neither to complex projects nor to measures in which the savings may be inconsistent among units or programme participants [54,55].

As more countries and utilities commit to aggressive decarbonisation goals, the electric grid needs to transition from a centralised, fossil-fuel-based system to one that is based on clean and distributed sources of energy such as solar and wind [56]. Together with demand-response, energy efficiency can support the transition to this new energy system and provide important benefits to the electricity grid. New business models, which will pay for grid-based savings based on performance at the meter in a similar way that traditional distributed energy resources are procured and financed, are needed to value those grid services at a large scale. This way, not only added value will be brought to the grid, but energy efficiency will be associated with consistent returns and stable long-term cash flows [57]. This could bring more opportunities for building owners to attract third-party financing and, therefore, to reduce upfront capital costs, and more opportunities for energy companies and innovative collaborations to successfully compete in the market [58,59]. Energy efficiency P4P programmes respond to these policy and market gaps. In particular, they aim to deliver greater and more persistent savings by compensating energy efficiency resources based on a comparison of metered and modelled counterfactual energy consumption, i.e., consumption in the absence of the energy efficiency action (performance) [48].

The idea behind a P4P programme financing an energy retrofit project is that the financial flows between the involved parties are linked to the actual/metered and weather-normalised energy savings produced by the project. Compared to traditional energy efficiency programmes, the latter allows for the performance risk of the project to be shifted from those who fund the programme (taxpayers or ratepayers) to the entities managing the project (e.g., energy service providers, aggregators, etc.). These entities often work with clients to choose which measures to install, are responsible for the quality of their installation, and provide advice on how to optimise their operation. Thus, by paying more attention to performance, the risk of underperformance can be reduced. The remaining performance risk can be managed then at a portfolio level through aggregation, which spreads the risk across many projects, each of which, may either under- or overperform. This risk transfer aligns the incentives of those receiving public support with policy objectives [48]. A schematic graph of an energy efficiency P4P programme is depicted in Fig. 2.

Through subsidisation, most energy efficiency programmes so far have focused on the provision of incentives to the private sector for installing as many energy efficiency measures as possible, without necessarily ensuring high-quality installation and maintenance. P4P programmes redirect these incentives to obtaining as many energy savings as possible. In principle, this results in a higher quality of the installation and maintenance processes, and in a more tailored deployment of measures that could deliver larger amounts of savings, also offering a boost in policy effectiveness (ability to deliver on goals) and an increase in the efficiency of public spending (value for money). A P4P programme can also allow energy efficiency to become a manageable and procurable resource that can contribute to bringing more flexibility into the grid. Applying a P4P programme, thus, means that the administrative entity would enter into agreements with aggregators or building owners to purchase the energy efficiency levels achieved through the use of metered data. Using smart-meter data makes it possible to track results by time and location and to value energy efficiency's contribution to reducing capacity requirements. This way, its "demand capacity" can make energy efficiency a distributed resource that would look very similar to other distributed energy resources [60]. Table 3 summarises the monetary specifications of an energy efficiency P4P programme and explains the differences for each involved actor compared to traditional energy efficiency programmes.

3. Real-world cases of energy efficiency pay-for-performance programmes

To fill in the knowledge gap regarding the design and implementation processes of energy efficiency P4P programmes, in this article, we analyse 11 such real-world programmes that have been applied in North America and Europe. Our work is mainly focused on programmes that use data-driven EM&V approaches, which provide better accuracy, more reliability, and higher levels of transparency compared to traditional energy efficiency programmes.

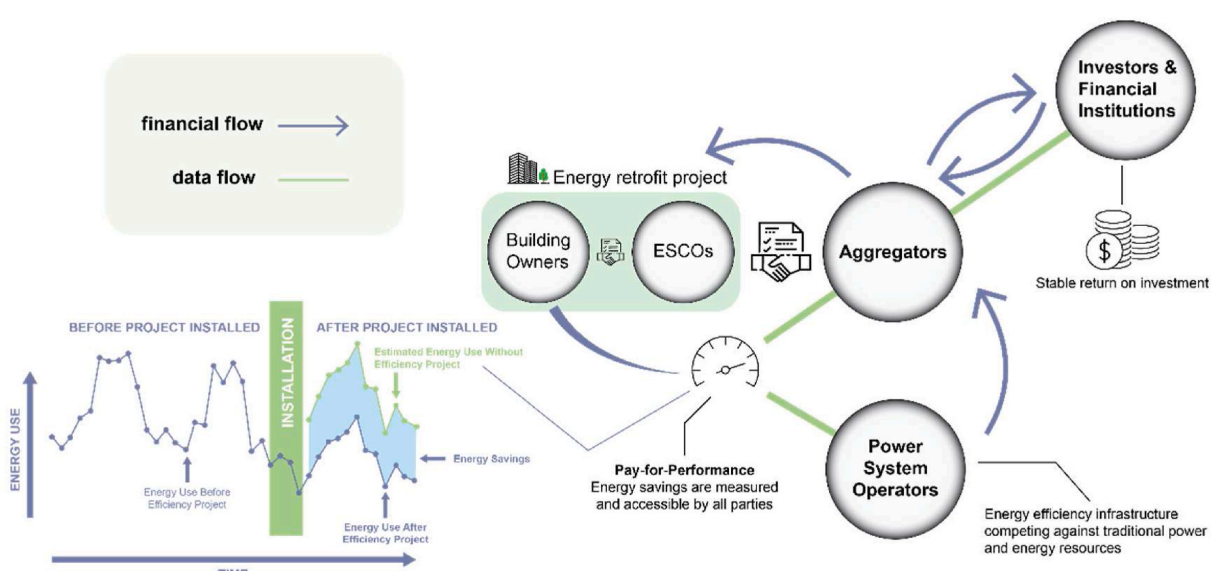

Fig. 2. Schematic graph of an energy efficiency pay-for-performance programme.

Table 3
A comparison of monetary relations and financial risks across the different actors participating in traditional and pay-for-performance programmes.

Involved actors	Traditional programmes	P4P programmes
Customers	Customers usually receive an up-front incentive from the programme administrator or implementer to partially or totally cover the initial costs of the energy efficiency interventions implemented, based on the expected deemed savings. In this case there is the risk that the measures implemented will not perform, or that the savings achieved will not persist as expected.	Customers are paid per measured unit of energy saved (e.g., 4 cents/kWh saved); some programmes differentiate payments based on the measures used to achieve savings to meet the specific programme goals. Again, there is the risk that the energy efficiency interventions implemented will not perform, but in most of the cases the project implementer (e.g., ESCO, etc.), or another aggregator/service provider takes on the performance risk. In some cases, the customer may also receive part of the remuneration upfront to reduce investment costs.
Implementers/ Aggregators	ESCOs, aggregators, or other service providers often sign a contract with a customer (directly or through the programme administrator) to implement a project. The payment is agreed in advance and delivered after the installation of the energy efficiency interventions.	Aggregators/service providers deliver the savings to utilities and take on the performance risk of the energy efficiency interventions. They may receive a higher payment per unit of savings to be compensated for taking the risk. If the interventions do not perform, aggregators/service providers may be required to implement more, or may receive lower payments as a penalty.
Programme administrators/ Utilities	Administrators/utilities estimate savings from predetermined deemed savings, but savings verified after the completion of the programme could be lower than expected. Administrators/utilities that are under specific obligations and requirements may not reach their emissions or energy efficiency targets and receive penalties.	Even in the case that savings are estimated and paid for on an ongoing basis, actual savings may still turn out lower than expected. However, administrators/utilities only pay for savings that are verified and can require additional savings if needed.
Taxpayers/Ratepayers	Administrators/utilities use funds raised by taxpayers or ratepayers to provide upfront incentives for deemed savings; the risk is that the anticipated savings may not materialise.	Taxpayers' or ratepayers' funds are used only for actual/verified savings and customers avoid paying for unrealised savings.

3.1. Case study selection

Step 1: Identification of the programmes.

As a first step, we conducted an extensive review of relevant scientific and grey literature documents. In the case of scientific literature, we conducted a broad search in energy-related peer-reviewed articles found in the scientific databases 'Science Direct' and 'Google Scholar', using relevant search keywords (e.g., pay-for-performance, energy efficiency, grid resource, etc.), individually and in multiple combinations. Our search process was mainly focused on utility programmes. In the case of grey literature, our search process was focused on the inclusion of state-of-the-art studies (e.g., published by the International Energy Agency, the Natural Resources Defence Council, etc.) and other relevant technical reports, project deliverables, requests for proposals, programme manuals, and business plans, developed by utilities and other organisations, using the same keyword combinations.

Step 2: Selection of the programmes to be analysed.

Search results from Step 1 were further curated by applying the following filters:

- Administrative entities: The cases selected concern programmes that are managed by utilities, system operators, public bodies, and/or organisations in charge of delivering on climate and energy goals.
- Relationship between payment and performance: The cases selected concern programmes that base compensation on verified performance.
- Calculation method of energy savings: The cases selected concern programmes that calculate performance based on metering energy data, and do not rely on deemed saving methodologies.
- Scope: The cases selected concern programmes that include a number of aggregated projects and not just a single one.

Following these filters, 11 real-world case studies in North America and Europe were finally selected and an in-depth review of the respective documents was conducted for each case study. Note that, since we did not find any scientific article explicitly referring to energy efficiency P4P programmes in the search databases, our work was mainly based on insights from the grey literature.

Step 3: Interviews with key programme representatives.

Finally, we supplemented our desk research by interviews with key programme representatives (i.e., administrators, managers and employees directly occupied in the programmes) to validate the outcomes of the review process and receive additional feedback, extra insights, and updates on the progress or final outcomes of each programme. To do so, a semi-structured questionnaire was developed to enable a flexible interview approach that combines a predetermined set of questions with the option of discussing any interesting emerging themes or details at greater length. This questionnaire is presented in Table A1 in **Appendix** and was developed around the four following thematic categories:

- Main information: This category included questions on the main information about each programme, e.g., name, geographical coverage, purpose, etc.
- Key design features: This category included questions regarding information about the end-users, the target sector, the actors involved, and the interventions and the measures that were eligible under each programme.
- Performance assessment: This category included questions regarding the EM&V methodology and the payment structure of each programme.
- Lessons learnt: This category included questions regarding the overall achievements, the barriers and the obstacles faced, and the drivers/enablers that led to the implementation of each programme.

Due to implications of the COVID-19 pandemic, all interviews were implemented online, as most of the stakeholder engagement activities in energy-relevant EC-funded projects at the time [61]. The interviews were conducted in spring and summer 2020, thus, our study presents the most updated information up to that period.

3.2. Case study overview

Fig. 3 shows the geographical location of the 11 programmes identified, while Table 4 presents these cases across three categories that reflect the target customer segment, namely:

- Commercial programmes: They engage businesses in energy efficiency activities. Some of the programmes cover public buildings or entities, while they can also be restricted to the service sector or be open to the industry sector. We distinguish between programmes targeting large buildings (buildings with conditioned space ≥50,000

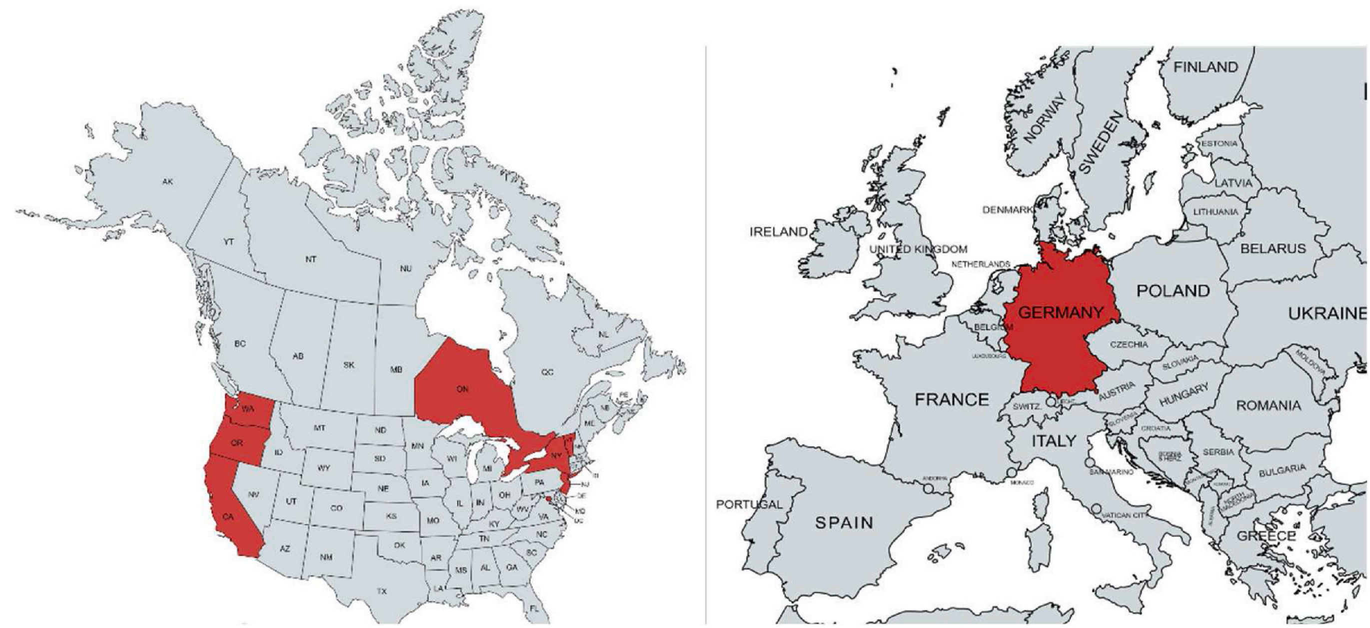

Fig. 3. Geographical location of the energy efficiency pay-for-performance programmes that were identified and analysed.

sq. ft.) and programmes targeting small buildings (buildings with conditioned space ≤50,000 sq. ft.).

- Residential programmes: They engage private households in energy efficiency activities.
- Open schemes: They do not have an eligibility requirement related to their target customer segment.

3.2.1. New Jersey Clean Energy program- pay-for-performance commercial & industrial program

This programme is implemented in the context of the New Jersey's "Clean Energy Program" (NJCEP), a state-wide programme established by the Division of Clean Energy of the New Jersey Board of Public Utilities (NJBPU). Its administration relies on an outsourced programme manager, TRC Companies, and on more than 100 technicians. The programme consists of two components: one on existing buildings and one on new construction buildings and was launched back in 2009 and is still ongoing. In terms of existing buildings, the programme uses a whole-building metering approach to energy efficiency in existing commercial and industrial buildings. Contractors and building owners are encouraged to lower their total energy consumption from a whole-building perspective instead of going for single equipment changeouts. In terms of new construction buildings, the programme incentivises new commercial and industrial projects to perform better than what is required by the energy code. A standardised energy simulation software is used to estimate the energy savings of the proposed building design compared to a baseline (limited to building code compliance). For both cases, a portion of project incentives is tied to the actual building performance, while part of the incentive is given based on projected savings.

3.2.2. Ontario Save on Energy- energy performance program

The Independent Electricity System Operator (IESO), the entity that manages Ontario's power system, offers energy efficiency incentives and rebates through a suite of "Save on Energy" programmes. The Energy Performance Program (EPP) included in the suite, is an energy efficiency P4P programme that started in 2013 and is still running for customers with commercial buildings across multiple local distribution company service territories. EPP encourages whole building energy performance improvements through an incentive that provides 4 cents/kWh of savings per year for up to two and a half years, while it significantly reduces the administrative burden on customers. This model encourages participants that are able to make behavioural and operational changes alongside capital investment projects to achieve and grow energy savings over multiple years. Participants must have a minimum annual consumption of 1,500,000 kWh per building (or a group of up to five buildings).

3.2.3. Seattle City Light- Deep Retrofit pay-for-performance program

Seattle City Light (SCL) is the public utility providing electrical power to Seattle, Washington (US) and parts of its metropolitan area. SCL started a three-year P4P pilot programme in 2013 with three medium/large commercial buildings. Savings were established using metered data and participants received a pre-determined incentive rate for energy savings achieved over the performance period. Incentive payments were made at the end of each year of the performance period. After the successful conclusion of the pilot, SCL launched the "Deep Retrofit" programme in 2018, which is ongoing and offers the option of a three- or five-year performance period. SCL administers the programme, and a contractor implements the comprehensive retrofits, including heating, ventilation and air-conditioning (HVAC) and lighting. The programme targets commercial buildings.

3.2.4. Efficiency Vermont- Continuous Energy Improvement

In Vermont, a dedicated energy efficiency utility, Efficiency Vermont, has been created for delivering energy savings based on plans agreed with the regulator. Efficiency Vermont runs a scheme called "Continuous Energy Improvement (CEI)," which applies a data-driven approach to understand how businesses and industries use energy; to set up a strategy that reduces energy use through a mix of behavioural, operational, and technical measures; and to measure the actual performance against a baseline to track improvements. The pilot started in 2014 and resulted in a full programme in 2018, which is still ongoing. Participants are not rewarded upon performance; Efficiency Vermont, which is managed by Vermont Energy Investment Corporation (VEIC), is remunerated against the achievement of a set of defined objectives. Efficiency Vermont pays for some related programme costs such as the installation of submeters. The payment structure of CEI is different compared to a typical P4P programme. Nevertheless, the programme was included in our study as it consists of many of the characteristics of a

Table 4
Key characteristics of the energy efficiency pay-for-performance programmes that were identified and analysed.

Name	Acronym	Location	Implementation year	References
Commercial programmes (large buildings)				
1. New Jersey Clean Energy Program- Pay-for-Performance Commercial & Industrial program	NJCEP	New Jersey (US)	2009	[62–66]
2. Ontario Save on Energy- Energy Performance Program	EEP	Ontario (CA)	2013	[67–69]
3. Seattle City Light- Deep Retrofit Pay-for-Performance program	SCL	Washington (US)	2013	[70–72]
4. Efficiency Vermont- Continuous Energy Improvement	CIE	Vermont (US)	2014	[73,74]
5. Energy Trust of Oregon- Pay-for-Performance pilots	ETO	Oregon (US)	2014	[75–80]
6. Puget Sound Energy- Pay-for-Performance pilot	PSE	Washington (US)	2018	[72,81]
7. District of Columbia Sustainable Energy Utility- Pay-for-Performance program	DCSEU	District of Columbia (US)	2019	[82–84]
Commercial programmes (Small buildings)				
8. Bay Area Regional Energy Network-Small and Medium Commercial Buildings, Pay-for-Performance program	BayREN	California (US)	2018	[85,86]
9. New York State Energy Research and Development Authority- Business Energy Pro	NYSERDA	New York. (US)	2019	[87]
Residential programmes				
10. Pacific Gas and Electric Company- Residential Pay-for-Performance programs	PG&E	California (US)	2018	[88]
Open programmes				
11. Germany- Energy Savings Meter programme	ESM	Germany (EU)	2016	[89]

P4P scheme (comprehensive approach, use of metered data, etc.). There is no obligation for participating companies to attain specific results, but, in the first three years, Efficiency Vermont aims to reduce consumption by 10–15% across the portfolio of companies involved in the programme.

3.2.5. *Energy Trust of Oregon- pay-for-performance pilots*

These P4P pilots were managed by the Energy Trust of Oregon (ETO), an independent non-profit organisation that helps utility customers in Oregon to benefit from energy efficiency and renewable energy services. It engaged energy service providers and the commercial sector, in particular office buildings, healthcare, grocery stores and municipality, universities, schools, hospitals (MUSH) buildings. Phase I of the programme started in October 2014 and ended in 2017. ETO was looking for three or more commercial office buildings to participate. Ultimately, only one project, a large commercial building in downtown Portland, was selected and the three-year contract was completed in 2017. The payment was partially performance-based. An initial incentive was given after the installation of energy efficiency measures (based on projected savings). The remaining savings were established using metered data and participants received payments based on a predetermined incentive rate at the end of each year over a three-year period. A Phase II Pilot was launched in 2017, but it had not been successful in identifying project candidates by the time of our interview with the programme representatives.

3.2.6. *Puget Sound Energy- pay-for-performance pilot*

In 2018, Puget Sound Energy (PSE), a Washington state energy utility that provides electrical power and natural gas primarily in the Puget Sound region, launched a three-year commercial P4P programme with the goal of enlisting five existing commercial buildings (e.g., offices, schools, universities, etc.) per year. The P4P pilot aimed to maximise energy savings through capital, operational, and maintenance improvements, and behavioural opportunities. All proposals required a minimum of 15% annual energy reduction target from capital measures, with an incentive structure that rewards a total building approach to manage the facility's resources. Up to 50% of the incentive was paid according to estimated project costs and estimated/deemed project savings (at the end of year one), while the remaining incentive was paid out annually for the years two through five.

3.2.7. *District of Columbia Sustainable Energy utility- pay-for-performance program*

This programme is run by the dedicated utility District of Columbia Sustainable Energy (DCSEU) in the District of Columbia, in the context of the utility's obligation to deliver energy savings. The programme focuses on existing large commercial and institutional buildings and was launched in 2019. The programme is still ongoing and targets measures delivering annual savings greater than 10% (based on pre- and post-project metered data). The incentive is paid once, and the amount paid per unit of energy saved varies according to the project. Savings can only be claimed for one year's timeframe.

3.2.8. *Bay area regional energy network- Small and Medium Commercial Buildings, pay-for-performance programme*

The Bay Area Regional Energy Network (BayREN) Small and Medium Commercial Buildings P4P programme works with commercial buildings owners and managers to install energy improvements that will pay for themselves over time. The programme was initiated in 2018 and is still available today. To better manage performance risks for both ratepayers and participants (small and medium commercial building owners), BayREN recruits Energy Service Companies (ESCOs) via a competitive solicitation to act as program allies. These organisations are compensated under an incentive structure, in which 50% of the compensation is based on approved ex-ante saving calculations and is paid upon project completion (Year 0). Year 1 and Year 2 performance payments are calculated as true-up payments, representing the performance-based balance after accounting for the first year's (Year 0) payment.

3.2.9. *New York State Energy Research and Development Authority- Business Energy Pro*

Business Energy Pro is a commercial P4P pilot programme administered by the New York State Energy Research and Development Authority (NYSERDA), a public-benefit corporation in the state of New York (US), and the utility Consolidated Edison, Inc. (Con Edison). In 2019, the first annual request for proposal was launched to select one or several portfolio managers. These third-party providers engage with small and medium-sized businesses (SMB) to deliver energy savings and are compensated over a performance period of three years. The payment per energy unit varies depending on the bids. Savings are measured and aggregated for the whole portfolio to calculate performance. The overall aim is to achieve a minimum of 5% energy reduction.

3.2.10. *Pacific Gas and Electric Company- residential pay-for-performance programs*

In 2018, the utility Pacific Gas and Electric Company (PG&E) contracted third-party providers to design and implement two-year P4P pilot programmes in the residential sector. Contractors are paid monthly for energy savings calculated using a set of empirically tested methods to standardise the way normalised meter-based changes in energy consumption are measured and reported. Programme evaluation aims to determine whether the P4P concept is sustainable for incentivising energy efficiency in the residential sector.

3.2.11. Germany- Energy Savings Meter programme

The pilot phase of the Energy Savings Meter (ESM) programme was launched by the Federal Ministry of Economics and Technology in Germany in 2016 and was concluded in 2018. Based on its success, it was decided to extend the programme until 2022. The programme aims to leverage digitalisation for the benefit of energy efficiency improvements. Public funding is provided to businesses (i.e., large companies and SMBs) that promote digitally-enabled energy efficiency solutions to their customers. These companies apply for funding to develop their digital solutions. The level of funding depends to a great extent on the amount of energy saved by the companies' customers. The digital services offered to customers can be combined with other offers, including support to investments.

4. Analysis of P4P programmes

The concept of P4P programmes can take a range of different forms, including different design features, administrators and payment structures [48]. Here, we analyse the P4P programmes identified, and we compare them in terms of their similarities and differences, based on four categories, namely: (1). Key drivers, (2). Basic design attributes, (3). Performance assessment, and (4). Payment agreement methods.

4.1. Key drivers

Motives for the adoption of a P4P programme vary across the selected cases. This is reflected in each programme's objectives and regulatory drivers.

4.1.1. Objectives

General objectives of the P4P programmes under study vary and are not necessarily mutually exclusive:

- Meeting energy efficiency and saving targets: Some entities have developed their P4P programmes in order to achieve deeper energy savings and meet their targets. Specifically, ETO aims to improve realisation rates of savings, while DCSEU's objective is to deliver more energy savings to their customers. Efficiency Vermont utilises the CEI programme to achieve demand-side saving targets.
- Using energy efficiency as a resource to the grid to support the electricity system: The main motivation for the majority of the programmes analysed is to exploit energy efficiency as a resource to the grid. For example, IESO and PG&E aim to ensure the availability of energy efficiency to support the electricity system, while NYSERDA's main focus is to enhance energy efficiency as a well-founded grid resource.
- Improving the cost-effectiveness of energy efficiency investments: When energy efficiency is paid in advance, uncertainty in results can lead to misalignment of incentives. In this context, SCL and PSE have identified the need to rely on the use of metered data to increase the cost-effectiveness of energy efficiency programmes. Representatives from PG&E and DCSEU reported that providing cost-effective programmes for ratepayers was an important factor behind the roll-out of their programmes. On the other hand, NJCEP aims to change the way contractors and users approach energy efficiency opportunities.
- Targeting specific sectors for energy savings: Some programmes focus on specific sectors identified as crucial and/or with high saving potential. BayREN, for example, adopted a P4P programme targeting SMBs, as utilities in the jurisdiction had not yet launched performance-based programmes for this sector, while NJCEP engages very large commercial and industrial buildings due to the high potential of energy savings in these sectors.
- Developing the energy service market: The ESM programme was specifically designed to boost the development of an independent energy service market using digital tools, rather than achieving predetermined energy saving targets.
- Improving understanding of energy consumption: Some of the programmes, like CEI, also aim to improve the understanding of energy consumption patterns in end-use sectors.

4.1.2. Regulatory drivers

All the P4P programmes analysed are directly or indirectly driven by regulation. In particular, many States (e.g., California, Washington, Vermont, etc.) have developed energy efficiency resource standards (EERS), which require utilities to achieve a certain percentage of energy savings based on the amount of electricity or natural gas sold. In Ontario, Canada, the conservation and demand management (CDM) code was established in 2016 for electricity distributors. Distributors are required to meet targets for both demand reduction (MW) and energy savings (GWh) and may achieve both by implementing their energy efficiency programmes, which must be approved by the Ontario Energy Board, or by contract with the Independent Electricity System Operator. Although it is not driven by utility regulation, the ESM programme in Germany participates in reaching the country's energy transition objectives.

4.2. Basic design features

P4P programmes consist typically of different design features, namely: the type of approach followed, the administration in charge, the roles of different actors, the source of funding, the customer segment and eligible measures under the programme. An overview of the main design features of the P4P programmes analysed is presented in Table 5.

4.2.1. Type of approach

P4P programmes involve a contractor, an aggregator, or even a building owner, receiving payment based on energy savings. A programme administrator offers a fixed or negotiated price (which can depend on bids), which will pay for a measured unit of saved energy over a certain period. The P4P programmes analysed in our work are mostly proposed in the context of utility energy saving programmes. In theory, P4P structures could be applied in the context of capacity mechanisms, which can establish the procurement of energy efficiency as a grid resource. However, our review did not identify any programme making capacity payments purely based on metered data.

4.2.2. Administration

Different entities are responsible for the administration of the P4P programmes analysed:

- Utilities: Most programmes are administered by investor-owned utilities, which are private enterprises acting like public utilities (e.g., PG&E, PSE, etc.); public utilities (e.g., SCL, etc.); and energy efficiency (e.g., Efficiency Vermont) or sustainable energy (e.g., DCSEU) utilities, both appointed to deliver energy savings.
- System operators: In Ontario, Canada, EPP is implemented and regulated by Ontario's power system operator (IESO).
- Public authorities or public service organisations: P4P programmes can also be launched by public authorities like the regional energy network BayREN, which is a collaboration between local governments, ministries like the German Federal Ministry for Economic Affairs (ESM programme), and state agencies like the NJCEP. Finally, it is also common that mission-based organisations like ETO and public benefit corporations like NYSERDA collaborate with utilities

Table 5
Overview of customer segment, eligible measures, and requirements across the P4P programmes analysed.

P4P programme	Customer segment	Eligible measures	Programme Requirements
New Jersey Clean Energy Program- Pay-for-Performance Commercial & Industrial program	Existing Buildings: - Commercial and industrial buildings, peak demands ≥200 kW. - Multifamily, peak demands ≥100 kW. New Construction: - Commercial and industrial projects. - Conditioned space ≥50,000 sq. ft.	Existing Buildings: - Lighting retrofit, high-efficiency HVAC equipment, building management/controls, variable-frequency drives, air-sealing, etc. New Construction: - At least one measure addressing each of the following building components: envelope, heating, cooling and lighting.	Existing Buildings: - No single measure. - 15% minimum savings. - Max. 50% from lighting. New Construction: - A minimum combination of measures. - Minimum performance above code.
Ontario Save on Energy-Energy Performance Program	- Commercial buildings that are not utilised for any industrial process. - Minimum annual consumption of 1,500,000 kWh per building or group of buildings.	- Equipment retrofits, controls installation, system, recommissioning, and behavioural initiatives.	- The programme does not include a specific requirement.
Seattle City Light- Deep Retrofit Pay-for-Performance program	- Medium-large commercial buildings including MUSH. - Conditioned space ≥50,000 sq. ft.	- Air Handling Unit (AHU) optimization, Roof insulation, Wall insulation, Window replacement/ upgrade - Change induction HVAC system to high-performance Variable Air Volume (VAV) system, Filter Redesign, Chillers with heat recovery, variable-frequency drives on pumps, Lighting retrofits, Continuous Commissioning, Replacing faulty HVAC equipment, Replacing old inefficient HVAC equipment with efficient one, Eliminating simultaneous heating and cooling, Schedule corrections.	- At least 15% energy savings from capital equipment upgrades with measure lifetimes over 10 years.
Efficiency Vermont- Continuous Energy Improvement	- Large commercial and industrial facilities.	- Process improvements in the office and on the manufacturing floor. - Employee engagement to foster best practices in saving energy (including training). - Regular maintenance of equipment. - Capital upgrades for equipment that is out of date or reaching end of life.	- Participants engaged as part of a cohort to encourage peer-to-peer learning.
Energy Trust of Oregon- Pay for Performance Pilot	- Commercial, in particular office buildings, but also healthcare, grocery stores, and MUSH. - Conditioned space ≥20,000 sq. ft.	- Economizer tuning, Supply Air Temperature reset, Duct Static Pressure Reset, Modulate condenser flow, Secondary Pump, variable-frequency drives, Adjusting cooling tower fan staging.	- At least three capital investments. - 5% minimum savings.
Puget Sound Energy- Pay for Performance pilot	- Commercial and Institutional facilities (e.g., 24/7 facilities, museums, medical facilities). - Conditioned space ≥50,000 sq. ft.	- Capital investments. - Maintenance and operational improvements. - Behavioural energy-saving opportunities.	- At least two measures. - Minimum 15% energy savings.
District of Columbia Sustainable Energy Utility - Pay-for-Performance program	- Large commercial and institutional buildings. - Conditioned space ≥100,000 sq. ft.	- Complex multi-measure efficiency projects. - Re-commissioning and retro-commissioning of equipment. - Advanced building controls and upgraded building automation systems. - Energy management information system. - HVAC and Lighting (mostly implemented).	- Annual savings greater than 10%.
Bay Area Regional Energy Network – Small and Medium Commercial Buildings Pay-for-Performance program	- SMBs, commercial sites. - Conditioned space ≤50,000 sq. ft. - Energy consumption: electricity ≤500,000 kWh, or annual gas ≤250,000 therms.	- Boiler Plant Improvements. - Building Envelope Modifications. - Electrical Peak Shaving/Load Shifting. - Electric Motors and Drives. - Electric & Day Lighting Modifications. - HVAC. - Appliance & Plug-Load Reductions. - Refrigeration & Food Service Equipment.	- Installation of equipment required to exceed the requirements of Title 24 of the California Code of Regulations. - Operational, behavioural, and retro-commissioning activities reasonably expected to produce multi-year savings.
New York State Energy Research and Development Authority- Business Energy Pro	- SMBs.	- The programme is "measure-agnostic" to provide the opportunity for flexibility and innovation. - Behavioural, retro-commissioning, and operational and maintenance measure savings are also eligible.	- Intervention includes more than a single measure. - Minimum of 5% portfolio energy reduction for either electricity or natural gas.
Pacific Gas and Electric Company- Residential Pay-for-Performance programs	- Residential sector.	- Smart thermostats, tuning and optimization of equipment, lighting. - Home energy use analysis with recommendations. - Full-home energy retrofits (HVAC equipment and fabric improvements). - Rebates on high efficiency, hybrid electric, heat pump water heaters. - Home maintenance, fabric improvements.	- Offers a variety of programmes that include different offers for customers, with contractors having the flexibility to choose from a wide variety of measures and approaches.
- Germany- Energy Savings Meter programme	- Residential, Commercial, Industrial, MUSH. - Implemented projects include offices, retail stores, hospitals, swimming pools, hotels, restaurants, and industrial sites.	- Improving access to energy-related information & installation of automatic control devices.	- Eligible savings under funding coming from innovative digital installations and improvements.

and government agencies to deliver sustainable energy programmes, including P4P.

4.2.3. Roles

Many actors are commonly involved in a P4P programme, with specific responsibilities and roles. The role of an administrator depends on each programme. It generally includes budgeting, and financial and contract management. The administrator often conducts the market assessment and the programme's design, and in most cases, administrators are also responsible for market outreach. The implementation of the programme can be accomplished by contractors, ESCOs, or another third-party entity responsible for a set of projects. These implementers/aggregators can conclude energy need assessments, develop energy reduction and energy management plans, implement the measures, and in some cases can also be responsible for model/simulation development (e.g., BayREN, ETO, etc.). Administrators may perform quality, model, and progress reviews on the reports provided by the implementers before approving eligibility for incentives.

In some cases (e.g., NYSERDA, etc.), a dedicated EM&V provider can be appointed to deal with data analysis. In the cases of BayREN and PG&E, for example, programme administrators and their P4P allies (ESCOs, contractors, manufacturers, engineers, and retailers) are responsible for engaging customers, while in the case of ETO, the P4P ally is responsible for customer recruitment and identifying prospective participating sites. In the case of the NYSERDA programme, portfolio managers are required to reach out to small and medium enterprises; in the case of the DCSEU programme, preferred contractors engage with potential customers, while in the case of the ESM programme, funding is provided to businesses (large companies and small and medium enterprises), which promote digitally-enabled energy efficiency solutions to their customers. NJCEP cooperates with a programme manager, who is responsible for administration, dissemination activities, engaging participants, and facilitating applications and agreement arrangements. Administrators often offer a pool of recommended/licensed energy implementers to avoid frauds and ensure programme achievements and customers satisfaction (e.g, PSE, ETO, NJCEP, DCSEU, etc.). Finally, after a pilot or a programme is completed, implementers provide feedback to administrators regarding the programme's design aspects and payment structures, contributing to the programme's further development.

4.2.1. Source of funding

All but one of the P4P programmes examined are funded by utility customers through their energy bills. Energy efficiency provides benefits to all customers by avoiding the need to build new power plants, transmission lines, and distribution facilities. These public benefits lower the costs for everyone, justifying the fact that all consumers participate in financing the programmes, including those who do not directly participate. Ratepayers contribute to funding energy efficiency programmes through a small public benefit charge (e.g., ETO, NJCEP, etc.), or other separate surcharges (e.g., in PSE, CEI, NYSERDA, etc.) added to utility customers' monthly utility bills. For example, in the case of NJCEP, the extra charge on customer bills is called "public benefit charge." Some entities include the costs of energy efficiency and demand reduction programmes in their electricity/gas rates (e.g., SCL, etc.). These charges are paid by all customers and are collected at utility territory, state, province, or country level. The ESM programme is funded by taxpayers. Like for all energy saving programmes, while taxpayers bear the costs, they eventually benefit from lower energy system costs (due to the energy saved), which flow through in lower energy prices.

4.2.4. Customer segment

P4P programmes are either targeted to customers from certain sectors, or to certain types of buildings, or are open to all customer segments. The majority of the P4P programmes analysed focus on large commercial, industrial, or institutional customers with a high potential for savings. In most cases, eligible facilities have to meet specific requirements regarding minimum total surface (e.g., square feet of conditioned floor area, etc.), average annual electricity and gas consumption, and/or annual peak demand. For example, the ETO P4P programme targets commercial buildings (in particular office buildings), but also healthcare, grocery stores, and MUSH buildings, which have at least 20,000 square feet of conditioned floor area, while the SCL and PSE programmes engage existing commercial and institutional buildings with more than 50,000 square feet of conditioned floor area. For DCSEU, the threshold is 100,000 square feet of conditioned floor area. CEI was initially designed to reach the largest commercial and industrial energy consumers in Vermont, while EPP requires each participant to have a minimum annual consumption of 1,500,000 kWh per building (or group of up to five buildings aggregated into a single baseline energy model). For NJCEP and its "Existing Buildings" programme, commercial and industrial buildings must have a peak demand of at least 200 kW in any of the most recent 12 months, while multifamily buildings must have a peak demand of at least 100 kW in any of the most recent 12 months. New or substantial renovation of commercial, industrial and multifamily buildings must have 50,000 square feet or more of gross heated/conditioned space.

On the other hand, some programmes have specific requirements regarding the maximum total surface, average annual electricity and gas consumption and/or annual peak demand. BayREN and NYSERDA have developed P4P programmes that provide energy efficiency services to SMBs, which is less common among the cases. In particular, BayREN engages commercial sites with no more than 50,000 square feet of conditioned space, with annual electricity consumption of less than 500,000 kWh and/or annual gas consumption of less than 250,000 therms, while for the NYSERDA programme, eligible customers are those with an average annual peak electricity demand of less than 300 kW. PG&E's residential P4P programme is the first attempt to scale a whole-building programme to the residential sector with a normalised metering-based approach, aggregating savings across a portfolio of many homes. Finally, one of the programmes studied allows for a high degree of flexibility rather than focusing on a specific sector. Applicants for ESM are free to choose the customers to whom they will address their offer (e.g., households, public bodies, companies or other end-users, etc.). Projects have been funded in a variety of settings, including offices and retail stores, hospitals, swimming pools, hotels, restaurants, and industrial sites.

4.2.5. Eligible measures

In general, eligible measures under energy efficiency programmes depend on each programme's goal and purpose and other parameters such as the return of investment, saving potential, customers' needs, etc. The P4P programmes examined target multiple measures combining device replacements, operational/behavioural improvements, and retro-commissioning, rather than focusing on individual retrofits (e.g., lighting, motors, etc.). Some of the programmes may encourage energy management, implementing employee training on best practices in energy management, regular maintenance of equipment and capital upgrades (e.g., CEI, etc.), while others target savings primarily from building retrofits and equipment upgrades (e.g., SCL, etc.). The ESM programme was specifically designed to leverage digitalisation for the benefit of energy efficiency improvements. The projects submitted by candidates shall develop and propose innovative digital solutions for customers to save energy. Combining a minimum number of measures (e.g., in PSE, a combination of two or more measures must be selected, etc.), or achieving a minimum percentage of energy savings compared to the baseline including through certain measures (e.g., a 15% electricity consumption reduction by capital upgrades is required by SCL, etc.), is often a programme requirement.

4.3. Performance assessment method

In a P4P programme, compensation is bound up with performance; thus, the estimation of energy savings must be reliable, accurate and clearly defined. The protocol and the methodology applied to establish the baseline scenario can vary. A variety of saving estimation methods are used, including Building Energy System (BES) simulation models, direct device measurements, and analysis of meter or billing data at various time intervals [33].

4.3.1. Protocol

Measuring and verifying savings from performance-based contracts requires adopting a methodology, which can influence the eligibility of measures and the programme requirements. Although EM&V is an evolving science, best practices have been developed. These practices are documented in several guidelines, including the International Performance Measurement and Verification Protocol (IPMVP) and the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Guideline 14, Measurement of Energy and Demand Savings [90]. Table 6 presents an overview of the IPMVP protocol options and examples of different energy efficiency retrofit scenarios and categorisation per option [91,92].

At least seven of the P4P programmes analysed estimate savings using the methodology and guidelines of IPMVP Option C. This approach offers continuous whole-building measurements of energy consumption and demand. This is suitable given that almost all the programmes target operational, behavioural, and retro-commissioning measures, strategic energy management, and multi-measure whole-building retrofits, and no single measures (e.g., solely lighting or equipment replacement, etc.). Savings are determined by measuring energy consumption and demand at the whole-facility/utility-meter level. In the case of multi-measure projects, it is hard to identify the effect of a single measure on overall usage, especially when the impact of the savings is small and can be easily confused with other activities (e.g., occupants leaving for vacation or missing from home for longer periods, etc.) [31]. According to Option C guidelines, savings should typically exceed 10% of the baseline to accurately discriminate the savings from the baseline data [91]. This can impact the programme requirements. For example, SCL requires at least 15% of the building's baseline electric consumption from capital equipment upgrades to improve the certainty of estimates.

The "Existing Buildings" programme of NJCEP is based on ASHRAE Guideline 14 "Whole Building Calibrated Simulation" approach [93]. The IPMVP and ASHRAE approaches are very similar, but the ASHRAE protocol is not widespread, mainly because of the extremely high restrictions required in evaluating and discussing uncertainties. It is acknowledged that IPMVP offers a more general approach and structure and that the ASHRAE protocol complements IPMVP in being more technical [94]. ETO's commercial Operations and Maintenance (O&M) measurement and verification guidelines were developed utilising both the IPMVP Option C and the ASHRAE Guideline 14 industry standards. On the other hand, BayREN, NYSERDA, and PG&E, which target smaller-size facilities, utilise the CalTRACK methods, which provide a transparent and peer-reviewed implementation of the IPMVP Option C [95]. Savings are estimated using real-time data collected through dedicated smart-meter technology and advanced metering infrastructure and are aggregated daily. CalTRACK methods reduce model uncertainty and errors related to the estimation of savings among different buildings by aggregating the saving estimates across a set of buildings and cancelling out the overestimates/underestimates of savings [96]. Typically, the accuracy of the aggregated saving estimations increases with the greater number of buildings in the portfolio.

4.3.2. Baseline scenario

The key factor for the determination of energy savings is the baseline scenario, which represents what would have occurred without the implementation of energy efficiency retrofits. Energy savings are calculated as the difference between this scenario and actual usage after an intervention. Fully specifying the baseline scenario requires a combination of technical information and assumptions. This depends on the measurement methodology used.

The IPMVP Option C protocol utilises statistical models in order to generate normalised metering estimates. Such models usually include variables such as weather data or occupancy, which affect energy consumption independently of the energy efficiency retrofits. If the measurement methodology is for the whole building, the baseline is typically based on metered data from a period of time prior to the intervention, normalised for that period's weather and/or other variables. As a result, most of the programmes require at least a 12-month period of metered data or more, if any significant changes in the building (non-routine events) have occurred in the past period. Statistical models adjust for building occupancy and other independent variable data if buildings stay relatively consistent through the baseline and post-implementation period. However, as most of this information is not publicly available, estimation software primarily accounts for weather differences and time of day. After the implementation of the retrofits, participants must report significant changes that affected energy consumption patterns. The frequency of the baseline setting exercise is also an interesting parameter. The SCL five-year contract is the one case where the baseline is resetting every year. This contract is particularly designed for

Table 6
Summary of IPMVP options and examples of different applications.

IPMVP protocol	Calculation of savings	Examples of application
Option A Retrofit isolation: Key Parameter Measurement	Savings are determined by field measurements of the key parameter(s), which define the energy consumption and demand of an isolated retrofit of a device. Measurement frequency ranges from short-term to continuous, depending on the expected variations in the measured parameters and the length of the reporting period.	- Pump/Motor efficiency improvements. - Boiler efficiency improvements. - Lighting efficiency. - Lighting operational control. - Compressed air leakage management.
Option B Retrofit isolation: All Parameter Measurement	Savings are determined by field measurement of the energy consumption and demand and/or related independent or proxy variables of energy efficiency retrofits. Measurement frequency ranges from short-term to continuous, depending on the expected variations in savings and length of the reporting period.	- Street lighting efficiency and dimming. - Turbine-generator set improvement. - Pump/Motor demand shifting.
Option C Whole Facility	Savings are determined by measuring energy consumption and demand at the whole facility's/utility's meter level. Continuous measurements of the entire facility's energy consumption and demand are taken throughout the reporting period.	- Mix of energy efficiency measures with metered baseline data. - Whole facility energy accounting relative to budget.
Option D Calibrated Simulation	Savings are determined through simulation of the energy consumption and demand of the whole facility, or of a sub-facility. Simulation routines are demonstrated to adequately model actual energy performance in the facility. This option requires considerable skills in calibrated simulation.	- Mix of energy efficiency measures in a building without energy meters in the baseline period. - New buildings designed better than the building code.

customers that lack initial capital or prefer to implement the energy efficiency retrofits gradually during the five-year period.

4.3.3. Metering technology

The majority of the programmes analysed collect data via advanced metering infrastructure in short time periods. For example, hourly or 15-min interval data is required in SCL programme, and hourly, or sub-hourly interval data is required in EPP.

4.4. Payment structure

Finally, a key element of the P4P programmes analysed is the design of payment flows, agreements, and processes between all the actors involved, i.e., the beneficiary of the performance payment, the duration of the contract, the reward structure, and prices per unit of energy saved.

4.4.1. Beneficiary of the performance payment

Since the performance risk is borne by the entity paid for delivering energy saving measures (rather than the utility or another programme administrator), the payment process is a core part of the programme's design. In some cases, the administrator contracts and compensates individual customers directly, who are in turn responsible for delivering the energy savings required, while in other cases, incentive payments are made to an implementer/aggregator. In the ETO, NJCEP, SCL, EPP, and DCSEU programmes, incentives are directly delivered to customers (building owners) but can also be assigned to the implementer (*i.e.*, ESCOs, contractors, or other service providers) via an incentive/agreement form. The same approach is applied by the PSE programme, but the option of assigning the rebates to the implementer is not available. PSE wanted to provide flexibility to customers to select a different implementer during the contract period. On the other hand, BayREN, PG&E, NYSERDA, and ESM target smaller buildings. In these programmes, the utility pays an implementer/aggregator, who contracts customers to install energy efficiency measures and delivers energy savings to the programme administrator. The price and other contractual terms and obligations for the installation and the maintenance of energy efficiency measures are determined between the customer and the implementer/aggregator.

4.4.2. Contract duration

Long contract periods encourage deeper savings since more measures with longer payback periods can be implemented. Nevertheless, contracts with a long duration can discourage implementers because they have to manage risks for a longer period. For example, ETO had initially started the P4P pilot with a three-year performance period but changed to a one-year contract period for the future pilot due to the common property owner changes in the area. The duration of the contract widely differs across the P4P programmes analysed, varying between one and five years. In the NYSERDA programme, the performance period lasts three years. In the EPP programme, it counts up to two and a half years, while in the ESM programme, the duration is designed to be five years. Some programmes have shorter periods than three years. Specifically, PG&E offers a two-year contract, as does BayREN, whilst ETO, DSEU, and NJCEP offer just one-year contracts. Aiming to satisfy and engage more prospective participants, the SCL programme offers two options for contract duration: a three-year contract, which is suitable for participants that have the sufficient initial budget to implement all the energy efficiency measures upfront during the first year; and a five-year contract that is designed for customers lacking the initial capital or preferring to gradually implement the energy efficiency retrofits during the five-year period. Under the five-year contract, a new baseline scenario is estimated each year.

4.4.3. Reward structure

The majority of the programmes also provide an upfront, non-performance-based incentive in addition to performance-based payments. This approach helps participants to manage cash flows and financial risks. In many cases, this upfront incentive is provided to the programme participant for the implementation of specific mechanisms/services. For example, EPP provides an initial modelling incentive for the deployment of the energy simulation model used, whilst ESM offers 25% of the project's estimated cost for the development of digitalisation services. In other cases, a compensation percentage (20–60%) is made to participants after the installation of the energy efficiency measures based on projected savings (e.g., PSE, ETO, etc.). In NJCEP, an initial incentive is offered based on the area of the building once participants have prepared an energy reduction plan. Finally, in BayREN, 50% of the total project's cost will be paid to programme implementers after the completion of the energy efficiency retrofits based on estimated savings, while the remaining incentives will be formed by actual savings. In some cases, programmes have a totally performance-based design (NYSERDA, SCL, DCSEU, and PG&E) and constitute pure P4P programmes. In these cases, upfront payments are sometimes made to deal with cash-flow issues, with adjustments taking place at a later stage to reflect on the actual performance. This is also partly the case for incentives in the NJCEP programme, which, although are delivered in advance, can be considered performance-based, since following payments are adjusted if the project underperforms.

The CEI programme differs from the typical P4P structure. Participants (industrial and commercial companies) are incentivised by Efficiency Vermont's enhanced technical engineering and consulting support on energy management practices, but they are not rewarded based on performance. Instead, Efficiency Vermont is the one who is compensated upon it. Efficiency Vermont and the participating companies sign a memorandum of understanding for estimated savings results anticipated with full commitment by the customer for programme participation. Savings are delivered and monitored and can then be claimed by Efficiency Vermont as part of its energy saving goals, which are negotiated with the Vermont Public Utility Commission for a two-year period. Efficiency Vermont's compensation is based on three components: actual incurred costs, performance compensation upon attainment of the utility's three-year performance targets, and operational fees. The performance-based element of the remuneration is not proportional to the savings achieved; its amount is a percentage of the other remuneration elements if a number of indicators, including energy savings, are achieved.

4.4.4. Price per unit

Finally, another distinction among the P4P programmes concerns the price per unit of energy saved. Most of the programmes offer a standard reward incentive for a measured unit of energy saved (e.g., 5 cents/kWh of energy saved for electricity and 15–20 cents/therm of energy saved for natural gas), as set by the programme administrator. However, a minority of the programmes rely on bidding prices. In particular, the NYSERDA, DCSEU, and PG&E programme rates depend on the bid presented by implementers and subsequent negotiations, meaning that rates will vary for each participant. NYSERDA and PG&E consider the lifetime of the measures in the price-setting mechanism. This approach aims to promote and not to discriminate against measures with a long-term effect. The performance is, therefore, rewarded for services that are provided beyond the contracting period. Table 7 summarises the payment structures for 10 of the P4P programmes analysed. The CEI programme is not included in the table due to its particular structure, which is not a typical P4P approach.

5. Discussion and conclusions

Energy efficiency has played a vital role in global efforts towards the reduction of GHG emissions, addressing both climate and energy security challenges and providing multiple benefits. However, despite its potential, energy efficiency ranks at the lower end of the spectrum of realised sustainable energy investment opportunities, mainly due to

Table 7
Payment structures of the P4P programmes analysed.

Programme	Pure P4P?	Payment schedule	Price setting	Contract duration
New Jersey Clean Energy Program- Pay-for-Performance Commercial & Industrial program	Hybrid	1. After planning 2. After installation 3. After 1 year	Path 2: $0.09/kWh Path 3: $0.90/therm Bonus for higher savings	1 year
Ontario Save on Energy- Energy Performance Program	Hybrid	Yearly	$0.04/kWh	2.5 years
Seattle City Light- Deep Retrofit Pay for Performance program	100% P4P	Yearly	Path 1: $0.08/kWh Path 2: $0.18/therm Bonus for higher savings	Path 1: 3 years Path 2: 5 years, baseline recalculated each year.
Energy Trust of Oregon- Pay for Performance Pilot	Hybrid	1. After installation 2. After 1 year	$0.15/kWh. $1.80/therm.	1 year
Puget Sound Energy- Pay for Performance pilot	Hybrid	Yearly	$0.35/kWh $5.00/therm Bonus for higher savings	5 years, including a 4-year performance period
District of Columbia Sustainable Energy Utility- Pay for Performance program	100% P4P	One-off payment	Project-specific	1 year
Bay Area Regional Energy Network- Small and Medium Commercial Buildings Pay-for-Performance program	Hybrid	Yearly	Price results of the bid process Bonus for higher savings	2 years with possibility to extend
New York State Energy Research and Development Authority- Business Energy Pro	100% P4P	Quarterly	Price results of the bid process Favours long lifetimes	5 years, including a 3-years performance period
Pacific Gas and Electric Company- Residential Pay-for-Performance programs	100% P4P	Monthly	Project-specific Full-lifetime reward	2 years
Germany- Energy Savings Meter programme	Hybrid	Yearly	Price result of bid process	5 years

issues such as lack of funding, uncertainties over financial gain, and lack of metering infrastructure. So far, energy efficiency interventions have mainly relied on traditional policy programmes that provide upfront incentives based on a predicted result, which, although have partially resolved funding problems, still create a lot of uncertainty and reluctance to investors. In order for energy efficiency projects to stimulate the energy service market and become more attractive to investors, they must be associated with consistent returns and stable long-term cash flows.

In this context, during the past few years, new, more market-oriented funding programmes have slowly been developed, rewarding end-users on an ongoing basis based on the energy savings achieved, and constantly evaluating the performance of an energy efficiency investment as the savings occur. By focusing, thus, on the output, these P4P programmes are able to align incentives with policy objectives, incentivise the persistence of energy savings over time in a more efficient way, and further boost the energy service market. Our study sets out to introduce the main specifications and features of energy efficiency P4P programmes by conducting a comparative analysis of 11 such real-world cases in North America and Europe, summarising experience and lessons learnt, and providing a set of key implications and recommendations for policymakers and other practitioners on further designing P4P pilot projects.

5.1. Lessons learnt

(1) **P4P programmes are often driven by the desire to modernise energy efficiency policies:** P4P programmes are mostly driven by regulation, and, in particular, utility energy efficiency obligations. In many cases, policymakers or regulators have specifically asked utilities or entities in charge of delivering energy savings to create innovative programmes to boost innovation, green job creation, and market transformation. Utilities' involvement in P4P programmes facilitates data access, even if the exchange of energy consumption or utility bill data between energy utilities and public authorities is not always straightforward (e.g., due to strict data protection protocols, extensive bureaucratic processes, etc.). In addition, P4P programmes were often a request formed by energy market actors (e.g., ESCOs, etc.), while in other cases, the main driver was the need to improve the cost-effectiveness of energy efficiency programmes or to deliver high-quality programmes funded by ratepayers.

(2) **P4P programmes are able to target multiple measures:** Combining a minimum number of measures or achieving a minimum percentage of energy savings compared to the baseline scenario through certain types of energy efficiency measures, is often a programme requirement. Behavioural and operational measures are often combined with technical measures to ensure that savings are delivered.

(3) **The residential sector is the new frontier for P4P programmes:** To date, most of the P4P programmes have been implemented in the commercial sector. This is also the case with the majority of the P4P programmes analysed in this study, which focus on large commercial, industrial or institutional customers. However, the P4P concept has not been very popular so far in the residential sector, possibly because measuring methodologies have been too expensive to scale up and not automated to this point [97]. Large customers and high saving opportunities make more complex EM&V procedures worthwhile for implementers. However, with the wider deployment of smart meters, collecting consumption data becomes less complicated, and the cost of whole-building measurements decreases, making the EM&V procedures, which are necessary for the success of a P4P programme, more practical for residential and small commercial buildings.

(4) **Selecting an EM&V methodology sets the basis for P4P programmes:** When selecting a methodology to estimate savings from a P4P programme, administrators must consider their tolerance for uncertainty, the magnitude of savings expected from the programme, and whether savings are aggregated in a

portfolio. Standardised guidelines reduce the bureaucracy and complexity burden for aggregators/implementers and customers and allow the counting of savings consistently and transparently by all parties. Finally, automated metering enables continuous whole-building measurements, while it also allows achieving time-specific energy savings that can be required to provide grid services.

(5) **Establishing the right payment structure requires research and consultation:** Our analysis show that there is not a standard approach regarding who is compensated. Each programme is designed based on specific local market conditions and in consultation with key stakeholders to decide on the payment structure. Contract duration is also a feature that should be decided in consultation with market representatives and other end-users, as local economic and social conditions can affect the willingness of customers to participate. Short contract durations can help mitigating risks for implementers or aggregators. They often require putting in place a mechanism to ensure that longer-term measures are rewarded appropriately. This can be reflected in the payment structure or in the eligibility criteria of the different energy efficiency measures. In most of the P4P programmes analysed, the aggregator/service provider delivers the savings to the programme administrator and takes on the performance risk, by making investments (e.g., equipment replacements, etc.) and bearing the EM&V costs. If project implementers/aggregators are paid by utilities one or more years after implementing a measure, and only on the basis of metered data, there is a risk of not being paid or receiving a penalty if savings do not materialise. This can increase the cost of their services and/or discourage them from participating. To be compensated for taking on the performance risks, and to ensure that they will have a return on their investments, they may receive a higher payment per unit of energy saved. A mix of non-performance-based and performance-based payments can also alleviate risks.

5.2. Implications for policy and practice

(i) As the electrification of end-uses accelerates, with the mass adoption of heat pumps and electric vehicles and shares of renewable energy sources contributing more to electricity generation, the value of demand-side resources will increase substantially. The resources required to ensure the electricity system's adequacy will be very different, depending on the time of the day, the weather, seasonal factors, and location. In this environment, energy efficient and self-sufficient/grid-interactive buildings can play a significant role in reducing electricity system costs. However, in order to be fully compensated for the services it provides, energy efficiency will need to prove its performance. As a result, piloting performance-based approaches such as P4P applications now will be an important first step in familiarising stakeholders with this concept and assessing whether the approach is appropriate to deliver on the objectives. Policymakers should consider requiring obligated utilities to deliver some of their targets using the P4P concept. In countries where capacity mechanisms are in place, policymakers could pilot P4P in the context of applying the "Efficiency First" principle to these capacity mechanisms. Wherever network constraints exist, regulators could provide incentives to distribution network operators to pilot P4P applications as part of performance-based regulatory changes.

(ii) P4P requires the energy efficiency industry to adapt to new forms of compensation and performance-based evaluation. In this dynamic environment, it is essential to closely work with stakeholders to develop the programme's design, measurement methods, and reporting infrastructure (e.g., data sharing platforms, EM&V procedures, etc.). A transparent, inclusive, and iterative approach to programme development will increase the likelihood of a better design and implementation. At the same time, being clear about why a P4P programme is being pursued will help to overcome legitimate concerns about changes to business models that may need to be developed.

(iii) P4P programmes, like many other utility programmes, competitive energy efficiency tenders and auctions, favour the take-up of the most cost-effective ways of meeting targets or achieving the specified outcomes. This is an advantage. On the other hand, there is a risk that programmes limited in their ambition by considerations of cost-effectiveness to ratepayers may be inconsistent with the achievement of broader climate and energy objectives that take account of broader societal costs and benefits. Ensuring that this risk does not materialise can be achieved through the linking of utility programmes (whether or not they involve P4P) to other taxpayer-funded programmes; by allowing, for example, co-funding, or by providing more per-unit compensation for higher levels of savings. Performance standards and targets are also needed to guide interventions. Information and tools such as building renovation passports can also help ensure consistency between the activities that take place at a building level and broader climate and energy goals.

5.3. Limitations and outlook

Our work is only a snapshot of the programmes analysed. As a result, updated information regarding the specifications of some of the programmes, e.g., duration, programme extension, etc., may not have been included. However, the latter is also attributed to the fact that not every case had comprehensive design and performance data available. Comprehensive documentation of programme designs, cost, and performance data would make the experience of a successful case more convincing when disseminated to an audience. To this end, P4P programmes should be evaluated and well-documented with performance results as well as with useful insights from policymakers and programme implementers. Open-source data-driven EM&V models and detailed documentation (e.g., programme implementation manuals, contract templates, etc.) should be distributed through existing public channels to promote the use, modification, and replication of P4P programmes.

With more P4P programmes implemented, and more data documented in the near future, more studies in the scientific literature, conducting an in-depth analysis of more real-world programmes are needed. Documenting specifications and best practices would be very helpful to demonstrate the effectiveness of P4P programmes and, thus, to reduce knowledge barriers and enhance transparency among the relevant stakeholders. Finally, as energy efficiency P4P programmes are still a fairly new concept, we managed to only identify and review 11 real-world cases, with 10 out of them being in North America. This implies that there is still a lot to be done in the European policy landscape. To this end, as further research, we intend to explore how the current policy environment and upcoming regulatory developments in the EU, e.g., the "Fit for 55" package, the European Green Deal, the Renovation Wave, etc., may become risks or opportunities and affect the viability of P4P programmes, also devising and presenting integrated strategies for rolling-out P4P pilot projects in the EU.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This paper is based on research conducted within the EC funded

Horizon 2020 Framework Programme for Research and Innovation (EU H2020) Projects titled "Smart Energy Services Integrating the Multiple Benefits from Improving the Energy Efficiency of the European Building Stock" (SENSEI, Grant Agreement No. 847066) and "Sustainable Energy Transitions Laboratory'' (SENTINEL, Grant Agreement No. 837089). The authors would like to acknowledge the support from the EC. The content of the paper is the sole responsibility of its authors and does not necessary reflect the views of the EC. The authors would also like to thank all the programme representatives for their time and their valuable insights and knowledge sharing.

Appendix

Table A1

Semi-structured questionnaire used for the interviews with the representatives of the energy efficiency pay-for-performance programmes analysed in this study.

Main information	
Name	What is the name of the P4P scheme?
Responsible entity	What is the name of the entity responsible for managing the scheme? What is the type of the entity? (e.g., utility, third-party administrator, etc.)
Purpose	What is the purpose of the P4P programme? (e.g., deliver energy efficiency as a grid resource, target specific sectors, etc.)
Start date and duration	When did the programme start? How long has it been in place?
Location	Where is the programme implemented?
Geographical coverage	What is the geographical coverage of the programme? (e.g., a set of multiple municipalities, state for the case of US, national, etc.).
Regulation	Is the programme driven by regulation? If yes, please explain briefly (e.g., national efficiency targets, etc.).
Website	Link of the programme required.
Summary description	Please provide a summary of the programme.
Key design features	
End-users or target sectors	What is the target sector of the programme? (e.g., residential, commercial, etc.) Does the programme target specific end users? (e.g., energy poor household, etc.)
Technical measure(s) and lifetime(s)	What type of energy efficiency measures are typically implemented through the programme? (e.g., replacing the heating system, lighting upgrades, etc.)
Actors involved	List all the actors involved and briefly describe their role.
Performance assessment	
Baseline and Metering methodology	How do you define the baseline of the projects and what metering methodology do you use?
Data collection	How and how often is performance data collected?
Price paid per unit rewarded	What is the price paid per unit rewarded?
Payment and reward structure	Please provide a detailed description of the monetary flows of the project and the non-monetary benefits for each actor involved.
Lessons learnt	
Achievements	What are the achievements of the programme since it was first launched? (e.g., total electricity (kWh), gas (therms) savings)
Drivers for the programme	Describe regulatory and non-regulatory drivers for the P4P programme
Barriers faced by the programme, and potential solutions (if identified)	Please provide a list of barriers, and how they have been addressed during the programme implementation
Lessons learnt	What was learnt from implementing the programme?
Next steps	What are the next steps for P4P programmes in your jurisdiction?

References

[1] Salvia M, Reckien D, Pietrapertosa F, Eckersley P, Spyridaki NA, Krook-Riekkola A, et al. Will climate mitigation ambitions lead to carbon neutrality? An analysis of the local-level plans of 327 cities in the EU. Renew Sustain Energy Rev 2021;135. https://doi.org/10.1016/j.rser.2020.110253.

[2] Stavrakas V, Flamos A. A modular high-resolution demand-side management model to quantify benefits of demand-flexibility in the residential sector. Energy Convers Manag 2020;205:112339. https://doi.org/10.1016/j.enconman.2019.112339.

[3] Krarti M, Dubey K. Review analysis of economic and environmental benefits of improving energy efficiency for UAE building stock. Renew Sustain Energy Rev 2018;82:14–24. https://doi.org/10.1016/J.RSER.2017.09.013.

[4] Reuter M, Patel MK, Eichhammer W, Lapillonne B, Pollier K. A comprehensive indicator set for measuring multiple benefits of energy efficiency. Energy Pol 2020;139:111284. https://doi.org/10.1016/J.ENPOL.2020.111284.

[5] Esser A, Dunne A, Meeusen T, Quaschning S, Denis W. Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU Final report. 2019. p. 87.

[6] European Commission. Communication from the commission to the European parliament, the Council, the European economic and social committee and the committee of the regions. In: A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives; 2020.

[7] Alam M, Zou PXW, Stewart RA, Bertone E, Sahin O, Buntine C, et al. Government championed strategies to overcome the barriers to public building energy efficiency retrofit projects. Sustain Cities Soc 2019;44:56–69. https://doi.org/10.1016/j.scs.2018.09.022.

[8] Patel MK, Broc JS, Cho H, Cabrera D, Eberle A, Federici A, et al. Why we continue to need energy efficiency programmes—a critical review based on experiences in Switzerland and elsewhere. Energies 2021;14:1–29. https://doi.org/10.3390/en14061742.

[9] De la Rue du Can S, Leventis G, Phadke A, Gopal A. Design of incentive programs for accelerating penetration of energy-efficient appliances. Energy Pol 2014;72:56–66. https://doi.org/10.1016/j.enpol.2014.04.035.

[10] Grillone B, Danov S, Sumper A, Cipriano J, Mor G. A review of deterministic and data-driven methods to quantify energy efficiency savings and to predict retrofitting scenarios in buildings. Renew Sustain Energy Rev 2020;131:110027. https://doi.org/10.1016/j.rser.2020.110027.

[11] Kontokosta CE. Modeling the energy retrofit decision in commercial office buildings. Energy Build 2016;131:1–20. https://doi.org/10.1016/J.ENBUILD.2016.08.062.

[12] Bianco V, Sonvilla PM. Supporting energy efficiency measures in the residential sector. The case of on-bill schemes. Energy Rep 2021;7:4298–307.

[13] Economidou M, Todeschi V, Bertoldi P. Accelerating energy renovation investments in buildings - Financial and fiscal instruments across the EU. 2019. https://doi.org/10.2760/086805.

[14] Advanced Energy Economy. Energy Efficiency as a Resource: The Power of Getting More for Less 2017. 2018.

[15] Kowalska-Pyzalska A. What makes consumers adopt to innovative energy services in the energy market? A review of incentives and barriers. Renew Sustain Energy Rev 2018;82:3570–81. https://doi.org/10.1016/j.rser.2017.10.103.

[16] Alasseri R, Rao TJ, Sreekanth KJ. Institution of incentive-based demand response programs and prospective policy assessments for a subsidized electricity market. Renew Sustain Energy Rev 2020;117:109490. https://doi.org/10.1016/j.rser.2019.109490.

[17] Spyridaki NA, Stavrakas V, Dendramis Y, Flamos A. Understanding technology ownership to reveal adoption trends for energy efficiency measures in the Greek residential sector. Energy Pol 2020;140:111413. https://doi.org/10.1016/j.enpol.2020.111413.

[18] Rana A, Sadiq R, Alam MS, Karunathilake H, Hewage K. Evaluation of financial incentives for green buildings in Canadian landscape. Renew Sustain Energy Rev 2021;135:110199. https://doi.org/10.1016/j.rser.2020.110199.
[19] OECD. Policy Responses to the Economic Crisis: Investing in Innovation for Long-Term Growth. 2009. https://www.oecd.org/sti/42983414.pdf.
[20] European Commission. Regional Policy, EU Solidarity Fund for COVID-19. 2020.
[21] Rodríguez M, Robaina M, Teotónio C. Sectoral effects of a green tax reform in Portugal. Renew Sustain Energy Rev 2019;104:408–18. https://doi.org/10.1016/J.RSER.2019.01.016.
[22] Spyridaki NA, Flamos A. A paper trail of evaluation approaches to energy and climate policy interactions. Renew Sustain Energy Rev 2014;40:1090–107. https://doi.org/10.1016/J.RSER.2014.08.001.
[23] Buildings Performance Institute Europe (BPIE). Energy Efficiency Policies in Buildings – the Use of Financial Instruments. 2012. https://bpie.eu/wp-content/uploads/2015/10/HR-Financing-Paper1.pdf.
[24] Collins M, Curtis J. Willingness-to-pay and free-riding in a national energy efficiency retrofit grant scheme. Energy Pol 2018;118:211–20. https://doi.org/10.1016/j.enpol.2018.03.057.
[25] Martín-Barrera G, Zamora-Ramírez C, González-González JM. Impact of flexibility in public R&D funding: how real options could avoid the crowding-out effect. Renew Sustain Energy Rev 2017;76:813–23. https://doi.org/10.1016/J.RSER.2017.03.086.
[26] Cicmanova J, Turner I, van Liefland S, Kaiser M, Ethuin P. Financing the energy renovation of residential buildings through soft loans and third party investment schemes. 2017. http://www.energy-cities.eu/IMG/pdf/guidebook_softloans_web.pdf.
[27] Economidou M, Bertoldi P. Financing building energy renovations: Current experiences & ways forward. 2014. https://doi.org/10.2790/28141.
[28] Mainali B, Mahapatra K, Pardalis G. Strategies for deep renovation market of detached houses. Renew Sustain Energy Rev 2021;138:110659. https://doi.org/10.1016/j.rser.2020.110659.
[29] Onuoha IJ, Aliagha GU, Rahman MSA. Modelling the effects of green building incentives and green building skills on supply factors affecting green commercial property investment. Renew Sustain Energy Rev 2018;90:814–23. https://doi.org/10.1016/j.rser.2018.04.012.
[30] Shazmin SAA, Sipan I, Sapri M. Property tax assessment incentives for green building: a review. Renew Sustain Energy Rev 2016;60:536–48. https://doi.org/10.1016/j.rser.2016.01.081.
[31] Szinai J, Amann J, Cluett R, Kushler M, Molina M, Nadel S, et al. Putting your money where your meter is: a study of pay-for-performance energy efficiency programs in the United States. January 2017;16–9.
[32] Tzani D, Stavrakas V, Santini M, Anagnostopoulos F. Policy developments in the EU and strategies for P4P business models. 2021. https://doi.org/10.5281/zenodo.5342246.
[33] Northeast Energy Efficiency Partnerships (NEEP). Pay for Performance Webinar. 2018. https://neep.org/sites/default/files/PayforPerformancePrimer.pdf.
[34] Golden M, Scheer A, Best C. Decarbonization of electricity requires market-based demand flexibility. Electr J 2019;32:106621. https://doi.org/10.1016/J.TEJ.2019.106621.
[35] Alshamsan R, Majeed A, Ashworth M, Car J, Millett C. Impact of pay for performance on inequalities in health care: systematic review. J Health Serv Res Pol 2010;15:178–84. https://doi.org/10.1258/JHSRP.2010.009113.
[36] Lin TY, Chen CY, Huang YT, Ting MK, Huang JC, Hsu KH. The effectiveness of a pay for performance program on diabetes care in Taiwan: a nationwide population-based longitudinal study. Health Pol 2016;120:1313–21. https://doi.org/10.1016/J.HEALTHPOL.2016.09.014.
[37] Milstein R, Schreyoegg J. Pay for performance in the inpatient sector: a review of 34 P4P programs in 14 OECD countries. Health Pol 2016;120:1125–40. https://doi.org/10.1016/J.HEALTHPOL.2016.08.009.
[38] Feng Y, Kristensen SR, Lorgelly P, Meacock R, Sanchez MR, Siciliani L, et al. Pay for performance for specialised care in England: strengths and weaknesses. Health Pol 2019;123:1036–41. https://doi.org/10.1016/J.HEALTHPOL.2019.07.007.
[39] Oxholm AS, Di Guida S, Gyrd-Hansen D. Allocation of health care under pay for performance: winners and losers. Soc Sci Med 2021;278:113939. https://doi.org/10.1016/J.SOCSCIMED.2021.113939.
[40] Jackson J, Urick B, Jackson J, Urick B. Performance-based pharmacy payment models: the case for change. Aust Health Rev 2019;43:502–7. https://doi.org/10.1071/AH18201.
[41] Harrington A, Malone D, Doucette W, Vaffis S, Bhattacharjee S, Chan C, et al. A conceptual framework for evaluation of community pharmacy pay-for-performance programs. J Am Pharm Assoc 2021. https://doi.org/10.1016/J.JAPH.2021.06.022.
[42] Perry T, Zenner M. Pay for performance? Government regulation and the structure of compensation contracts. J Financ Econ 2001;62:453–88. https://doi.org/10.1016/S0304-405X(01)00083-6.
[43] Cadsby CB, Fei S, Tapon F. Sorting and incentive effects of pay for performance: an experimental investigation. Acad Manag J 2007;50:387–405. https://doi.org/10.5465/AMJ.2007.24634448.
[44] Gerhart B. Incentives and Pay for Performance in the Workplace 2017:91–140. doi:10.1016/bs.adms.2017.02.001.
[45] Healey H, Rozanova V, Rooney T, Lorentzen M. New Jersey ' s Clean Energy Program : Pay for Performance : Integrating Performance Programs and ENERGY STAR. ACEEE Summer Study Energy Effic Build; 2010. https://www.aceee.org/files/proceedings/2010/data/papers/2028.pdf.
[46] Egnor T, Hayes D, Foundation TB, Jennings J. Metered energy efficiency transaction structure in ultra-efficient new construction : pay-for-performance at the bullitt center in Seattle , WA. ACEEE Summer Study Energy Effic Build 2016; 1–16.
[47] Shaban H, Golden M, Tine D. Who wins the pay-for-performance game? Measuring and controlling performance risk. ACEEE Summer Study Energy Effic Build 2018; 1–7.
[48] Rinaldi KS, Bunnen E, Rogers S. Residential Grid-Interactive Efficient Building Technology and Policy: Harnessing the power of homes for a clean, affordable, resilient grid of the future. 2019. https://naseo.org/data/sites/1/documents/publications/AnnDyl-NASEO-GEB-Report.pdf.
[49] Guibentif TMM, Patel MK, Yilmaz S. Using energy saving deficit distributions to assess calculated, deemed and metered electricity savings estimations. Appl Energy 2021;304:117721. https://doi.org/10.1016/J.APENERGY.2021.117721.
[50] Bryson J, Conlin B, DeYoung R, Eckman T, McNamara M, Mulholland D, et al. Guidebook for Energy Efficiency Evaluation, Measurement, and Verification. 2019. https://www.epa.gov/sites/default/files/2019-06/documentsguidebook_for_energy_efficiency_evaluation_measurement_verification.pdf.
[51] Grillone B, Mor G, Danov S, Cipriano J, Sumper A. A data-driven methodology for enhanced measurement and verification of energy efficiency savings in commercial buildings. Appl Energy 2021;301:117502. https://doi.org/10.1016/J.APENERGY.2021.117502.
[52] Grillone B, Danov S, Sumper A, Cipriano J, Mor G. A review of deterministic and data-driven methods to quantify energy efficiency savings and to predict retrofitting scenarios in buildings. Renew Sustain Energy Rev 2020;131:110027. https://doi.org/10.1016/J.RSER.2020.110027.
[53] Connecticut Energy Efficiency Board. Review of Impact Evaluation Best Practices. 2016. https://energizect.com/sites/default/files/2019-06/R91-ReviewofImpactEvaluationBestPractices_FinalReport_3.30.16.pdf.
[54] Papadelis S. Methods for the dynamic measurement and verification of energy savings. 2020. https://doi.org/10.5281/zenodo.4695123.
[55] Bourgois C, Coolen J, Gordon G, Lapietra A. The ex-ante evaluation of financial benefits in the SENSEI P4P scheme. 2020. https://doi.org/10.5281/zenodo.4771652.
[56] Taylor NW, Jones PH, Kipp MJ. Targeting utility customers to improve energy savings from conservation and efficiency programs. Appl Energy 2014;115:25–36. https://doi.org/10.1016/J.APENERGY.2013.10.012.
[57] Better energy efficiency policy with digital tools – analysis - IEA n.d. accessed September 21, 2021, https://www.iea.org/articles/better-energy-efficiency-policy-with-digital-tools.
[58] Nowak S, Baatz B, Gilleo A, Kushler M, Molina M, York D. Beyond Carrots for Utilities: A National Review of Performance Incentives for Energy Efficiency. 2015. http://kms.energyefficiencycentre.org/sites/default/files/u1504.pdf.
[59] ACEEE. Snapshot of Energy Efficiency Performance Incentives for Electric Utilities. 2018. https://aceee.org/sites/default/files/pims-121118.pdf.
[60] Santini M, Tzani D, Thomas S, Stavrakas V, Rosenow J, Celestino A. Experience and lessons learned from P4P pilots for energy efficiency. 2020. https://doi.org/10.5281/zenodo.3887823.
[61] Süsser D, Ceglarz A, Stavrakas V, Lilliestam J. COVID-19 vs. stakeholder engagement: the impact of coronavirus containment measures on stakeholder involvement in European energy research projects. Open Res Eur 2021;1:57. https://doi.org/10.12688/openreseurope.13683.2.
[62] New Jersey Board of Public Utilities (NJBPU). New Jersey: Energy Master Plan Pathway To 2050. 2019. https://s24.q4cdn.com/601515617/files/doc_downloads/2020/01/Final-2019-NJBPU-EMP.pdf.
[63] Healey H, Rozanova V, Rooney T, Lorentzen M. New Jersey's Clean Energy Program: Pay for Performance: Integrating Performance Programs and ENERGY STAR. ACEEE Summer Study Energy Effic Build; 2010. https://www.aceee.org/files/proceedings/2010/data/papers/2028.pdf.
[64] New Jersey's Clean Energy Program. Pay for Performance (P4P) Program Guide for Commercial & Industrial (C & I) New & Existing Buildings. 2020. https://njcleanenergy.com/files/file/BPU/P4P%20FY20%20Program%20Guide%20Final.pdf.
[65] Rozanova V, Rooney T, Ruderman J, Mosser M. The Transformation of Commercial & Industrial Energy Efficiency Programs : A Whole-Building Approach to Energy Savings. ACEEE Summer Study Energy Effic Build; 2012. https://www.aceee.org/sites/default/files/publications/researchreports/a1402.pdf.
[66] New Jersey's Clean Energy Program. 4QFY19 Report submitted to the New Jersey Board of Public Utilities. 2019. https://www.njcleanenergy.com/files/file/FINAL%20REPORT%20-%204QFY19(1).pdf.
[67] Lundhild E. Implementation of a pay for performance program in Ontario. 2017. https://www.aceee.org/sites/default/files/pdf/conferences/mt/2017/Lundhild_SessionD1_MT17_4.3.17.pdf.
[68] Hoss A. IESO Energy Performance Program. 2017. https://cleanairpartnership.org/cac/wp-content/uploads/2017/03/IESO_EPP-Presentation-Customer-V9.pdf.
[69] IESO. Pay-for-Performance: Program Engagement Plan. 2016. http://www.ieso.ca/en/Sector-Participants/Engagement-Initiatives/Engagements/Completed/Province-wide-Pay-for-Performance-Engagement.
[70] Seattle City Light. DEEP RETROFIT PAY FOR PERFORMANCE: A How-To Guide & User Manual for Commercial Customers. 2018. https://www.seattle.gov/documents/Departments/CityLight/DeepRetrofitP4PManual.pdf.
[71] Moen L, Rodenhizer D. PERFORMANCE-BASED pilots. 2016. http://nwenergy.org/wp-content/uploads/2016/10/3-Seattle-City-Light-Pilots-Part-12.pdf.
[72] Washington Department of Commerce Energy Division. Biennial Energy Report: Issues, Analysis and Updates. 2018. 2019. http://www.commerce.wa.gov/wp-content/uploads/2013/01/COMMERCE-Biennial-Energy.pdf.
[73] [Continuous Energy Improvement | Efficiency Vermont n.d].
[74] EEU Budgets, Performance Goals, and Annual Plans | Public Utility Commission n.d.

[75] Smith C, Belkhayat K, Kesting O. Pay for Performance Case Study – 3 Years of Performance. ACEEE Summer Study Energy Effic Build; 2018. https://businessdocbox.com/114348697-Green_Solutions/Pay-for-performance-case-study-3-years-of-performance.html.
[76] Oregon Public Utility Commission. Summary Report for Executive Order 17-20 Action Item 5A. 2019. https://www.oregon.gov/energy/Get-Involved/Documents/2018-BEEWG-Directive-5A-Summary.pdf.
[77] Kroll R, Willems P, Rubado D. Strategic Energy Management. Keys to Behavioral and Operational Change. UC Berkeley Conf Proc; 2015. https://escholarship.org/uc/item/8rm3h9h5.
[78] Sam W. Pay for Performance (PfP) - Commercial About Energy Trust of Oregon. Energy Coalit Energy Effic Work; 2016. http://nwenergy.org/wp-content/uploads/2016/10/4-Walker-NWEC-PFP-Commercial.pdf.
[79] Public Utility Commission of Oregon. Performance Measure Recommendations for Energy Trust of Oregon. 2019. 2019, https://www.energytrust.org/wp-content/uploads/2019/03/2019-Oregon-Public-Utility-Commission-Performance-Measures-for-Energy-Trust-of-Oregon-Inc.pdf.
[80] MetaResource Group. Energy Trust Pay-for-Performance Pilot – Process Evaluation. 2016. https://energytrust.org/documents/pay-performance-pilot-process-evaluation-phases-1-2/.
[81] Utilities Washington, Transportation Commission. Clean Energy in Washington State. 2019. https://www.utc.wa.gov/regulatedIndustries/utilities/Documents/5116 Fact Sheet.pdf.
[82] THE COUNCIL OF THE DISTRICT OF COLUMBIA. Clean and Affordable Energy Act of. 2008. Group. 2008, https://doee.dc.gov/sites/default/files/dc/sites/ddoe/publication/attachments/CAEA_of_2008_B17-0492.pdf.
[83] Dc Sustainable Energy Utility. Method OF savings analysis for DCSEU pay for performance. 2019. p. 1–4. https://www.dcseu.com/Media/Default/docs/business/MethodSavingsAnalysisP4P.pdf.
[84] NMR Group Inc. Evaluation of DC Sustainable Energy Utility FY2017 Programs. 2018. https://doee.dc.gov/sites/default/files/dc/sites/ddoe/publication/attachments/DCSEU FY2017 EMV Program Report - FINAL 092818.pdf.
[85] BayREN. Small and Medium Businesses (SMB) Pay-for-Performance (P4P) Program Implementation Plan. 2019.
[86] BayREN. Small and Medium Businesses (SMB) Pay-for- Performance (P4P) Program Manual 2018.
[87] NYSERDA and DPS Plans for Pay-for-Performance Efficiency in New York | Recurve Blog n.d.
[88] Jacobson E, Relations R, Gas P, Company E, Francisco S. Submission of High Opportunity Projects and Programs (HOPPs) Proposal - Residential Pay-for-Performance Program. 2016.
[89] Case Study: Energy Savings Meter Programme in Germany – Analysis - IEA n.d. https://www.iea.org/articles/case-study-energy-savings-meter-programme-in-germany (accessed October 11, 2021).
[90] Federal Energy Management Program. M&V guidelines: measurement and verification for performance-based contracts -Version 4.0. US Dep Energy 2015;3:1–108. https://doi.org/10.1016/j.radmeas.2006.01.002.
[91] Efficiency Valuation Organization (Evo). International Performance Measurement and Verification Protocol Core Concepts. 2014. https://www.acaraenergy.ie/wp-content/uploads/2014/12/Core-Concepts-EVO-IPMVP-2014_Dec2014.pdf.
[92] Joint Research Centre European Commission. Performance Measurement & Verification methodology report. 2021. https://www.delta-h2020.eu/wp-content/uploads/2019/11/DELTA_D1.4_PMV_v1.pdf.
[93] Pay NJCEP. for Performance Program Guidelines Existing Buildings Program. 2017. https://businessdocbox.com/Green_Solutions/124896696-Pay-for-performance-program-guidelines-existing-buildings-version-4-2.html. [Accessed 19 October 2021]. https://businessdocbox.com/Green_Solutions/124896696-Pay-for-performance-program-guidelines-existing-buildings-version-4-2.html. accessed.
[94] Natural Resources Canada's CanmetENERGY. Overview of Different Measurement and Verification (M&V) Protocols. 2008. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/canmetenergy/files/pubs/NRCan_MV_Overview_Report.pdf.
[95] Young M, Efficiency OE. Proof of the pudding: using real-world data to empirically develop M&V standards. In: 2018 ACEEE Summer Study Energy Effic Build; 2018.
[96] CalTRACK - CalTRACK Methods n.d. https://www.caltrack.org/(accessed October 12, 2021).
[97] Grandersona J, Touzani S, Fernandes S, Taylor C. Application of automated measurement and verification to utility energy efficiency program data. Energy Build 2017;142:191–9. https://doi.org/10.1016/j.enbuild.2017.02.040.